

PREFACE

The principal purpose of this book is to serve as a classroom training text for NROTC and OCS students. It will also be useful to weapon department officer personnel as a reference and as a convenient general reference in ordnance and gunnery for others.

This text is not intended to supersede or supplant official publications of the Chief of Naval Operations, the Naval Ordnance Systems Command, the Naval Ship Systems Command, or the Bureau of Naval Personnel with regard to doctrine, weapons and ammunition, shipboard organization, or shipboard operations. (See the official publications of these authorities on these matters.)

This is the first of three volumes on naval weapons. This volume (NavPers 10783) is concerned with all U.S. Navy weapons with the exception of guided missiles (and their control systems) and nuclear weapons. The second volume (NavPers 10784) is devoted to guided missiles and nuclear weapons, and the third (NavPers 10785, CONFIDENTIAL) is a supplement to volume 2. The titles of the second and third volumes are, respectively, Principles of Guided Missiles and Nuclear Weapons, and Navy Missile Systems.

This text is specifically designed to meet the needs of NROTC and OCS students. To cover the complex field with which it is concerned, the text concentrates on elementary functional operation of complete systems, rather than on descriptive details of a wide variety of individual instruments. The book is not written for maintenance or repair personnel. Ordnance Pamphlets and other technical publications issued by the Naval Ordnance Systems Command and the Naval Ship Systems Command are available for all equipments discussed in this book. They should be consulted for detailed information.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

The United States Navy is responsible for maintaining control of the sea and is a ready force on watch at home and overseas, capable of strong action to preserve the peace or of instant offensive action to win in war.

It is upon the maintenance of this control that our country's glorious future depends; the United States Navy exists to make it so.

WE SERVE WITH HONOR

Tradition, valor, and victory are the Navy's heritage from the past. To these may be added dedication, discipline, and vigilance as the watchwords of the present and the future.

At home or on distant stations we serve with pride, confident in the respect of our country, our shipmates, and our families.

Our responsibilities sober us; our adversities strengthen us.

Service to God and Country is our special privilege. We serve with honor.

THE FUTURE OF THE NAVY

The Navy will always employ new weapons, new techniques, and greater power to protect and defend the United States on the sea, under the sea, and in the air.

Now and in the future, control of the sea gives the United States her greatest advantage for the maintenance of peace and for victory in war.

Mobility, surprise, dispersal, and offensive power are the keynotes of the new Navy. The roots of the Navy lie in a strong belief in the future, in continued dedication to our tasks, and in reflection on our heritage from the past.

Never have our opportunities and our responsibilities been greater.

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CHAPTER 1

INTRODUCTION TO NAVAL WEAPONS

Naval weapons have played and continue to play an important role in achieving battle victories, both on land and sea. In addition to their destructive power against ships and their gunfire support role, Navy weapons can be used to destroy enemy strongholds far inland.

NAVAL WEAPONS AND SEAPOWER

What is seapower? It is that portion of a nation's overall power which enables that nation to use the sea in furtherance of its interests, objectives, and policies. This definition implies two facets of control of the sea—control that permits the nation to use the sea as a highway open to itself and its allies, and control that permits the nation to prevent its use by the enemy.

Seapower depends directly on the armament of vessels (submersible and surface) and aircraft. The naval power that can most effectively bring its airborne and waterborne weapons to bear in a given area of the sea or air, controls that area in either or both of the senses mentioned in the preceding paragraph. The United States Navy's mission is to do its part in providing for the security of the United States and to support the national policy throughout the world. Its primary way of accomplishing this is to gain and maintain control of the seas, to use the seas for the nation's purposes and those of its allies, and, in time of war, to deny use of the seas to an enemy.

SOME BASIC TERMS DEFINED

Throughout this text you will encounter many unfamiliar terms. Most of these are defined in appendix I. Some of the basic terms are discussed here, however, to help you better understand the remaining chapters.

ORDNANCE, GUNNERY, AND BALLISTICS

This text is concerned with the study of naval ordnance and gunnery. Together, the terms **ORDNANCE** and **GUNNERY** embrace weapons and their use.

Ordnance comprises weapons and other physical equipment pertaining to them. All this is further classified as explosive ordnance (which includes gun ammunition, missiles, torpedoes, mines, bombs, and rockets) and inert ordnance, which includes projecting devices (such as guns, launchers, and release gear), protective armor, and all equipment needed to operate and control weapons. Aboard ship it refers to all elements that come under the general term "ship's armament."

Traditionally, gunnery is the art and science of using guns. Weaponry is concerned with the practical use of all ordnance.

BALLISTICS is the science of projectile motion. (In this book, unless otherwise qualified, the term ballistics refers to the motion of projectiles fired from guns.) It falls naturally into two aspects: interior ballistics, which relates to the motion of the projectile within the bore of the gun, and exterior ballistics, which considers the action of the projectile in flight.

Each of these fields is the subject of careful and detailed study by specialists. Their findings are of enormous importance in gun design and in the development of fire control instruments. A general understanding of ballistics is essential to the naval officer afloat, so that he may achieve the best results with his ordnance equipment.

NAVAL WEAPONS AND ASSOCIATED EQUIPMENT

The weapons to be discussed in this text include:

GUNS. Essentially a gun is a tube closed at one end, from which a projectile is ejected at a

high speed by gases produced by a burning propellant. Guns may be used against surface, shore, and air targets.

ROCKETS. The essential component of a rocket is a propellant-filled tube equipped with a nozzle at one end. The burning propellant produces gases which are ejected through the nozzle; the rocket is driven by the reaction thrust developed.

GUIDED MISSILES. A guided missile is any unmanned vehicle moving above the earth's surface whose path can be changed by a mechanism within the vehicle. A ballistic missile is a guided missile designed to follow for a substantial part of its flight a ballistic (free or unsteered) trajectory.

AHEAD THROWN WEAPONS. These are explosive antisubmarine weapons fired forward of the attacking surface vessel. They may be propelled by gunlike projectors or by rocket motors.

TORPEDOES. A torpedo is a self-propelled underwater explosive missile used against submarine and surface targets.

MINES. A mine is an underwater explosive weapon which in performing its function is not propelled, but is actuated when it is approached or touched by a target.

DEPTH CHARGES. A depth charge is an anti-submarine weapon dropped or fired from surface vessels and designed to function either at a preset depth or in proximity to a submarine.

BOMBS. A bomb is any missile, other than torpedoes, mines, and guided missiles, that is dropped from an aircraft.

NUCLEAR (ATOMIC) WEAPONS. Nuclear weapons are explosive devices which obtain their disrupting energies from reactions in and between atomic nuclei. In context, the term special weapons means nuclear weapons.

RESTRICTED WEAPONS. These weapons include atomic, biological, and chemical types. Special doctrines apply to the use of these, and they are kept under the tight direct control of the President.

This volume does not cover nuclear (atomic) weapons or guided missiles; for these, see the next two volumes in this series.

The methods and devices used to control guns and other weapons or weapon launchers constitute fire control. With guns, fire control can be considered as the practical application of exterior ballistics to ensure that the projectile will hit the target. With nonballistic weapons (such as surface-to-air guided missiles,

torpedoes, and mines) fire control comprises the control of weapon launchers and weapons so that the weapons will function in the desired manner.

Some equipment included in weapon control systems are:

SIGHTS. Sights are optical devices which establish the line of sight to the target and provide for positioning the gun so that its projectile will hit the target.

RANGEFINDERS. Rangefinders are optical devices used to measure the distance (range) to the target.

RADAR. Radar uses echoes of high-frequency radio pulses to establish continuous values of target elevation and bearing (which corresponds to the line of sight to the target) and target range.

GUN DIRECTORS. Gun directors incorporate optical sighting and radar equipment (generally) which establishes the location of targets and controls the positioning of guns so that their projectile will strike the target. Gun directors may be located at some distance from the guns they control, or they may be quite close, depending on type and size, but they are usually higher in the ship's structure. Directors may or may not include computer equipment. Directors for torpedoes are associated with sonar equipment for underwater fire control. Some gun directors may be used to control rocket or missile launchers.

FIRE CONTROL COMPUTERS OR RANGE-KEEPERS. These are electronic or electromechanical devices into which are fed the mathematical variables in the fire control problem, and which yield solutions in the form of control settings required for the weapon and launcher to have maximum effect on the target.

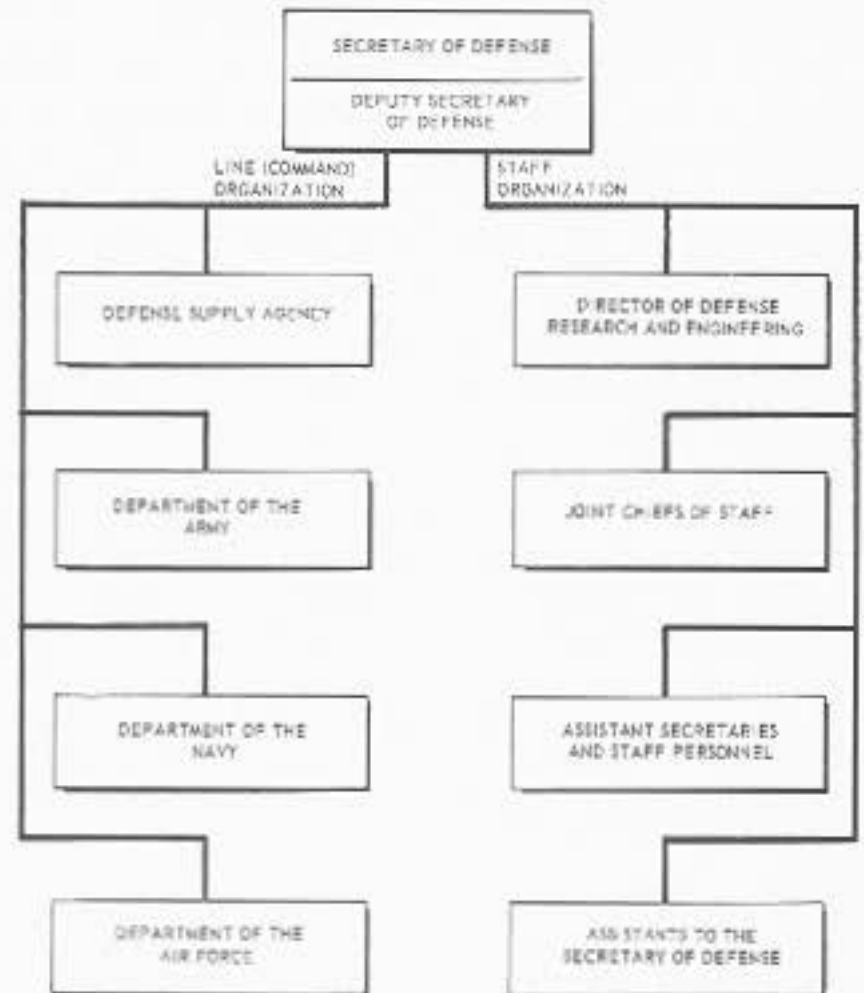
STABLE ELEMENTS OR STABLE VERTICALS. Stable elements or stable verticals are gyroscopic devices that maintain a reference horizontal, independent of ship's pitch and roll, for use in solving the fire control problem.

DATA TRANSMISSION SYSTEMS. Data transmission systems are electrical lines and devices used for transmitting, with optimum precision, electrical signals corresponding to fire control information from one equipment component to another.

SONAR. Sonar is the underwater analogy of radar. It functions by detecting echoes of pulses of ultrasonic sound, and furnishes range, bearing, and depth of targets.

WEAPON SYSTEMS. The naval officer today thinks of these weapons and associated equipment not as individual units but as weapon systems. NWP 10 series defines a weapon system as the combination of a weapon (or multiple of weapons) and the equipment used to bring the destructive power of the weapon against the enemy. It goes on to point out that maximum weapon capabilities are realized when associated units are conceived and developed by properly relating them to other elements in their operational environment.

The weapon system concept, which is not new, finds its most thoroughgoing application with newer weapons such as guided missiles. Although the formal recognition of the concept is relatively recent, its implications have been understood for some time, and for this reason it is possible to consider certain combinations of weapons with other equipment as constituting a "system" even if the combination is not formally designated as such. The concept is therefore applied in later chapters of this book when, for example, the student takes up common combinations of gun directors, other fire control equipment, and gun mounts.



16.1

Figure 1-1.—Organization of the Department of Defense.

ORGANIZATIONAL RESPONSIBILITY FOR ORDNANCE

Any military organization must make some provision for the procurement of weapons, for supplying them with ammunition, for supplying them to personnel or installing them on vessels, vehicles, or aircraft, for keeping them in working condition, etc. These responsibilities are allocated to an organizational unit called an "ordnance department" or the equivalent.

In the United States military system, from the point of view of the Navy, these responsibilities are assigned most importantly at three levels—in the Department of Defense (for the entire military establishment), in the Navy Department (for the fleet and for shore facilities), and in the individual ship's weapons department. (These responsibilities appear also at other organizational levels, but are not taken up in this book.)

ORDNANCE RESPONSIBILITIES IN THE DEPARTMENT OF DEFENSE

The Department of Defense was created as a part of a program designed to provide for the future security of the United States through the

establishment of integrated policies and procedures for the agencies of the Government concerned with the national security. Figure 1-1 is a simplified chart of the Department of Defense, emphasizing the relationships described below.

At the head of the Department of Defense is the Secretary of Defense, whose staff includes a number of assistant secretaries and others. (The Secretaries of the Army, Navy, and Air Force have a line relationship to the Secretary of Defense.) So far as ordnance is concerned, the most important member of the Defense Secretary's staff is the Assistant Secretary of Defense (Applications Engineering). This Assistant Secretary is concerned with engineering phases of development, design, and production of weapons and weapon systems, particularly with respect to military and engineering standards and characteristics, economy in use and maintenance, and production scheduling. The Assistant Secretary (Logistics) and the Assistant to the Secretary (Atomic Energy) are also concerned with ordnance matters—respectively as regards supply and atomic weapons. (For details on

Defense Department organization, see the U.S. Government Organization Manual, issued annually by the General Services Administration.)

With respect to ordnance, as with other matters, the Navy functions as a member of a team which includes the Army and Air Force. Ordnance equipment is usually developed by and procured by the service primarily interested. However, there are hundreds of ordnance items used by all three services, or by at least two of them. For instance, the Navy and Air Force both use Army rifles and pistols; the Air Force carries Navy mines, and the Navy uses Air Force bombs; the Army uses some Navy projectile fuzes, and the Navy uses several Army rocket fuzes. When one service procures a device for another, it usually furnishes all appropriate spare parts, instructional materials, and special tools as well.

The Marine Corps and Coast Guard do not maintain ordnance departments. Except for a few specialized items of equipment, they are

dependent for their ordnance on the Army, Navy, and Air Force.

NAVY DEPARTMENT RESPONSIBILITIES FOR ORDNANCE AND GUNNERY

Within the Navy Department, Naval Ordnance Systems Command (NavOrdSysCom or NavOrd) is chiefly responsible for ordnance material. Figure 1-2 shows NavOrd in the Department of the Navy organizational structure. As defined by Navy Regulations, 1948:

"The Bureau of Naval Weapons (which is now NavOrd) shall be responsible for the following, except as otherwise prescribed in these regulations or by the Secretary of the Navy:

"The design, development, procurement, manufacture, distribution, maintenance, repair, alteration, and material

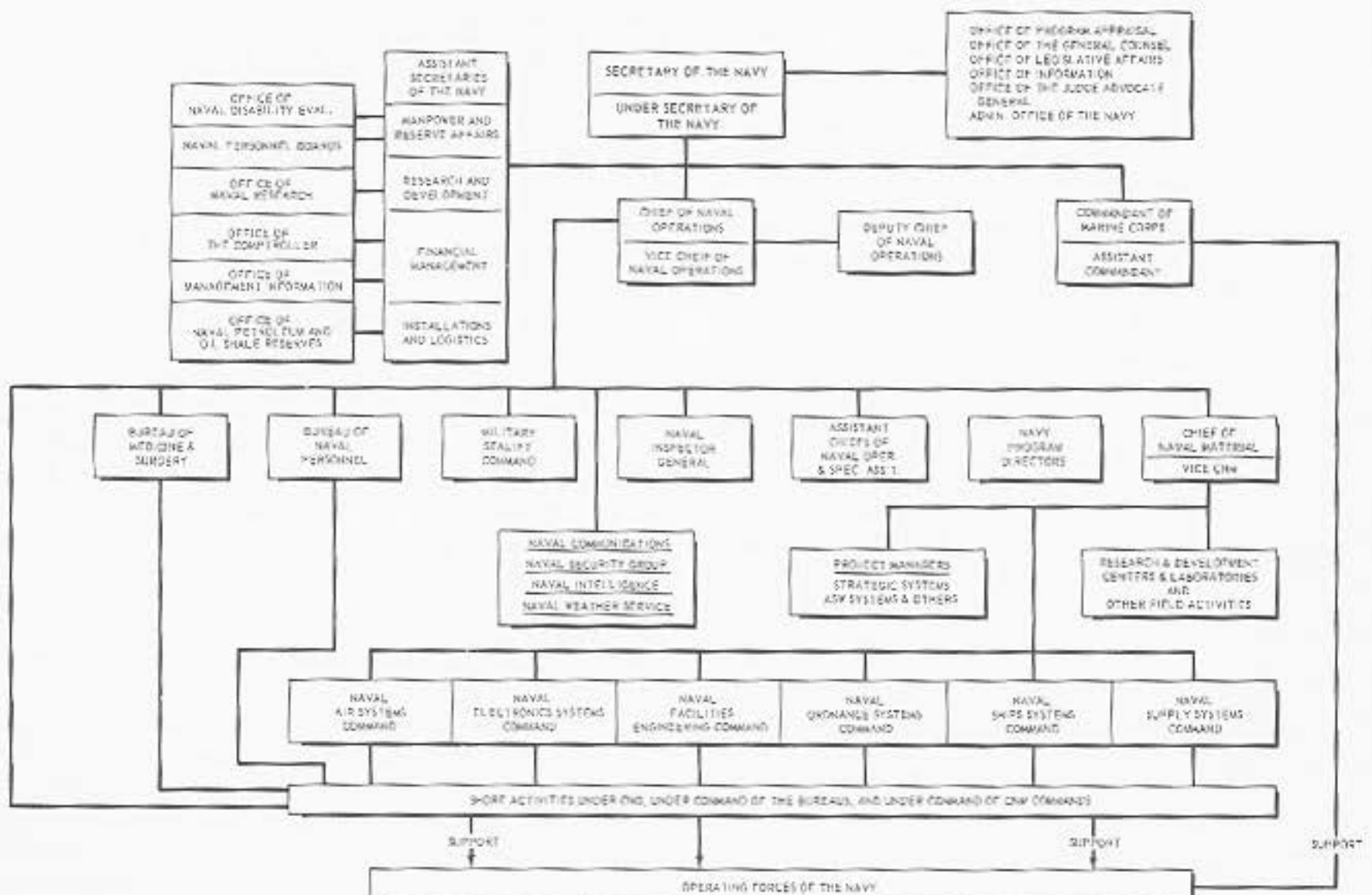


Figure 1-2. — Organization of the Department of the Navy.

effectiveness of naval ordnance; the research therein; and all pertinent functions relating thereto, including the control of storage and terminal facilities for, and the storage and issue of, ammunition and ammunition details."

Naval Ordnance Systems Command's responsibility includes ordnance material for ships and small craft, and that used by Marine troops. Naval Air Systems Command is responsible for aircraft ordnance.

The excerpt from Navy Regulations pertaining to the responsibilities of the Bureau of Naval Weapons is not entirely true for NavOrd. For example, weapons research and development comes directly under the control of the Chief of Naval Material.

The Naval Ordnance Systems Command has several field activities under its control. These activities include naval ammunition depots, naval ordnance system support activities, naval weapons stations, and naval ordnance laboratory test facilities.

The Chief of Naval Operations (CNO) controls, through fleet and force commanders, the operational use of weapons, with appropriate liaison with the technical commands concerned. The CNO also controls operational and team training in the use of weapons.

The Bureau of Naval Personnel (BuPers) is responsible for the training of officers and enlisted men (as individuals) in the use and maintenance of weapons.

The Naval Ship Systems Command (NavShips) is concerned with design problems in installation of ordnance in ships.

Naval Supply Systems Command (NavSup) is responsible for the general fiscal management of the Navy (except personnel matters), including those aspects that are concerned with ordnance.

Full details concerning the relationship of each Naval System Command with ordnance and gunnery are published in the manual that governs the organizations and operation of that command. The CNO Organization Manual performs the corresponding function for CNO.

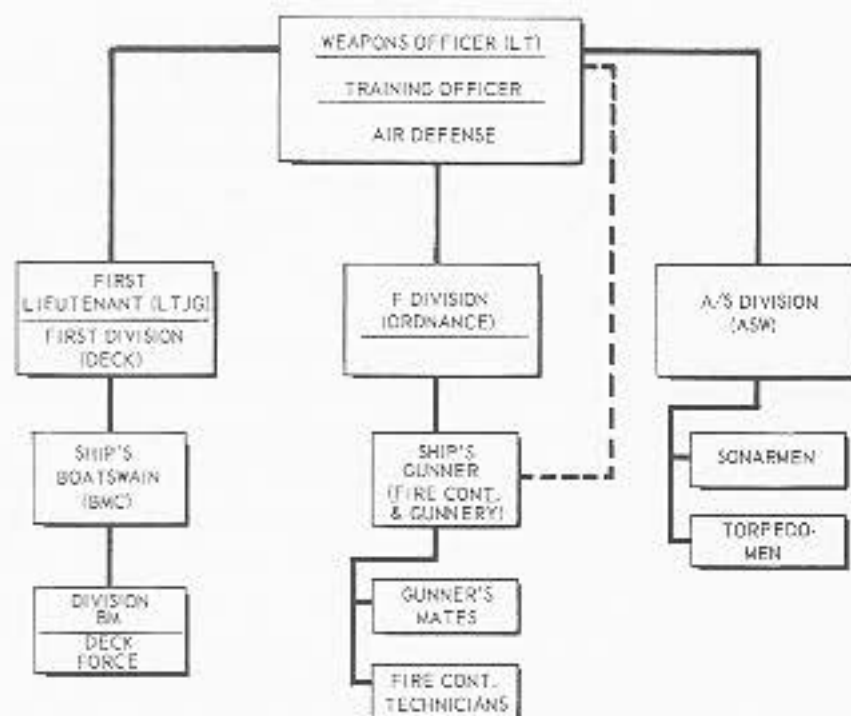
FUNCTION OF THE SHIPBOARD WEAPONS DEPARTMENT

Naval ships are organized into departments, which are further broken down into divisions. In ships-of-the-line—that is, those ships which have been designed primarily to launch or fire weapons—the ordnance department is called the

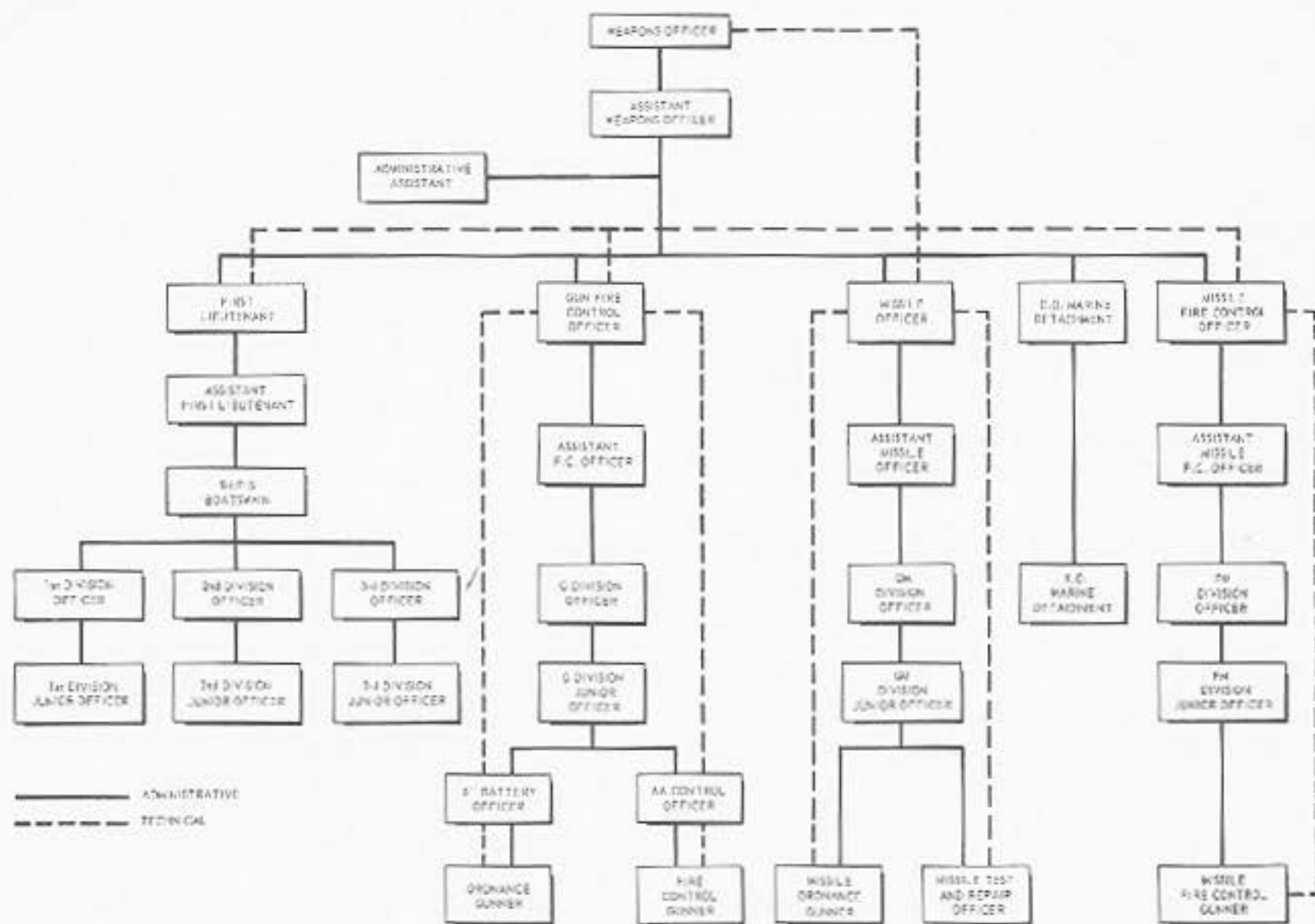
weapons department. The weapons officer is the head of this department. He is responsible for all of the ship's armament, and its deck seamanship and related equipment. The weapons officer will have certain officer assistants within the department who direct their attention to specific weapons, equipment, and administrative matters. The duties of these weapons assistants are discussed in chapter 15. Notice in figures 1-3, 1-4, and 1-5 that the weapons departments consist of several divisions, each headed by an officer assistant who bears a title descriptive of his duties, e.g., Fire Control Officer, Missile Officer, etc. In figure 1-4 you can see that a division officer's job on a cruiser is a primary billet, but this same job may be a collateral duty on a destroyer, as shown in figures 1-3 and 1-5.

In ships whose offensive characteristics are not primarily related to ordnance or aircraft, deck responsibilities will overshadow weapons. In such cases (usually auxiliaries and support ships) the first lieutenant is assigned as head of the department and as assistant for weapons. The weapons (or gunnery) officer is the assistant head of department, and the department will probably be called the deck department.

The details for weapons department organization must be separately established for each type of ship. Although there is considerable variation from one ship type to another, certain



63.5
Figure 1-3.—Weapons department organization for USS Forrest Sherman Class DD.



63.3

Figure 1-4.— Weapons department organization for a representative guided missile light cruiser.

general aspects of organization apply to all ship types. There is a designated head of department (weapons officer, or first lieutenant) and he is assigned certain assistants. The number and titles of his assistants vary with the type of ship, its weapons installation, and the number of officers on board.

Further details on the organization and operation of the shipboard weapons department can be found in Navy Regulations, 1948; in Shipboard Procedures, NWP-50; and in directives from the Chief of Naval Operations and type commanders.

IDENTIFICATION OF ORDNANCE EQUIPMENT

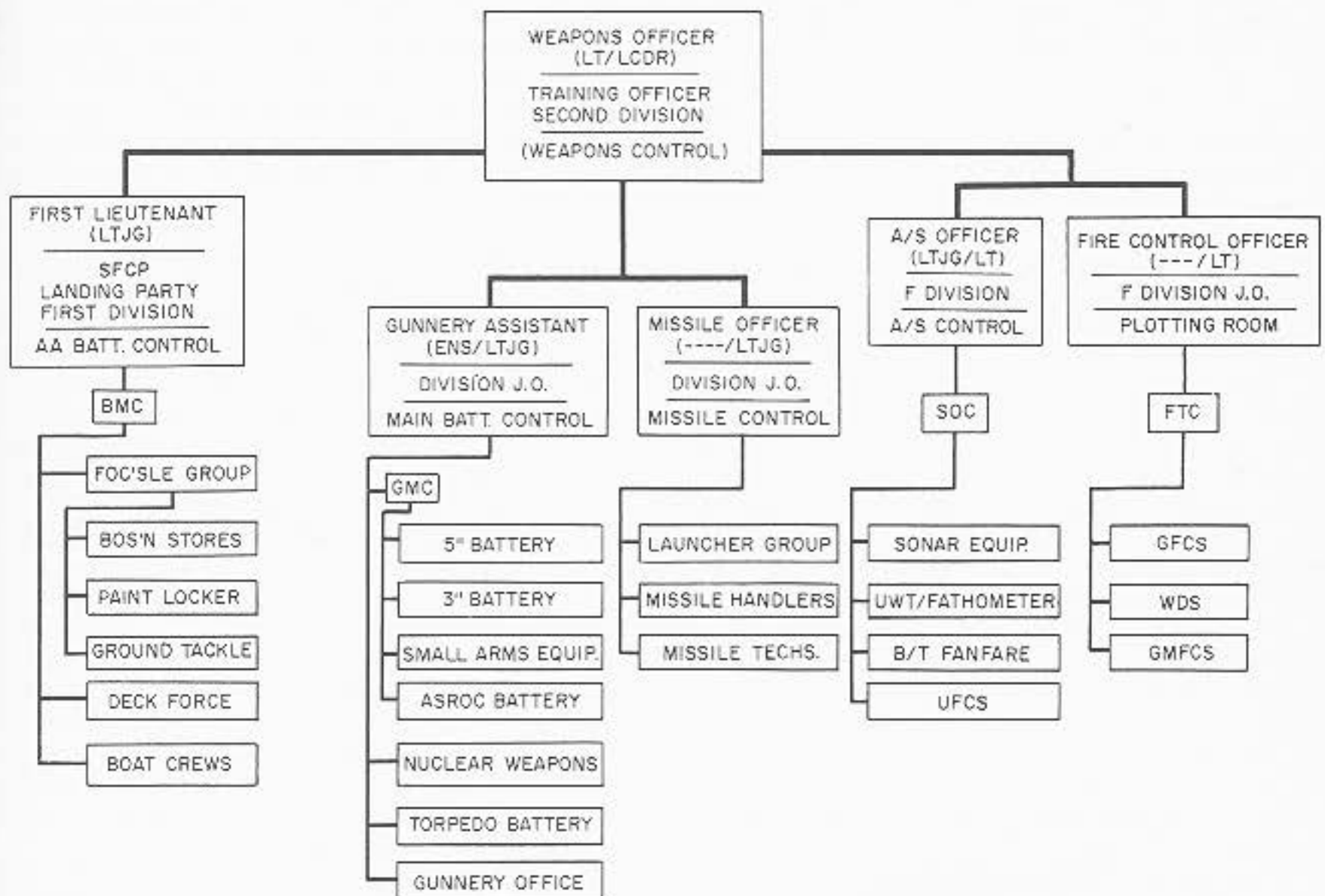
Never underestimate the importance of cataloging, classification, and nomenclature when

dealing with ordnance. In fact, the word "ordnance" is related to the word "order," in the sense of arrangement or classification. Its use in connection with weapons has been traced back to England's Henry VIII, in whose reign the royal armament was classified and cataloged.

Ordnance classification, cataloging, and standard nomenclature, which were a welcome innovation in the 16th century, became an unavoidable necessity in the 20th. In this text it will not be possible to describe in detail the complexities of U.S. naval ordnance cataloging and classification. This section will attempt only to explain enough to make the main principles clear.

NOMENCLATURE AND IDENTIFICATION

The standard nomenclature for any item of naval ordnance equipment includes a basic noun,



63.4

Figure 1-5.—Weapons department organization for USS Farragut Class DLG.

often accompanied by descriptive adjectives, plus identifying numbers. For example: "3-in. 50 cal rapid-fire twin gun mount Mk 33 Mod 4." Reading this from left to right, "3-in." specifies the bore diameter or caliber, "50-cal" specifies the gun barrel length in terms of calibers (since this is a 50-caliber gun, its length is 3×50 or 150 in.); "rapid-fire" indicates that its ammunition is fed into the gun automatically by a power-driven loader; "twin" indicates that the complete mount assembly incorporates two gun barrels mounted in parallel. The basic noun here is "mount," which here includes not only the gun barrels with their breech and recoil mechanisms, but also their training and elevating gear, gun mount shield, power drives, power rammer and loader, and fire control and sighting equipment located on the mount. "Mk 33 Mod 4" is abbreviated from "Mark 33 Modification 4," which specifies a particular version of a certain mount design.

In Navy usage, the modifiers in the nomenclature of a given item are flexibly used; thus, an ordnance technical manual may refer to the gun mount named above merely as "3-in. mount Mk 33 Mod 4." This represents the minimum. Note that the reference to "gun" is omitted. When not otherwise specified, a mount is always a gun mount.

The mark number identifies a major item (like a gun mount) or principal component (like a sight or a power drive) of a particular design. When the Navy makes a basic change in design, or designs new equipment of the same general type, the name remains the same but a new mark number replaces the old. Thus the Mk 33 Mod 4 twin mount mentioned above has a different mark number from the generally similar Mk 34 single mount, and also a different mark number from the Mk 27 twin mount, which differs significantly from the Mk 33 in the design of the slide. The mod number (mod here stands for modification,

not model) indicates a minor design change or alteration. For example, the Mk 33 Mod 4 mount mentioned above differs from Mod 2 chiefly in that Mod 4 has an aluminum shield while Mod 2 has not. Modifications may be made also because of improvements in design based on experience, or to adapt the equipment for mounting in different places or for operation with different associated equipment.

The nomenclature of any naval gun barrel or mount always includes its caliber. There is a separate series of mark numbers for each caliber; for example, 3-inch and 5-inch gun barrels are numbered in different series. However, as long as the bore diameter is the same, gun barrels are numbered in the same series, regardless of bore length. Thus, both 5-inch gun barrels—the 5"/38, and the 5"/54 (and their mounts)—are numbered in a single series.

The mark and mod numbers, as well as the rest of the nomenclature, are assigned by the Naval Ordnance Systems Command. The place to find this official nomenclature is the current edition of Ordnance Pamphlet (OP) 0. (This publication is described later in this chapter.) For nomenclature of components or parts of units designated by mark and mod, use the OP or the ordnance supply catalog for the equipment concerned.

Gun mounts are identified not only by mark and mod but also by assembly number. This is so because gun mounts (especially the larger ones) are not single units, but are really combinations of smaller units, each of which has its own mark and mod. For instance, the 5-inch Mount Mk 39 Mod 0 may be equipped with any one of a number of different mods of the Elevation Indicator-Regulator Mk 54, or with one of several mods of the Train Indicator-Regulator Mk 46. It may have either Mod 0 or Mod 1 of the Mk 54 shield, and so on. Each assembly differs from the other in details like this. Each assembly is, therefore, designated by an assembly number to distinguish it from the others.

Each individual unit of a given mark and mod has its own serial number. Identification by mark and mod is standard usage for weapons and fire control equipment. Some types of fire control radar use mark and mod designations, but most fire control radars, sonars, and other electronic equipment use a different system which is fundamentally composed of two groups of letter prefixes followed by an identifying number. An example is "Sonar equipment AN/SQS-23." Letter group "AN" means that the nomenclature complies with the system adopted

jointly by the U.S. armed forces. In the following group, "SQS," the first "S" identifies the type of installation (It stands here for "water surface craft.") the "Q" stands for the type of equipment (sonar and underwater sound), and the final "S" indicates the purpose (detecting and/or range bearing). The numeral "23" serves as a model number, or the equivalent of a mark number. (However, modification numbers are not used in this system. Instead, a letter suffix "A," "B," etc., follows the model number.)

A complex electronic equipment like a sonar or radar system usually consists of several interconnected units. A letter group prefix is used instead of "AN/" to identify such a unit. For example, "IP-SQS-23" might be used to designate a cathode-ray display indicator tube used in conjunction with the AN/SQS-23 system.

Navy ordnance equipment (such as small-arms weapons) and ammunition procured from the Army normally retain the Army model designation, which consists of the letter "M" (standing for model), followed by a number corresponding to mark number, then (if there are modifications) by the letter "A" followed by a number designating the mod. Thus "Carbine, cal .30, M3A1," identifies a certain carbine with a bore of 0.3 inch as what would correspond in Navy terminology to Mk 3 Mod 1.

Aircraft bombs which have been adopted jointly by the Air Force and Navy are identified by AN-followed by either Army style numbers (M__A__) or Navy mark and mod numbers.

NAMEPLATES AND OTHER MEANS FOR IDENTIFYING EQUIPMENT

Each item of equipment assigned a mark and mod number or equivalent bears a metal nameplate secured to some easily visible spot on its exterior. This plate is engraved or otherwise marked to provide the following information:

Standard nomenclature of the equipment, including mark and mod or equivalent, and identification of the system of which it is a part (unless it is an individual self-contained item).

Standard Navy Stock Number, Federal Stock Number, or other catalog identification.

Name of cognizant Naval Material Command agency (i.e., the Navy agency that procured the unit).

Manufacturer's part number or drawing number.

Name of manufacturer.

Number of contract under which the equipment was supplied.

Serial number, assembly number, or other numbers which identify the specific unit. Items produced in large quantities may have a lot number instead of a specifically assigned serial or other number.

The nameplate will probably also contain other information, such as the voltage and frequency of electric power to be supplied to the unit, precautions to be observed in using it, and blanks for recording alterations that have been made to the equipment. But the information listed above is approximately what you can normally expect to find. There will be some minor differences in equipment procured by different agencies of the Navy, but the nameplate will always be the best primary source for identification of equipment. It is obvious that the nameplate must never be detached, defaced, obliterated, or permitted to become illegible, either through neglectful accumulation of grime and dirt, through being painted over, or through overdiligent scouring that erases the information it contains. Nor may the information on it be changed or added to, except as specifically directed by the cognizant technical command.

Many smaller assemblies and parts can be identified by numbers or coded markings. Numbers printed or engraved on parts or assemblies may be catalog numbers, Navy or contractor's drawing numbers, or code symbols that correspond to symbols on schematics. For most effective use of all of these, it is necessary to have available the technical manual or instruction book for the equipment, as well as (if possible) the appropriate part of the Navy's material catalog and available prints of the drawings on the equipment. With these, it is possible to establish positive identification of all parts and assemblies of the equipment.

The preceding paragraphs cover only the bare outline of the equipment identification and nomenclature systems used in the Navy. The subject is a complex one which can be completely mastered only by considerable specialized study.

In referring to a piece of ordnance, the information needed for identification depends upon the circumstances. For example, to identify the entire equipment as a functioning unit, the name, mark, and mod will be sufficient. But for requesting spare parts from the Ordnance Supply Office, the serial number (and the assembly number, if any) may be necessary in addition to the Federal Stock Number. These, together with

mark and mod numbers, identify the specific unit involved, which enables the supply officer to contact the manufacturer if necessary.

FURTHER EDUCATION IN ORDNANCE AND GUNNERY

In your four-year NROTC program your chief opportunity for training in naval ordnance and gunnery (in addition to this text) up to the time you graduate will come during a summer cruise prior to graduation. At this time, you can expect a tour of training duty in the weapons department of a ship—quite likely aboard a destroyer or escort vessel, or possibly aboard a cruiser or carrier. This cruise will give you experience in working as part of the weapons department at several different points. You may have an opportunity to serve in a number of general-quarters stations—in ammunition handling in gun mounts, in gun laying and firing, in fire control directors, in fire control or missile plot, in sonar and underwater battery plot, and at torpedo and guided missile control stations. To make sure that you are successful in your later career on active duty, you will have to make the most of this shipboard training.

You will probably find that the subject matter of naval ordnance and gunnery is intrinsically interesting, particularly when you have the opportunity to work with the weapons and the equipment itself on board ship. But even if your primary area of interest is elsewhere, it is well to remember that all naval line officers have weapons department assignments sooner or later in their careers, and that it is worth working to make such assignments successful and profitable in terms of broadening your background and increasing your knowledge and experience. Moreover, your life and the lives of your shipmates may depend on your effectiveness as a member of the weapons department.

UNDERGRADUATE TRAINING IN RELATED SUBJECTS

This text on naval ordnance and gunnery is to some extent self-contained in that it includes in chapter 3 the principles of mechanics, hydraulics, electricity, electronics, optics, and sound as they apply later in the text. The basic material in this book and the mathematics and physics training that you have had are only a bare minimum. Amplification of this minimum

is strongly recommended. Valuable reading material that would solidify the basis on which your naval training will be founded would include texts on college chemistry, advanced mathematics (through calculus), elementary drafting, elementary electricity, electronics, nucleonics, mechanical engineering, and elementary aeronautical engineering (particularly with reference to guided missiles). All of these are not likely to be possible for all students, but any that you can study will be of great advantage. In planning your choice of technical study material, you would do well to consult with your Professor of Naval Science so that you can select material of maximum value in your naval career.

TRAINING ON ACTIVE DUTY

It is true that education does not end when you receive your diploma. It applies to your naval career as well as other aspects of your life, and it applies regardless of how you earned your commission.

When you are on active duty aboard ship, your professional education may be continued both on the job during duty hours and watches, and on your own time through personal study and through correspondence courses. This book by no means delimits the boundaries of your learning. The next section indicates possible study material sources that you should investigate once you are on board ship and in a position to take advantage of them. You can obtain details on correspondence courses through your education officer. Most of the books that you will find it profitable to study will be available aboard ship; the others can easily be obtained through routine channels. These study sources will help you both in training for current assignments and in preparation for future work of more scope and responsibility.

You will find special educational value in ship and fleet exercises and drills. You will get more out of such exercises if you prepare for them by studying the appropriate doctrinal publications in advance, and if you participate in the technical preparations your fellow officers and leading petty officers make for them.

OCS STUDENTS

During your intensive training period, you, as an Officer Candidate School (OCS) student, will be more or less limited to this textbook and other study materials on ordnance and gunnery that are furnished by the school. The suggestions in the

preceding paragraphs on "Training on Active Duty" apply to you as an OCS graduate as much as they apply to all other naval officers—and you have probably learned by now that a conscientious naval officer's professional education continues all through his career.

PUBLISHED SOURCES OF INFORMATION

The competence of a naval officer depends not only on what he knows, but also on his ability to find quickly a reliable, authoritative source for other information he needs. For this he must depend on and be well acquainted with published sources of information.

The principal types of Navy publications which you as a naval officer aboard ship will use in connection with ordnance and gunnery include technical, tactical, and training publications.

TECHNICAL PUBLICATIONS

Most of the technical publications the weapons officer is concerned with are issued by NavOrd. Other technical publications are handled by NavSup. Naval Supply Systems Command operates Naval Publications Supply Center at Philadelphia, Pa. The available publications are indexed in NavSup Publication 2202, Cognizance Symbol I.

Ordnance Pamphlets (OPs) are of two types. Most OPs are of the type that serves as a technical manual on a specific ordnance equipment, including a description of the equipment, its operation, maintenance, installation, and repair. The other type of OP, of which there are relatively few, is a treatise on some ordnance subject such as battery alignment or ammunition. All OPs are indexed in OP 0. They are numbered consecutively without any attempt at coding.

Ordnance Data (OD) publications are used for publishing a variety of technical information, including test and inspection information, advance information or instructions on ordnance equipment, and ordnance equipment lists for specific types of ships. ODs are numbered serially and are indexed in OP 0.

Ordnance Alterations (OrdAlts) prescribe specific authorized changes (as distinguished from repair and other maintenance work that does not alter the design or characteristics of the equipment) in specific ordnance equipment. Alterations of ordnance equipment are permitted only as authorized by OrdAlts, and they must be made strictly in accordance with the drawings and

instructions that form part of the OrdAlts. After they are completed, they must be recorded in the maintenance records of the weapons department and reported to NavOrd. OrdAlts are listed in a special index published as OrdAlt 00.

Ordnance Instructions and Ordnance Notices are NavOrd-issued directives published in accordance with a decimal numbering scheme prescribed by the Office of the Secretary of the Navy. This scheme provides for subject classification and numbering of issues relating to administration, supply, procurement, production, fiscal matters, and the like. NavOrd directives are indexed in NavOrd Note 5215.

The ordnance section of the Coordinated Shipboard Allowance List (COSAL) is the authority for issue of ordnance material to ships. COSAL includes the spare part items for all departments on the ship. The COSAL does not include resale clothing, bulk fuel, medical supplies, recreational equipment, and expendable ordnance. These items (as well as some others) are covered by separate outfitting and load lists. Each COSAL is tailored to meet the needs of a specific ship, and it is prepared in segments by category of material in simplified and uniform format. (A more detailed discussion of the COSAL may be found in other NavPers publications, including Military Requirements for Petty Officer 3 & 2, NavPers 10056-C.)

NavOrd Bulletins are classified, quarterly periodicals containing articles on new developments in naval ordnance, equipment in the fleet or under development, new safety information, newly developed modifications to ordnance gear, and other timely information. They also list new publications issued since the latest issue of OP0.

Weapons department personnel use and may maintain a considerable amount of equipment under the cognizance of NavShips—equipment such as dredger hoists, compass repeaters, sonar gear, speed indicators, and wind data receivers. Technical manuals for such equipment are published by NavShips and furnished to weapons department personnel.

Weapons department personnel also maintain all or part of such systems as high-pressure air distribution systems and sprinkler systems. For technical information on these systems, see the appropriate drawings (ship's plans), your ship's Damage Control Book and General Information Book, and the NavShips Technical Manual. The NavShips manual consists of a number of separate chapters, each bound like an independent pamphlet, and each on some aspect of the ship's structure or plant.

TACTICAL PUBLICATIONS

The Chief of Naval Operations (CNO) issues several series of publications intended to present doctrines and procedures for the use of U.S. Navy ships, aircraft, and weapons in combat. In naval warfare usage, a doctrine may be defined as a working principle or rule of combat that has been developed theoretically and proved by experience. Procedures are methods used to put the doctrine into effect. These publications are concerned also with team combat training—the training of groups in fighting units, as distinct from individual training mentioned later on in this chapter. All these doctrinal publications are classified.

The primary series of doctrinal publications issued by the CNO are Naval Warfare Publications (NWPs). There are four groups of these. Group I takes up basic principles and planning, groups II and III are devoted respectively to naval operations and the procedures they require, and group IV deals with specific fleet exercises. The group I doctrinal publications also include, besides NWPs, several Allied Tactical Publications (ATPs) and Allied Communications Publications (ACPs); these apply in the U.S. Fleet as designated by the CNO. The group IV publications are identified either as Fleet Exercise Publications (FXPs) or Allied Exercise Publications (AXPs), not as NWPs.

Supplementing the primary doctrinal publications mentioned above are the Naval Warfare Information Publications (NWIPs) and several ATPs and FXPs. These expand in detail certain aspects of primary publication content. The entire doctrinal publications system is described in NWP 0, which contains charts explaining in detail the interrelationships among the publications mentioned above, and has detailed indexes of their contents.

In your duties aboard ship as an officer in the weapons department, you will find that the doctrinal publications most useful to you at the outset will be:

1. The publications directly concerned with the type of ship you are on, its mission, and often your assignment in your department. For example, if the DD you are in is preparing for amphibious operations and you are assigned as weapons liaison officer in CIC, you should be studying NWP 22, NWIPs 22-2 and 22-7, NWP 31A, ATP 4,

and appropriate parts of FXP 3. These have to do with amphibious operations, CIC operations, naval gunfire support, and fleet exercises (including amphibious).

2. ATP 1, Volume I. The information here is essential to any officer assigned as watch officer, JOOD, or OOD, particularly when underway.

3. NWP 10, a basic publication on the principles of sea power and the U.S. Navy's mission. In some commands this is more than recommended reading; it is required.

4. NWP 50. The student should concentrate on those parts of this book that deal with weapons department organization and operation, and the relationship of the weapons department to other shipboard departments.

TRAINING PUBLICATIONS

The Bureau of Naval Personnel (BuPers) is charged with all training of naval personnel other than group combat training (which is under CNO). BuPers therefore issues all text material specifically designed for training purposes and intended for Navy-wide distribution. The book you are now studying is a BuPers publication of this type. The training materials published by BuPers fall into the following categories:

1. Navy training courses for enlisted personnel. Most of these are intended for enlisted personnel to study in preparation for advancement to specific ratings and grades, but some are courses in common subjects such as electricity and mathematics.

2. Navy courses for officer personnel. These cover subjects of specific interest to officers, such as this book and The Weapons Officer, NavPers 10867 series.

3. Correspondence courses on specific subjects. These are designated as enlisted or officer courses. The courses are based respectively on the texts of the two types mentioned above. Officer courses are available to personnel on active duty or in the reserves. They are administered by the U.S. Naval Correspondence Center, Scotia, New York.

4. Special-purpose publications that do not fall into the categories above, such as the

periodically issued List of Training Manuals and Correspondence Courses, NavPers 10061 (followed by a letter indicating the revision). NavPers 10061 serves as a catalog of NavPers publications.

Aboard ship, the officer newly assigned to the weapons department will probably find most useful a copy of the books in the present series, plus The Weapons Officer, NavPers 10867, and such others as will be applicable to his assigned duties. NavPers 10061 is a good reference to investigate for this purpose.

SAFETY PRECAUTIONS

A universal objective of all U.S. naval training programs for all personnel is safety education. Active attention to safety is a part of all courses taught in Navy schools, and all training publications are concerned with it as well as with their principal subject matter. All supervisory personnel, enlisted and commissioned, are concerned with safety.

Since safety is so all-pervading a subject, it is obviously impractical to try to divorce it entirely, for study purposes, from the activities and operations with which it is connected. To indicate the type of safety considerations that the Navy deems important in connection with ordnance, an extract from the Navy publication U.S. Navy Safety Precautions is reprinted as an appendix to this book. However, the weapons department officer aboard ship should be aware of other primary sources of information on safety available to weapons department personnel. They are listed here for reference purposes.

1. Technical publications issued by NavShips and NavOrd on equipment under their cognizance contain safety information as required in connection with proper operation, maintenance, and adjustment of the equipment.

2. NavOrd also issues OPs on certain aspects of safety, as follows:

a. OP 4, Ammunition Afloat, and OP 5, Ammunition Ashore, Handling, Stowing, and Shipping.

b. OP 1014, Ordnance Safety Precautions; Their Origin and Necessity.

c. OP 1591, Clearing of Live Ammunition From Guns.

3. BuPers issues the following publications containing safety information:

a. The Weapons Officer, NavPers 10867.

b. Navy training courses (including basic courses) contain safety information in appropriate contexts.

4. Other sources.

a. Safety placards and cautionary nameplates appear on equipment and in its vicinity where considered advisable for the warning of operating and maintenance personnel.

b. Army technical publications, used in the Navy particularly for small arms, have considerable safety information as it concerns small arms and ammunition.

CHAPTER 2

SHIPBOARD WEAPONS AND WEAPON SYSTEMS

Shipboard weapon systems — crude as they may have been — have existed for many years. The older systems were less complex (and less accurate) than the ones today, but they were weapon systems nonetheless.

A weapon system is, according to the definition given in NWP 10, the combination of a weapon (or multiple of weapons) and the equipment used to bring the destructive power of the weapon against the enemy. Before guns were invented, the ship was used to sink or damage an enemy ship by ramming it. This tactic was used occasionally as late as World War II.

In this chapter, we are concerned with the weapon systems (e.g., gun, missile, and torpedo) within the ship and not with the ship itself as a weapon system. Also, we will briefly discuss weapons and their revolution, detecting devices, weapon delivery devices, and weapon control units.

EVOLUTION OF NAVAL WEAPONS

In your naval orientation course you studied the influence of seapower on world history, tracing it as far back as the wars in ancient times between the Greeks and the Persians. You may recall how Roman seapower turned the Mediterranean into what the Romans called "Mare Nostrum" (our sea), so that the invading Carthaginians had to go hundreds of miles overland to bypass Roman seapower. You may also recall how, following Columbus' voyages, seapower made Spain's access to the New World the root of her imperial power and how Britain later gained this power with a single major victory at sea. Examples of the influence of seapower on history could be multiplied. Instead, consider briefly now how evolving armament and the technique of using it have affected seapower in the past, and a few dominant trends in the future.

GUNS AND OTHER WEAPONS EFFECTIVE AT A DISTANCE

Warships in classical and early medieval times engaged each other effectively by ramming or by grappling and boarding for hand-to-hand combat. Until the development of the naval gun, this remained the classical pattern, although crossbows, incendiary pyrotechnics ("Greek fire"), and shipborne spring- or torsion-powered artillery did allow some battle action before actual ship-to-ship contact. As guns developed, ranges increased from 80 to 300 feet for early naval cannon to 40,000 yards and beyond for the World War II battleship. Most of this increase took place shortly before and during World War II. In our Civil War a mile was rather far for accurate gunnery, and even in the Russo-Japanese War (1905) the opening range was only about 6,000 yards. Aircraft and guided missiles have even more radically increased battle ranges.

The most significant results of the increasing range of seaborne weapons have been (a) an increase in the importance of naval firepower in land warfare, (b) an increase in its potency as compared to landbased firepower, and (c) an increase in the importance of amphibious warfare. Modern naval gunfire and aircraft can range many miles inland to attack specific objectives, to support land forces (as supplements to land artillery), and to support amphibious landings. Compare, for example, the successful Inchon beachhead (Korean War) with the Gallipoli fiasco (World War I).

The increase in range has increased the distance between combatant forces in purely naval engagements also, and it has had a number of other side effects. The extreme in this trend toward increasing separation between attacker and target has recently been attained by missiles which can span whole oceans to reach their targets.

The development of nuclear fission and fusion revolutionized not only weapons but also even the art of war, to say nothing of its effects (still not entirely known) on mankind in general. But explosives have been revolutionized before—first with the discovery of gunpowder, then with the invention of guncotton and its nitro-based successors, followed by the development of powerful but insensitive explosives, and the continuing improvements in gun propellants and in the later chemical explosives.

One effect of the increased lethal range of explosive weapons resulting from the use of the new explosives, particularly nuclear, has been an increase in the dispersion required to minimize combat damage to ships in convoy and combat groups. Coupled with the improvement of aircraft, undersea craft, and missiles, another effect has been to force the development of picket vessels and early-warning systems.

FUZES AND RELATED DEVICES

Projectiles designed to explode on impact were used soon after cannon were developed. They were quite unreliable and unsafe however. They were the "bombs bursting (prematurely) in air" that Francis Scott Key saw; they did relatively little damage, and did not become really practical until around the middle of the 19th century when adequate fuzes were first developed. Fuzes have since become more and more subtle and refined, from simple impact types through mechanical time fuzes and modern proximity fuzes. These last, in a general sense, include not only projectile fuzes that operate by radio transmission, but also the equally sophisticated underwater weapon devices—acoustic, magnetic, and pressure-sensitive—which are used in mines, torpedoes, and depth charges.

The result of all these developments has been an increase in the destructive efficiency of the weapons and projectiles in which they are used, in that the weapon or projectile will function effectively without actual physical contact with the target. The consequent increase in anti-aircraft weapon effectiveness has to some degree offset the development of higher performance aircraft. Underwater, the effect has been to increase the complexities of defense and attack, as well as the dangers of both surface and undersea targets. Probably the most spectacular

corollary of the development of sensitive underwater devices has been the concurrent development of the torpedo that can seek out and home in on its target. This, along with the snorkel, nuclear power, and hydrodynamic developments (e.g., the shape of the Albacore shown in figure 2-1) has had a revolutionary influence in changing submarine and antisubmarine warfare from what it was early in World War II.

UNDERWATER WEAPONS

Underwater weapons include the mine, the torpedo, and the depth charge.

The mine is a weapon effective at a distance, in time as well as space. After the mine is planted, it lies dormant until a ship (or other metallic object) comes close enough to detonate it. Mines are a means of controlling the sea by denying ships passage through it or making such passage extremely hazardous. An example of the effectiveness of mines in such an application during the Korean War was the enemy's mining of the Wonsan area, a relatively favorable landing site. This prevented the United Nations forces from making a second beachhead there, and impaired the effectiveness of the campaign to repel the North Korean-Red Chinese forces.

The automotive (self-propelled) torpedo, an unmanned explosive-laden submarine, was first developed in practical form in the 1870s. Early in the 20th century it was considered so potent (particularly in the days of metal ships lacking modern compartmentation) that special torpedo-boats were used to launch them. A specialized craft to counter the torpedo-boat was developed—the torpedo-boat destroyer, which has evolved into the modern DD. The torpedo (and torpedo-like weapon) is now the most advanced weapon used against submarines as well as the chief weapon used by submarines other than FBM.

Unlike mines and torpedoes, which can be used against either surface or submarine targets, the surface-launched depth charge (when dropped from aircraft, called the depth bomb) is specifically an antisubmarine device. When first developed in World War I, and until the midst of World War II, large depth charges were either dropped astern or heaved a few score yards over the side by a small propelling charge in a special gun, after which they were detonated by a hydrostatic device upon reaching a set depth. Currently used designs are much smaller. They



71.1-569

Figure 2-1.—U.S.S. Albacore (AGSS 569).

may be propelled by a rocket or a mortar device and are either contact- or proximity-fuzed, but their most important characteristic is that they can be fired at much greater ranges (up to several hundred yards). This has led to a change in antisubmarine warfare (ASW) tactics. ASW vessels are no longer forced to stay close to the target submarine, crossing and recrossing its presumed location which frequently caused the DD to lose sonar contact in its own screw noises. Weapons can be thrown ahead of the DD's track (ahead thrown weapons) to eliminate this difficulty. Newer depth charge weapons that extend the aerial flight time are discussed in a later chapter.

FIRE CONTROL

The improvements in gun ranges mentioned earlier could make guns effective only if the guns were adequately directed so that their projectiles would hit the target. The evolution of gun fire control as we know it today began in the 19th century with the invention of fixed sights, and continued with the development of movable sights (something like those on modern military rifles) in the 1840's, telescopic sights and drift- and windage-compensating sights (1850's and 1860's), fire control directors and optical rangefinders (World War I), analog fire control computers and plotting techniques (after World War I), and

high-speed, digital fire control computers and automatic target acquisition and tracking (after World War II).

The most spectacular World War II fire control innovation was radar, which made accurate fire control possible even when optical instruments were useless. Radar has been mainly responsible for the enormous accent on the electronics characteristic of the fleet today. A pre-war DD had, for example, perhaps 100 electron tubes altogether; a postwar DD has more than 3,000 tubes and transistors.

Parallel with the development of radar came the development of sonar. Even as early as World War I, hydrophones were used both by destroyers and submarines to listen for underwater and surface targets. The development of active ('ping') sonar revolutionized underwater detection by making possible the detection of passive targets (i.e., those that do not radiate noise). Although sonar and radar are similar in principle, their range and accuracy are not on the same order. (Radar has the advantage over sonar in both range and accuracy.) With the increased emphasis placed on antisubmarine warfare in recent years, sonar is being constantly improved. Modern sonar is capable of detecting targets at far greater ranges and depths than sonar of the World War II era. Sonar is invaluable in both surface and subsurface naval vessels.

CONCLUSION TO HISTORICAL DISCUSSION

The preceding paragraphs have indicated in broad outline some of the effects of developments in important naval weapons, but much has been omitted (guided missiles and rockets for example); and the development of the vehicles themselves (surface ships, submarines, aircraft, propulsion and navigation equipment, etc.) has not been covered. Some of the present trends in weaponry are indicated later in this chapter.

THE WEAPON SYSTEM CONCEPT

The effective use of any naval weapon requires that a payload (generally an explosive device) be delivered to (usually) a moving target. Accuracy in determining the location and velocity of the target is vital to the success of the attack. The result of the increase in target velocity and range has been that today, for effective use, a weapon must be considered and employed not individually but as part of an accurate weapon system.

ELEMENTS OF A WEAPON SYSTEM

The phrase "weapon system" was defined in general terms in the preceding section. We can now be more specific. A weapon system, taken as a whole, must include:

1. Elements which detect, locate, and identify the target.
2. Elements which deliver or initiate delivery of the destructive device of the weapon to the target. (The term "weapon" is used flexibly in different contexts; for example, a gun is a weapon which delivers a projectile to the target, while a mine is a weapon that itself explodes when a target activates it.)
3. Elements that control a delivery unit or weapon to direct its delivery; that set the fuze (or equivalent) of the destructive device; or (as with a torpedo) that "program" or preset a target-seeking device as required for maximum effectiveness in reaching the target.
4. Destructive payloads (usually termed "weapons") that will destroy the target when in contact with it or when in its vicinity.

Each of these types of component elements will be discussed in somewhat more detail later.

WEAPON SYSTEM REQUIREMENTS AND EVALUATION

The Navy has a rather elaborate series of stages through which any weapon or associated item must go from the time it is proposed until the solid hardware itself is installed for service use aboard ship. Although the fundamental idea on which the item is based may originate almost anywhere (ideas are welcome regardless of the source), it is the Chief of Naval Operations, speaking for the ultimate user, the fleet, who sets the requirements that the weapon or whatever it is must meet. The prototype (first installed model) of any instrument or piece of equipment which bears a Navy nameplate that you see on a naval vessel has been through exhaustive engineering and shipboard application tests, and meets the fleet's requirements for what that specific item must do, and how well it must do it.

The trend in recent times has been increasingly toward design and procurement of complete weapon systems, rather than of component units which later evolve into a system. This is especially true of newer systems such as missiles with their complex guidance and propulsion systems, as contrasted with most systems based on guns, which were not originally conceived as systems but evolved that way.

The statement of requirements for any weapon system or component unit can be considered as responses to two questions—

1. What is the system or component unit supposed to do?
2. How well is the system or component unit supposed to do it?

The answer to the "what" question is often called the "military requirements." It is a statement of the nature of the equipment (whether it's a gun, a torpedo, a radar, a computer, etc.) and its capabilities or what it can do (if a gun, its range, rate of fire, etc.; if a torpedo, its speed, range, accuracy, etc.; if a radar, its range, accuracy, sensitivity, etc.; if a computer, its speed, accuracy of solution, limits of operation, etc.). Obviously, all this is entirely dependent on the nature of the system or component

unit. Moreover, in a system, each component's requirements depend on the characteristics of the other components and on the requirements of the system as a whole. Thus, the capabilities of any system are limited by those of the "weakest link" in the system. (For example, a computer in an ASW system can solve fire control problems beyond the ranges possible to the sonar equipment in the system; the sonar's range therefore establishes the system's range.)

Aside from what we have here called the military requirements that depend on the nature and task assigned to weapon systems and weapon system components, there are some requirements that are generally applicable to all, regardless of the nature of the system or component. These can be considered as the answer to No. 2 above. We can state them here only in qualitative terms, since this is a general discussion; in system specifications these requirements are reduced to specific values:

1. **RELIABILITY.** The system must be capable of continuous long-period functioning under specified adverse conditions at specific rates (e.g., rounds per minute fired, or hits maintained at specified accuracy, etc.).

2. **FLEXIBILITY.** The system must be capable of functioning satisfactorily in spite of failures in quality of power supply, ammunition, etc.; it may also be required to function satisfactorily with certain components omitted or disabled, or with others substituted.

3. **SAFETY.** The system must be perhaps not foolproof, but hazardous conditions must be eliminated by interlocks or other means; it must not endanger friendly ships and aircraft or own-ship structure or personnel.

4. **SIMPLICITY OF OPERATION.** Complex modern weapon systems cannot be made inherently simple, but they should be designed for facility of operation by human beings. These considerations influence design of control arrangements, provisions for safety and comfort of operating personnel, and functional design to make the equipment as simple to operate as its nature will permit.

5. **MAINTAINABILITY.** This requires not only design using long-life components, but also convenient (and in many cases almost entirely automatic) testing and trouble-diagnosing gear that is either part of or is easily connected to the equipment. Moreover, this requirement has led

to the development of the unit replacement principle—thus, if an amplifier, for example, burns out, the procedure is not to test each component in it and make repairs as necessary, but to pull out the whole amplifier (which is a complete plug-in unit) and plug in a replacement. The defective unit can then be repaired later and put back in stock as a spare.

Note that in weapon component or system design these requirements often conflict with each other. For example, a fuzing system may be made so safe that it won't function reliably. Much of the work in weapon design is concerned with attaining practical compromises between conflicting requirements.

The evaluation of a weapon system or component unit can be defined as the study of the system or unit, measurement of its effects, and appraisal of its effectiveness. As in development of ordnance material, the trend is toward evaluation of complete systems rather than independent units; in system testing and evaluation, however, component units are tested individually as well as with relation to their systems. Before a system or component is accepted for fleet use, it must go through both **TECHNICAL** (i.e., engineering) and **TACTICAL** evaluation, following standard prescribed procedures.

COORDINATION AND DISPERSION IN WEAPON SYSTEM EMPLOYMENT

Concurrently with the increasing complexity of weapons and weapon systems, naval operations have become more complex. The variety and the effective ranges of weapons are increasing, and the speed and maneuverability of targets are increasing.

As the ranges and explosive effect areas of modern weapons have increased, they have dictated increased dispersion of formations of naval ships. Convoys and task groups arranged according to present day doctrine have ships much more widely spaced than was the practice before and during World War II. An attributable factor is the development of atomic weapons, which add to the blast and fragmentation effects of former conventional weapons (but, of course, on a much magnified scale) the threat of radioactive contamination. Another factor which makes wider dispersion necessary is the increased speeds of aircraft and missiles which may attack the formation. More dispersion is needed, in the direction of the threat, so that outer perimeter units may give early warning of an attack.

The effects of this dispersion requirement are to increase the difficulties of coordination and to increase the requirement for improved long-range underwater target detection performance.

DETECTING DEVICES

The first steps in the functioning of a weapon system are the detection, location, and identification of the target. Ideally, the device performing these functions should detect the target at maximum range, and establish the target's location, orientation, and velocity with respect to own ship, with maximum accuracy and minimum delay. At the same time this device should identify the target as to exactly what it is and whether it is enemy or friendly. Ideally, the device should be equally efficient regardless of which medium it operates in, regardless of the conditions in that medium, and regardless of interference originating with the enemy, with friendly forces, or with natural causes.

No detecting (for the present let this term include locating and identifying) device or system yet developed measures up, without possibility of improvement, to any of these ideals. The ideals are useful chiefly as standards by which the effectiveness of detecting devices can be judged. The principal detecting devices now used in the fleet include:

1. Optical devices.
2. Radar.
3. ECM (electronic countermeasures).
4. Sonar.
5. MAD (magnetic anomaly detection).

All except the last of these depend on detection of radiation—the first three on electromagnetic radiation, the fourth on sound radiation. MAD depends on detecting differences in magnetic fields.

Optical devices are invariably passive, i.e., they detect radiation emitted or reflected by the target, but don't produce the radiation they detect.

ECM equipment falls into the passive category when used for detection. But ECM gear also has an active mode for use in jamming the enemy's electronic detection equipment. Sonar may be either passive or active when detecting subsurface targets. Its active device produces radiation which it detects as a reflection from the target. In order for passive sonar to detect

a target, it has to receive noise from the target. Radar can only be active.

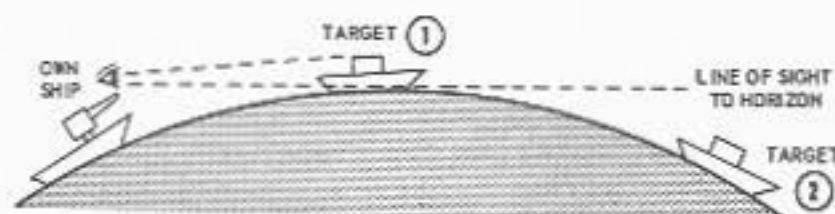
OPTICAL DEVICES

Optical devices in weapon systems function to establish target bearing and (for air targets) target elevation. Some optical devices can measure the range to the target. Except for highly unusual atmospheric conditions, in which light rays reflected from the target to own ship are perceptibly bent by refraction, the line of sight (a straight line from target to observer) is truly straight. Optical devices which incorporate lens systems are designed to magnify the image of the target; this extends the capabilities of the human eye in target detection and identification.

Since optical devices depend on visible light reflected from the target, they are handicapped by darkness (unless the target is luminous), fog, and visible obstacles. Optical devices are always passive (i.e., they never provide the light that makes the target visible), but an attacking ship can illuminate a target by firing gun projectiles which release parachute-supported flares in the vicinity of the target, or by using aircraft to drop such flares.

At the present time, only a few U.S. Navy ships have night observation devices, but eventually, most Navy ships will have these. Night observation devices actually intensify the brightness of an image and are used for observation, surveillance, and for the aiming of weapons during night operations. They use natural light radiations of a very low level to produce a useful, visible image.

Since light, in general travels in straight lines, a target cannot be optically detected if it is entirely below the horizon (like target 2 in figure 2-2).



110.1

Figure 2-2.—Limits of optical detection.

RADAR

In our short discussion of radar we will concentrate on its ability to measure the range or distance to a target. Navy radars can measure the target's angle of elevation above the surface horizontal, its altitude, and its true or relative bearing. This is, of course, if they are designed to do so. The target's speed can also be quickly determined if we add some minor computing units. In chapter 6 you will learn more about how radar works, but for now let's find out how it measures range.

Every naval ship is equipped with a powerful sound producer—its whistle. Suppose that the whistle on your own ship sounds a short, sharp blast while it is a mile or two distant from another ship. If you listen carefully after the blast sounds, you will hear an echo reflected from the other ship. If you know the speed of sound, and can measure accurately with a stopwatch the time elapsed between the whistle blast and the echo, you can easily determine the range to the other ship. This is a simple application of the distance, rate, and time equation which you learned years ago. You'll notice one slight variation however; the product of rate and time must be divided in half to account for the two-way travel of the sound wave.

If instead of a sound producer you use a powerful radio transmitter, and instead of your ears you use a radio receiver, you have the essentials of radar. (The name "radar" is an acronym for Radio Detection And Ranging.) Figure 2-3 shows one transmitted pulse and one reflected echo as they travel between our own ship and the target. Notice that the transmitted pulse covers a larger area in space as it gets farther away from own ship. The amount of this increase depends on many variables, one of which is the type of transmitting antenna used. Notice also that the reflected echo is smaller in amplitude since only a portion of the transmitted energy is reflected by the target. Further, the echo expands as it approaches own ship and only a portion is actually received by the receiver.

To be of any use the reflected echo must be greatly amplified in the radar receiver before it can be displayed on the cathode-ray tube. The cathode-ray tube (similar to a TV picture tube) provides a visible display which can indicate target range, bearing, or elevation. The display in figure 2-4 is designed to provide range information only, and it could be the results of the situation in figure 2-3. The vertical "pip" or "blip" at the left of the sweep trace in figure

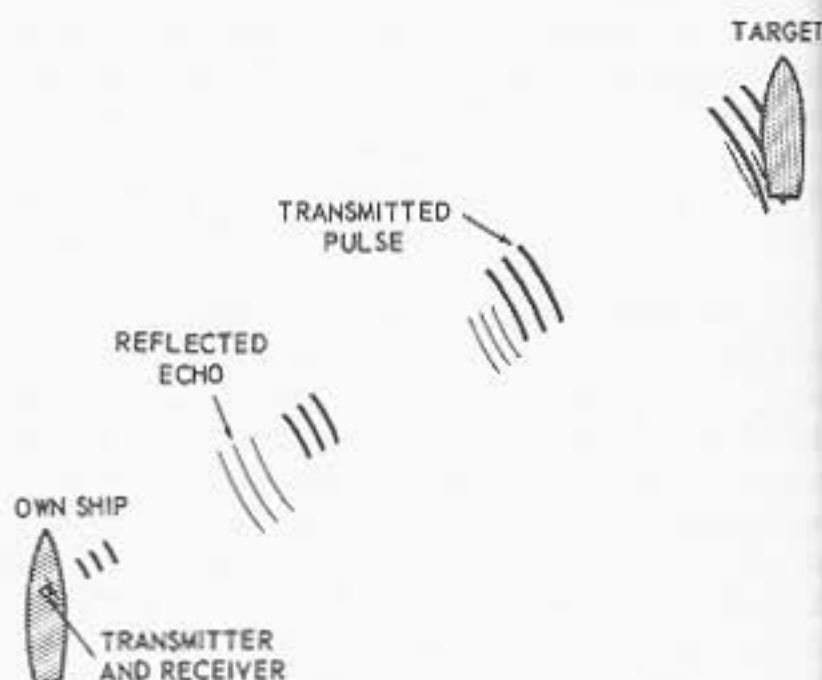
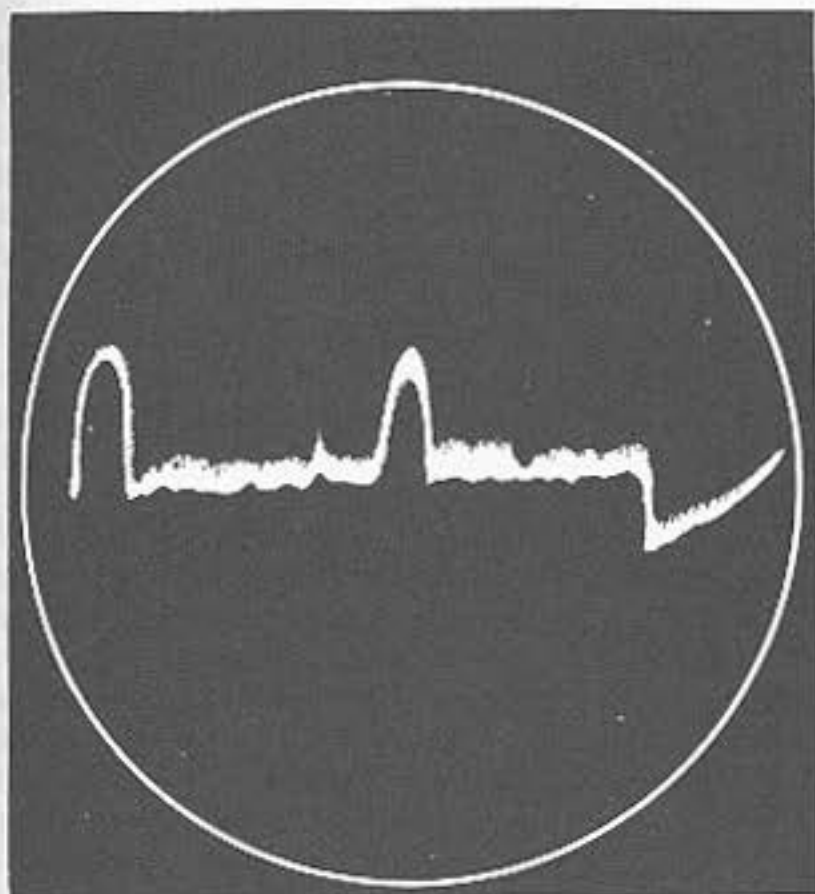


Figure 2-3.— Principle of radar.

2-4 represents the transmitted pulse; the center pip is the target echo. The sawtooth like shape at the right of the display is the range measuring device, which is called the "range stop" in this case. You will see in a moment how the range stop is moved to the echo to measure range, but, first, let's learn a little more about the sweep trace.

Even though the display appears to be continuously illuminated, it is in fact caused by a pencil-point beam of electrons which are made to "sweep" across the face of the scope from left to right. The sweep frequency is the same as the pulse repetition frequency of the radar. In layman language this simply means that every time a transmitted pulse leaves the antenna, a sweep is started. Actually, the sweep starts just a little earlier so the transmitted pulse can be viewed. The apparently continuous picture is the result of a property of the scope face called persistency, which means that a given point on the scope face continues to give off light for a short time after the beam of electrons has passed it. You have seen this effect before when you turned off a TV set and watched the illumination slowly fade.

The transmitted pulse, echo, and range stop are traced by bending the beam of electrons above and below the vertical center of the scope, which is the normal vertical position of the sweep trace. Vertical deflecting plates or vertical deflecting coils are used for this purpose. In our example, the transmitted pulse must have been



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Figure 2-4.—A common type of radar display.

applied to the vertical deflecting plates before the reflected echo, and the echo was applied before the range step. This is how the stopwatch is replaced. The designers simply arrange the scope so that a given portion of the sweep trace equals a certain number of yards (in some cases, miles). Then we can measure the trace distance, which is based on time, between the transmitted pulse and the echo. The sweep is made to move from left to right on the scope by horizontal deflecting plates or coils. The sweep movement is linear. It is based on time, and it is accurately matched to the range measuring circuitry.

In the preceding paragraph we mentioned "based on time"; let's explore this a bit further. The speed at which radar energy travels is 186,000 miles per second or 300,000,000 meters per second—the speed of light. Because of this great speed, the time elapsed between transmitting and then receiving an echo is measured in microseconds (millionths of a second, or μ secs). Obviously, a stopwatch will not do the job. As you have seen, a cathode-ray tube is used instead. With the speed of light as the reference, we find that radar energy travels 328 yards in 1 μ sec. From this we can say that 1 nautical mile (about 2,000 yards) will be

traversed by the energy in 6.1 μ secs. This is the time standard upon which most radars, and certainly most fire control radars, have been designed. Once again, it takes 6.1 μ secs for the energy to travel approximately 2,000 yards. These 6.1 μ secs represent 1,000 yards of RADAR RANGE.

Now let's measure the range to the target. A range counter is attached by mechanical linkage to a range handcrank, or to a range drive motor which drives the mechanical linkage. Moving the mechanical linkage by either method moves the counter and positions the range step to the corresponding position on the sweep. All the operator has to do to measure range is position the range step under the target echo and read the range from the counter. Moving the range linkage changes the time relationship between the transmitted pulse and the range step, and therefore controls the horizontal position of the range step on the sweep. If the range step were under the transmitted pulse, the range counter would read approximately zero yards. It would increase as the range step moves from left to right across the sweep in response to the operator's input.

Radar transmission is made from a metal structure called an antenna. Unlike the sound from a ship's whistle, which radiates almost equally in all directions, most of the energy in a radar pulse is directed along the bearing on which the antenna is pointed at the instant of transmission. The same antenna also picks up the echo. To get 360° coverage, radar antennas rotate continuously; antennas on radars designed to concentrate on a narrow angular sector are instead aimed by an operator. In addition, many of the latter type also oscillate or nutate through a small angle.

Radar signals are conducted to and from the antenna by special tubular waveguides that look something like ordinary air or water piping. Some use coaxial cables.

Radar shares many of the characteristics of optical detecting devices. Except for certain atmospheric conditions which to a minor extent distort the paths of the transmitted and reflected pulses, they travel in straight lines. As compared with a sound-ranging system like the one mentioned briefly by way of example at the beginning of this article, radar has much more range, functions several thousand times more quickly and much more accurately, and is not affected by audible noise. It is quite accurate (to within a degree) in measuring target bearing and elevation (though not quite as accurate as

optical devices). It is the most accurate and the longest in range of our range-measurement devices. It is not severely affected by adverse weather and fog, is just as usable at night as in the daytime, and is virtually immune to static and electromagnetic disturbances that plague communications radio and TV. Also, its signals can be used to guide missiles or to guide target-tracking equipment.

But radar has disadvantages too. It can be jammed or interfered with by enemy radar transmissions and other countermeasures. It does not permit easy identification by target silhouette or other visible characteristics; it shows only a blip for a target, and may show but one blip for several targets. As compared with optical methods, it requires skills in interpretation of its displays amounting almost to an art. Its complex electronic circuitry, waveguide plumbing, and mechanical rotating and nutating gear require constant attention to maintenance. As is true of any revolutionary technical advance that is depended on heavily, its loss through malfunction or battle damage is an especially severe handicap. Lastly, radar pulses can be detected by the enemy at much greater ranges than those at which the pulses will reveal to the originating ship the enemy's presence. As the discussion later of ECM will indicate, radar pulses are a telltale that may reveal a great deal of other information to the enemy also.

In spite of these disadvantages, radar is the primary means of detection used in the fleet today.

ECM

ECM (Electronic Countermeasures) have been defined as the means by which your own forces attempt to nullify advantages of enemy electronic devices, and to obtain all possible information concerning enemy electromagnetic radiations. ECM may be either passive or active.

Passive ECM are measures not detectable by the enemy. The most important is intercept search, by sensitive receiving equipment, of all electromagnetic wavelengths that the enemy might use, detection of electromagnetic radiations, and determination of their source and characteristics. Intercept search will detect radiation from any kind of electronic equipment—radars, radios, electronically controlled weapons, and electronic navigational aids. It will show the direction from which the radiation is coming, and display and record the radiation so that it can be analyzed. From such analysis can be

determined information such as the type of equipment radiating, what its function may be, and the number of transmitters involved. You can think of ECM as a kind of passive radar.

Other passive ECM methods are tactical evasion (to avoid detection by the enemy) and control of electromagnetic radiation by own ship (i.e., silence imposed on own-ship electronic transmitters) to avoid telltale radiation detectable by enemy ECM.

Active ECM includes those methods which the enemy can detect. In fact, its purpose is to impair the operation of the enemy's electronic devices (such as radar) by feeding them false signals. One method is jamming—radiating interfering or deceptive signals by electronic transmitters. The other is deception—using mechanical reflecting material to mislead his radars.

ECM does not have as important a role in weapon systems as optical devices, radar, and sonar do. Weapon systems can incorporate active ECM; there are gun and rocket projectiles designed to scatter radar-reflective material. Passive ECM may be used for direct guidance of weapon systems. The commonest present naval application of passive ECM is the use of intercept search in preliminary guidance of weapon system detecting equipment. Other passive ECM methods are used to prevent enemy interference with weapon system functioning.

SONAR

Radar cannot be used under water, because water absorbs radio waves. But water does conduct sound—better than air does, in fact. And sound is what the Navy uses to detect underwater targets.

It is possible to detect a submarine operating under power by merely listening—with the aid of a suitable microphone. But present-day submarine detection equipment more often functions somewhat like radar—it emits a pulse of sound energy, then picks up echoes. The equipment is called SONAR—SOUND Navigation and Ranging—and it not only detects underwater targets, but also locates them in terms of range, bearing, and depth.

The main units of the sonar equipment (fig. 13-6) are a transducer housed in a waterfilled dome (a streamlined housing protruding from the ship's hull) and console (STACK), manned by a sonarman. The stack periodically produces a powerful pulse of alternating current, which is transmitted to the transducer. The transducer converts the current into a pulse of high-frequency

sound (around 20,000 Hertz—one Hertz = 1 cycle per second) and projects it into the water. The transducer then switches to receive echoes, which are amplified in the stack. However, sound vibrations of 20,000 Hertz (Hz) are too high in pitch to be audible to people of normal hearing. Consequently, the stack's electronic circuits convert the echo to an easily audible 800-Hertz note, which the sonarman hears over the stack's loudspeaker. A visual indicator presents an image of sonar echoes as blips on the face of a cathode-ray tube (much as with radar). Additional sonar equipment determines the depth of the target.

Sonar is most frequently active—that is, an ultrasonic sound pulse is transmitted and the echo detected as described above. However, the sonar transducer can also be used to pick up sounds in the water, such as the sound of a submarine's propellers beating the water, the sounds of machinery in the submarine's hull, or sounds from subsurface animal life, such as whales grunting or squealing.

Sonar is the principal method now known for detecting underwater targets that are not themselves radiating sound signals. The principal factor limiting the success of antisubmarine warfare at this time is the limitations of sonar equipment. Although sonar is in some ways analogous to radar in the principle of its operation, it is more limited in range, less accurate in establishing target bearing and range, more severely affected by environmental factors such as variations in water temperature and flow at various depths, and is much more responsive to spurious echoes (as from schools of fish, wakes, air bubbles released by the target, and from the ocean floor or surface). Sonar echo interpretation (using both audible and visual responses) is exacting and requires much skill and experience.

Sonobuoys are used in one application of passive sonar. They are floating unmanned radio transmitters which lower microphones into the water and broadcast the sounds that they pick up. Sonobuoys are generally dropped by fixed-wing aircraft. Analysis of the sound pattern broadcast from several of them will indicate the location of sound-radiating submarines in the vicinity.

Sonar gear is carried aboard surface vessels and submarines. A special adaptation called DIPPING SONAR, in which the transducer can be lowered by cable from a helicopter, is used to supplement surface ASW forces.

MAGNETIC ANOMALY DETECTION

Any ferrous object will distort the earth's magnetic field. This distortion can be detected by a sensitive device—Magnetic Airborne Detection (MAD) equipment—that can either be towed by a ship or carried in an aircraft. At present, MAD gear is even more limited in range than sonar. Its principle of operation is applied also in guidance of some weapons.

DELIVERY DEVICES

Broadly, delivery devices launch, carry, or project a destructive device to the target. Examples are guns, torpedo tubes, rocket launchers, projectors, and depth charge racks. The term weapon is with one major exception properly applied to the destructive unit that is launched, carried, or projected. Thus, a rocket launcher is not, strictly speaking, the weapon in a weapon system, but the rocket itself is; the torpedo tube is not a weapon, but the torpedo is. The major exception is the gun. The gun is normally called the weapon in any system based on guns; a gun projectile generally is not called a weapon. Also, it should be noted here that gun systems are called batteries (e.g., 5" battery and 3" battery) and missile systems are called weapon systems (e.g., Tartar weapon system and Talos weapon system).

The term "delivery device" for such a weapon as an aircraft bomb or a ship-laid mine refers to the bomb rack and dropping gear or to the minelaying gear, not to the bomber aircraft or minelaying ship—which are vehicles.

FUNCTIONS OF DELIVERY DEVICES

To function effectively on their targets, all weapons (and projectiles) must either be directed to their targets or to the target area, or programmed so that they will operate properly in the target approach—or they may require both directing and programming. This is done by or through the delivery device either at or before the time of launching. Directing the destructive unit to the target may be done simply by aiming the delivery device (gun barrel or rocket launcher guide, for example). Or it may be done without aiming (as in torpedo tubes and missile launchers) by conveying program instructions into the weapon either mechanically or electrically. Programming

of functions to be performed by the weapon after launching (including the setting of devices which will initiate its explosion upon approach to or upon contact with a target) is done electrically in some weapons, mechanically in others.

Another function of many delivery devices is to propel the weapon or projectile over all or part of its course. Most mines and all aircraft bombs, for example, are conveyed to their targets by their vehicles, and the delivery device functions only to drop them.

TYPES OF DELIVERY DEVICES

Delivery devices now in use include:

1. Guns, which provide all the propulsion energy to their projectiles, direct them (by the position of their barrels), and program their functioning by adjusting some fuzes or causing them to arm (i.e., become set for action).

2. Rocket launchers, which direct rockets by positioning them. Similar launchers are also used with other weapons that are not classified as rockets.

3. Missile launchers, which position missiles for the initial stages of flight, and feed into them electrically steering and programming information up to the instant of firing.

4. Depth charge and thrown weapon projectors, which propel depth charges or thrown weapons to a selected point on the surface of the water. The weapons sink and function under water. The projectors may function on the principle of either the gun or the rocket.

5. Minelaying gear, which sets mines to perform arming and other functions after launching.

6. Bomb release gear, which initiates the arming process in bombs at the time of release.

7. Torpedo tubes and other launching devices, which set torpedoes to run in a specific direction, and may program them to arm at a specific range, undertake a selected search pattern, or perform other functions.

Some delivery devices which you may encounter on surface vessels will be discussed further in later chapters.

CONTROL UNITS

As previously defined, control units in a weapon system develop, compute, relay, and introduce data into a delivery unit, weapon, or

both, in order to direct, control, or guide the weapon to the target and cause it to function in the desired manner.

The devices that perform these or allied functions, in whole or in part, include:

1. DATA TRANSMISSION SYSTEMS (generally electrical) to convey the target data developed by detecting units into the remainder of the system, to convey these and other data among the components of the system, and to convey aiming and programming data to the delivery device and to the weapon.

2. COMPUTER DEVICES (either mechanical or electrical, sometimes both) to process the input data from the detecting units and other sources and put out aiming and other programming data required to cause the weapon to reach its target and function at the proper time.

3. INDICATORS (sometimes called repeaters) to display data inputs and outputs as required at various locations on the ship.

4. DIRECTORS, which with the aid of detecting devices discussed earlier in this chapter establish target location, which may incorporate computer devices to function as described in No. 2 above, and which always incorporate data transmission components.

5. REFERENCE DEVICES, such as stable elements, which establish reference planes to stabilize lines of sight, aiming positions, etc. These are always gyroscopically stabilized, though devices based on other principles may be used in emergencies.

6. ELECTRONIC CONTROL DEVICES intended to control guided missiles. These are generally radars or radio transmitters and receivers.

7. TRAINING AND ELEVATING GEAR. Most types of delivery units must be positioned to specific angles with respect to reference planes and lines in order to initiate correctly the launching of the weapon or projectile. This may be done through gear trains driven by hand, and this kind of manual operation is generally provided for emergency use or for adjustment of the equipment. In normal service, however, this function is performed by electric or electric-hydraulic power drives, controlled through data transmission systems by computers or directors. Training gear positions the delivery unit by rotating it in a plane parallel to the ship's deck; elevating gear positions it by rotating it in a plane perpendicular to the deck.

Table 2-1. — Table of weapon characteristics

Weapon or projectile	Propulsion incorporated	Guidance-control system incorporated	Usual type of target	Delivery unit	Vehicle	Guidance-control system in vehicle
Gun projectile	None or rocket ¹	Fuze; no guidance control.	Air, surface, or land target.	Gun	Aircraft or surface craft.	Gun fire control system or gun mount sights. Bomb sight.
Aircraft bomb	None	Fuze; no guidance control.	Surface or submerged target.	Bomb release gear.	Aircraft	
Rocket ²	Rocket propellant	Fuze; no guidance control.	Air, surface or land target.	Rocket launcher	Aircraft or surface craft.	Special fire control system.
Guided missiles ³ and ballistic missiles	Rocket or jet	Full guidance, various types.	Air, surface, submarine, or land target.	Missile launcher	Aircraft, surface craft, or submarine.	Special fire control and guidance system.
Depth charge ⁴ and other ASW thrown weapons . . .	Either none, gun-type propelling charges, rocket propulsion.	Pistol (equivalent to fuze); no guidance control.	Submerged targets.	Release rack, gun-type projector, or rocket launcher.	Surface craft. .	ASW fire control system.
Torpedo	Screw propeller driven by electric motor or steam turbine; some types have rocket propulsion for initial stage.	Gyroscopic, programmed, and homing; fitted with exploder.	Surface craft and submerged targets.	Torpedo or rocket launcher, torpedo tubes, launching racks.	Aircraft, surface craft, or submarines.	Torpedo or ASW fire control system.
Mine ⁵	Usually none; one has electric motor propulsion so it can reach a location inaccessible to the minelayer.	Programmed operation; fitted with pistol.	Surface craft and submarines.	Minelaying gear.	Surface craft or aircraft.	None (except for propelled type).

¹Used for rocket assist projectiles.²See second volume of this series.³One type rocket-propelled; several types gun-launched.⁴All mines are passive weapons that lie in wait for targets.

WEAPONS AND PROJECTILES

The end purpose of detection equipment, delivery units, and control systems is to get the destruction unit (weapon or projectile) to hit the target. It is then the function of the destruction unit to destroy or inflict maximum damage on the target. Except for small-size gun projectiles (those used in small arms, and those used in calibers up to 40-mm), most weapons and projectiles used in combat operation are loaded with explosive and equipped with devices to set off the explosive at the proper time. With some weapons and projectiles, the proper time is the instant the target makes physical contact with the weapon. With others (especially those designed to penetrate targets protected by armor or concrete) the proper time is after penetration. Still others are intended to explode when they are in the vicinity of the target.

ELEMENTARY WEAPON COMPONENTS

All weapons and projectiles have the following functional components, which take different physical form in different varieties:

1. A CONTAINER OR BODY which houses the other internal components. The body may have such other functions as piercing armor, breaking up into high-velocity fragments when the weapon or projectile explodes, or (by its streamline shape or by aerodynamic fins) improving ballistic characteristics.

2. A DETONATING DEVICE (called a fuze, pistol, exploder, detonator, etc.) which initiates explosion at the proper time, and includes safety devices to prevent explosion prematurely.

3. A BURSTER consisting of a quantity of explosive material. The main "payload" of the weapon may, more rarely, be a chemical agent, with a small amount of explosive to release or scatter it. Weapons for training purposes may contain still other payloads.

Weapons of some types have their own propulsion systems. The outstanding examples are guided missiles, torpedoes, and rockets. Gun projectiles, aircraft bombs, and most mines do not incorporate propulsion systems. Except for rockets, weapons with propulsion systems incorporate guidance and control devices.

CHARACTERISTICS OF WEAPONS AND PROJECTILES NOW IN USE

Table 2-1 summarizes in general terms the characteristics of the principal types of weapons and projectiles now in use. In interpreting the table, bear in mind that it is intended only as an aid in understanding the usual characteristics of contemporary weapon types. Some weapons combine the characteristics of more than one type, and don't fit neatly into the pigeonholes. Also be wary of nomenclature; e.g., some weapons not called rockets are at least in part rocket propelled.

CHAPTER 3

BASIC SCIENCES FOR NAVAL ORDNANCE AND GUNNERY

INTRODUCTION

This chapter may not be needed by all students because of its basic nature. It deals with the scientific principles — and particularly the practical applications of those principles — that should be part of the background of every junior naval officer. Without an understanding of these principles, a naval officer would be at a loss to comprehend the operation of even the oldest and simplest shipboard weapons. As for the new "sophisticated" ordnance, even the casual skimmer of newspaper headlines knows that our recently developed weapons demand a broad and sound scientific background.

This chapter will not, in and of itself, enable the reader to explain every detail of a specific weapon or installation. It should, however, prepare him to read, without great difficulty, the ordnance publications that do give complete details. It should also help him to understand a variety of standard components — such, for example, as gear trains — that are used in many types of machinery, ordnance and non-ordnance alike. Finally, it should help him to understand the general operational cycle (though not the fine details) of so complex a system as a train or elevation power drive.

For convenience, the chapter has been divided into separate sections dealing with mechanics, hydraulics, electrical devices, electronic devices, optics, and sound. In any specific ordnance device, principles from more than one of these areas are frequently combined.

Whenever practical, the illustrative examples have been selected from naval ordnance. Some types of ordnance equipment, however, are not well suited to serve as preliminary examples, and simplified examples have been used instead.

A reader who has studied general physics will recognize many of the topics in this chapter. He may also notice that the chapter passes lightly over large classes of conventional textbook material, and omits some classes altogether. An

omission does not mean that a topic lacks importance. It simply means either (1) that the omitted topic is not closely related to ordnance problems or (2) that it will be covered later in this text, or possibly in another text.

Some readers may desire amplified explanations at the present time. Abundant supplementary reading in the background sciences may be found in the physics section of college libraries and in certain BuPers publications, such as: Fluid Power, NavPers 16193; Basic Machines, NavPers 10624; Basic Electricity, NavPers 10086; Basic Electronics, NavPers 10087; and Digital Computer Basics, NavPers 10088.

SOME FUNDAMENTAL DEFINITIONS

If one specialist is to understand another specialist correctly, the two men must agree exactly as to what they mean by certain important "technical" words. In the sciences, including physics, some of the specialized words are long and difficult. Frequently these long words have been derived from classical Greek or Latin — languages which, being "dead," are no longer subject to change. Or they may be derived from the names of renowned scientists of the past. This is especially true of units of measurement such as ohm, volt, and ampere.

Other scientific words look deceptively simple, for they have been taken from everyday speech. The scientist, however, does not use common words in a loose sense. He gives each a single precise meaning, thus restricting the word to one out of the many values it may have in social conversation. This meaning the student must learn and remember. Such words are generally used in this text in their precise scientific sense.

The paragraphs below give a few basic definitions that are used in the several branches of physics. Other definitions, more specialized in their applications, will be given in later sections of this chapter.

FORCE. A force is a pull or push on a material object that causes (or tends to cause) the object to move or (if moving) to change its direction or rate of motion. A force can be present even if no motion or changes in motion actually result from it. This can happen if the force is balanced by an equal force in the opposite direction. An example is a man standing on a floor. The floor exerts an upward force equal to the downward force exerted by the man.

PRESSURE is force per unit area. Obviously, the amount of pressure depends on two things—the amount of force and the area it's applied to. Imagine a 10-pound weight on your desk. It's applying a force of 10 pounds to the desk top. But what pressure is it applying? If the bottom of the weight has an area of 10 square inches, the weight applies a pressure of one pound per square inch. But if the bottom of the weight has an area of only one square inch, then it applies a pressure of 10 pounds per square inch.

WORK. As understood by the physicist, work is performed when (and only when) a force called an effort MOVES a material object against an opposing force called a resistance. Motion is the important idea in this definition. A seaman who simply stands and holds a 50-pound projectile may become tired, but he is not performing work in the physicist's sense of the word. But, if he lifts this projectile three feet in opposition to the 50-pound downward pull of gravity, he is working. The exact amount of work he does is 50×3 , or 150 foot/pounds. In short, work is force acting through distance.

POWER. The word power, as used by the physicist, adds the idea of time to the idea of work. If our seaman hoists his 50-pound projectile 10 feet in 2 seconds, his power is $\frac{50 \times 10}{2}$, or 250 foot-pounds per second. Power, then, is the rate, or speed, of work. When time is important, as it usually is in combat, power becomes a major consideration. Many shipboard operations are mechanized because a machine has more power—that is, can move a heavier load in a shorter time—than the human labor available.

ENERGY. The capacity for doing work is known as energy. There are many sources of energy. The **CHEMICAL** energy released by a burning propellant moves a projectile toward its target. This chapter will be concerned with mechanical, hydraulic, electrical, radiant, and acoustic forms of energy.

A substance or mechanism that is ready to perform work, but is not actually performing it,

has **POTENTIAL** energy. By virtue of their chemical composition, propellants and high explosives in magazine stowage have potential energy.

Energy in action is called **KINETIC** energy. A burning propellant has kinetic energy.

The total amount of energy in the world remains always the same (except that matter can be converted to energy in nuclear reactions). This statement is the law of the conservation of energy. Energy can be converted from one form to another, as when the kinetic energy of a waterfall drives a generator to produce electrical energy, which in turn drives a motor to produce mechanical energy. In any of these conversions, at least a small amount of energy becomes lost to the user, because radiation or internal friction causes it to be dissipated as heat. Designers of power equipment try to keep the incidental losses of energy as low as possible.

MASS. Mass is a fundamental property of all matter. In elementary terms, the mass of a body is the quantity of matter in it. When a force acts on a mass, it tends to move it or to change its motion (depending on the direction of the force). Gravity acting upon a mass at the earth's surface exerts a force tending to pull the mass toward the center of the earth. The amount of this pull we call weight. If we transferred the mass to the moon, whose gravity is only a fraction of the earth's, its weight would be different, but the mass would be the same.

INERTIA AND ACCELERATION. As we have said, it takes a force acting upon a mass to get the mass to move, or to change the mass' motion. In this sense, the mass resists the force. This property of mass is inertia. For a given force, the greater the mass, the greater the inertia and the smaller the change in motion. Any change in the motion of a mass is acceleration (speeding up) or deceleration (slowing down).

MOMENTUM. A mass in motion continues moving because of its inertia, and will resist forces that tend to stop it. This tendency to continue moving is momentum. Momentum is proportional to both mass and rate of movement and is equal to their product. Thus a projectile weighing 5 pounds and moving at 2,000 feet per second has the same momentum as a motor launch weighing 2,000 pounds and moving at 5 feet per second. These are examples of momentum in masses moving in a straight line. A rotating mass also has momentum. In addition to the effect of its mass-inertia, the rotational momentum of a spinning mass such as a heavy-rimmed wheel will cause it to resist any force

that tends to change the direction in which its axis of rotation is pointing. This is why a top remains upright as long as it maintains sufficient rotational speed. This effect constitutes the operating principle of the gyroscope, described in the next section of this chapter.

CENTRIFUGAL FORCE. This is a special case of inertia. Any spinning object develops a centrifugal force. The rim of a turning wheel, for example, pulls outward on its spokes. The strength of the centrifugal force varies as the square of the speed at which the wheel is turning. For double the speed of rotation, for example, the centrifugal force will increase four times; for triple the speed, the centrifugal force will be nine times as great.

NEWTON'S LAWS OF MOTION

Sir Isaac Newton is famous for his enunciation of the law of gravitation, but equally fundamental in physics are his three laws of motion. These are the basis for the sciences of mechanics and statics. A clear understanding of them and their implications is essential for the realistic comprehension of any mechanical device or system. The laws are:

1. First law. A body at rest tends to remain at rest and a body in motion tends to continue moving in a straight line unless (in either case) the body is acted on by some unbalanced force. (In applying this law to practical examples about you, always remember that friction, gravity, and air or water resistance must be taken into account).

2. Second law. A body acted on by an unbalanced force will accelerate in the direction of the force, and the acceleration will be directly proportional to the unbalanced force and inversely proportional to the mass of the body. (Note that this idea has already been presented implicitly in the preceding article's discussion of acceleration and momentum. In fact, the law can be restated more briefly in terms of momentum.)

3. Third law. To each action there is an equal and opposite reaction. ("Action" here is the force which body No. 1 exerts on body No. 2; reaction is then the force which body No. 2 exerts on body No. 1. A book lying on a table exerts a push downward on the table equal to its weight; the table's reaction pushes the book upward with equal force. The rotating screw of a ship pushes the water rearward; the water reacting against the screw exerts an equal forward

push. The combustion chamber and exhaust nozzles of a rocket exert backward thrust on the exhaust gases; the gases react with an equal forward push on the rocket.)

BASIC PRINCIPLES OF MECHANICS

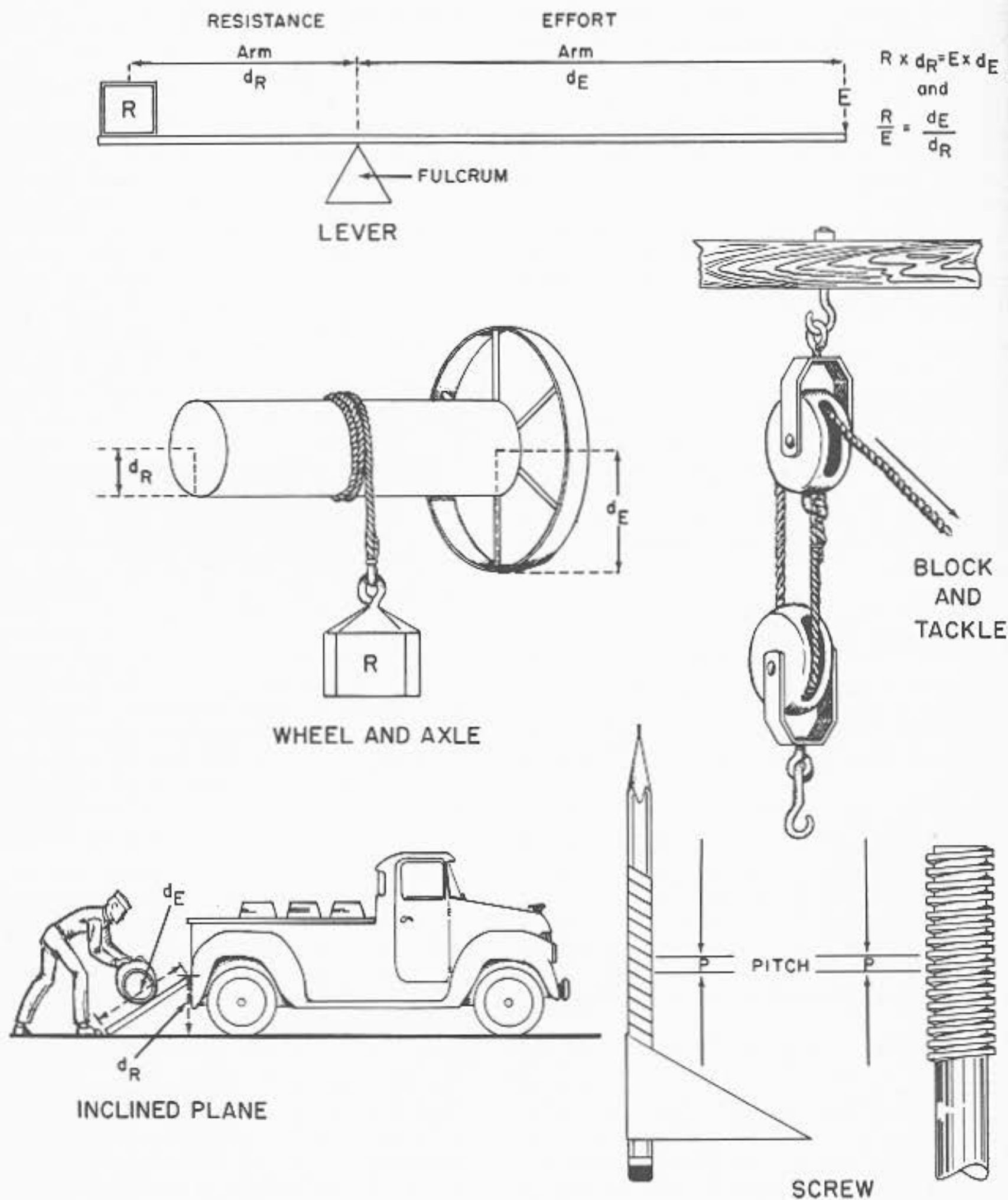
All machinery—no matter how complex it may be—can be broken down into simple components or basic mechanisms. These include the lever, the wheel and axle, the pulley (block and tackle or block and falls in Navy parlance), the inclined plane, the screw, the gear, the shaft, the cam, the spring, the clutch, the pawl and ratchet, the piston and cylinder, the friction brake, the roller or ball, the bearing, and so on. Some of these are actually applications or rearrangements of others. (Examples: the wheel and axle is a special type of lever; a screw is a special type of inclined plane.)

Figure 3-1 shows representative examples of five of these basic mechanisms. They illustrate one objective—to do work or transmit motion by moving a load (often called the resistance) through application of force or effort. (Or the force may be used in the mechanism to counterbalance another force.)

Historians and others have attempted to reduce all mechanical devices to six (or some other number) "basic machines," but since different lists include different mechanisms, and frequently omit mechanisms as important as those they include, we shall concentrate on those particularly applicable to ordnance devices, without attempting to develop universal generalizations or niceties of classification.

ANALYSIS OF CERTAIN BASIC MECHANISMS. The lever principle is probably the most basic one in mechanics. The drawing of the lever (fig. 3-1) shows that a resistance acting at one side of the pivot or fulcrum can be counterbalanced by an effort applied at the opposite side. (In this particular class of lever, the effort is a downward push.) The distance from the fulcrum to the point at which the push of the resistance seems to be concentrated (that is, to the center of gravity of the resistance) is called the resistance arm. The distance from the fulcrum to the effort is called the effort arm.

Balance is achieved when the product of the effort and the effort arm becomes equal to the product of the resistance and the resistance



110.4
Figure 3-1.—Five basic mechanisms.

arm. This principle is called the lever formula. It may be expressed mathematically as follows:

$$R \times d_R = E \times d_E$$

in which E = effort,
 R = resistance
 d_E = effort arm,
 d_R = resistance arm.

(Not all texts use the same symbols for the two arms, but all texts teach the same fundamental relationship.)

The ratio $\frac{R}{E}$ (which, as is easily shown, is equal to d_E/d_R) is the theoretical mechanical advantage of a machine. In actual practice the mechanical advantage is always lower than the theoretical figure, since part of the effort must be consumed in opposing the machine's internal resistance, or friction.

The wheel and axle can be analyzed as an application of the lever idea. By the term "wheel and axle" the physicist does not mean a wheel that turns about an axle, as in a wagon. He means, instead, a wheel (or part of a wheel) and a shaft that are firmly secured to each other and turn as a single unit. The ordinary doorknob is a wheel and axle in the physicist's sense. So is the crank, which is really a single spoke that acts like a wheel when it is turned. In a wheel and axle, the effort arm is the radius of the wheel (or wheel segment) that the operator turns. The product $E \times d_E$ is known as torque or twisting force, and is expressed in pound-feet, ounce-inches, or similar units. The tool called a torque wrench acts automatically to warn the operator when he has applied the set value of torque to a screw.

Not all basic mechanisms are applications of the lever. The inclined plane is the basis of the wedge, of the screw (i.e., the mechanical component, not the fastening device), of some types of cam, etc. To understand the relation between the screw and the inclined plane, note how figure 3-1 shows that in effect a screw is an inclined plane wrapped around a cylinder, as the hypotenuse of the paper triangle is wrapped around the pencil. The pitch of the screw (P in the illustration) is the distance between threads. A screw must make a complete turn to move a load along a resistance arm equal to P .

The gear principle is the act of meshing teeth to permit mechanical engagement of rotating and reciprocating mechanical components. This makes possible the linking of a number of individual components such as screws, wheels and

axles, etc. A wheel becomes a gear when its rim is cut to form regularly spaced teeth that mate with corresponding teeth on another wheel. Usually (but not necessarily) the shaft is firmly fixed to its gear. Gears and shafts will be discussed later in the chapter.

Though they can be—and often are—used alone, the basic mechanisms are frequently combined to form machines or mechanical systems. The next article will deal with these more complex systems.

MECHANICAL SYSTEMS

There are two major classes of mechanical systems—driving machines (often called prime movers) and driven machines. An electric motor is a driving machine; a sump pump powered by the motor is a driven machine. In many small, compact ordnance devices, such as bomb fuzes, compressed springs act as driving mechanisms.

Some machines act simultaneously as driving and driven components. The pump in a gun's electric-hydraulic drive is driven by an electric motor. The pump, in turn, acts to drive a hydraulic motor, and this motor drives the training or elevating devices.

There must always be some connecting link to transmit power between a driving machine and a driven machine. When the two machines are near each other, the link is frequently a mechanical one, such as a belt, a chain, or a system of shafts and gears. Under some conditions, enclosed fluids are used to transmit mechanical motion. This use of fluids will be taken up in the section on hydraulics. When the driving and the driven machines are widely separated, electrical transmission is normally used.

BASIC PURPOSES. All mechanisms serve one or more of the following purposes:

1. They may transmit motion, force, or power. As already mentioned, belts, chains, and gearing systems are used for this purpose.

2. Mechanisms with a high mechanical advantage are used to increase a small force to a large one, at a corresponding sacrifice of speed and distance. By using the block and tackle shown in figure 3-1, a man can hoist an 80-pound weight by giving a 40-pound pull. But, to hoist this weight 12 feet, he will have to haul in 24 feet of line.

3. Provided a low mechanical advantage (some fraction less than 1) is acceptable, a machine can increase the speed and extent of motion. If a crank 10 inches long acts through a common

shaft to turn a wheel 20 inches in radius, a point on the rim of the wheel will travel twice as many inches, in a second, as the crank does. Since the effort arm, this time, is only half the resistance arm, the applied effort will have to be double the resistance.

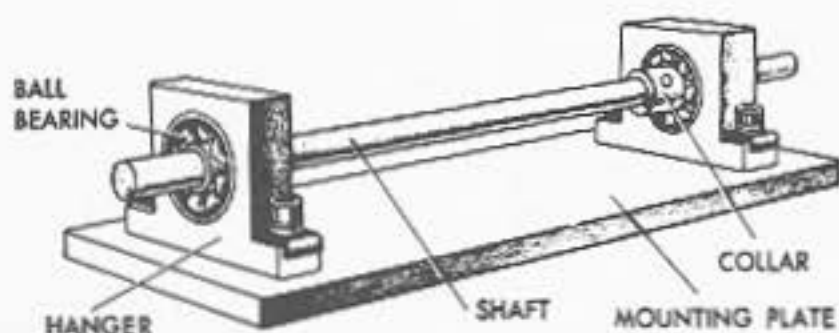
4. Finally, a machine may change direction or type of motion. In the lever shown in figure 3-1, a downward effort moves the resistance upward. As will be shown later, gearing systems are effective in changing the direction of motion, and even in converting circular motion to straight-line motion, or vice versa.

PRINCIPAL COMPONENTS. The paragraphs following deal with the principal components of complex mechanical systems. As will soon become evident, these components are either basic mechanisms or connecting devices.

A **SHAFT** is a cylindrical rod used to transmit turning motion. A shaft may be pinned to input or output gears, or it may have splined or toothed ends that mesh with gears. A shaft is mounted to turn without interfering with other components. Figure 3-2 shows a common type of shaft mounting used in mechanical computational devices.

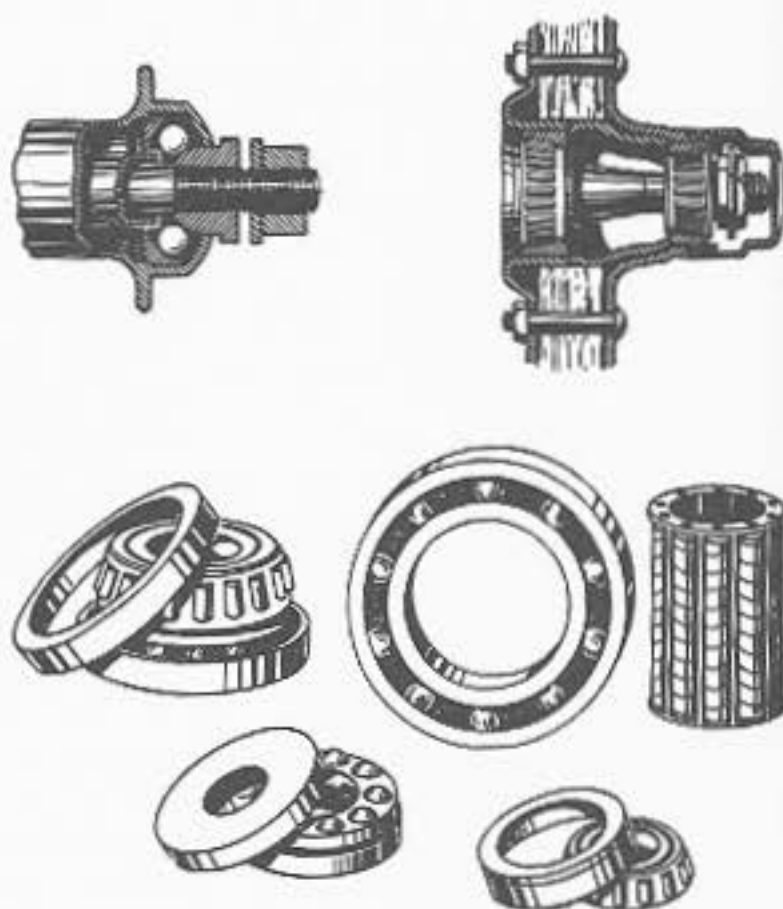
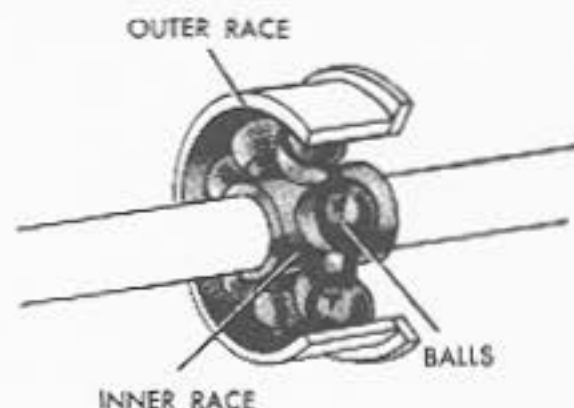
One shaft may be joined to another by a rigid sleeve, by a flexible coupling, by a universal joint (described later under pivots), by gears, pulleys, or clutches, etc.

BEARINGS permit rotation of a shaft with respect to a support that does not rotate with the shaft. A plain or journal bearing (not illustrated) uses a sleeve within which the shaft turns. To reduce friction, the sleeve is generally of softer metal than the shaft. Ball and roller bearings (figure 3-3) substitute rolling friction (which is comparatively small) for sliding friction between surfaces. Thrust bearings are designed to take



12.49

Figure 3-2.—A representative shaft and mounting.

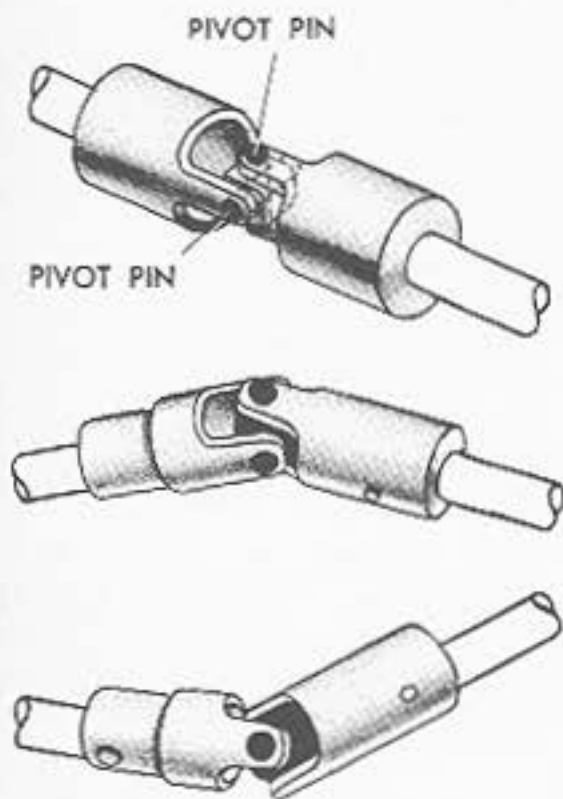


12.50

Figure 3-3.—Representative bearings.

up an axial thrust while permitting shaft rotation. There is a variety of thrust bearing designs. Jewel bearings are used in very fine machinery. The pointed end of a hard steel shaft rotates in a V-shaped depression in the fixed jewel (usually a sapphire or ruby).

A **PIVOT** is a fixed pin or short axis that permits one part to turn with respect to another. Pivots are closely related to bearings. The main distinction between them is that pivots are generally associated with limited arcs of rotation. An arrangement of pivots called a universal joint (fig. 3-4) is used to connect rotating components (for example, a pair of shafts) that must be permitted to swivel as they rotate.



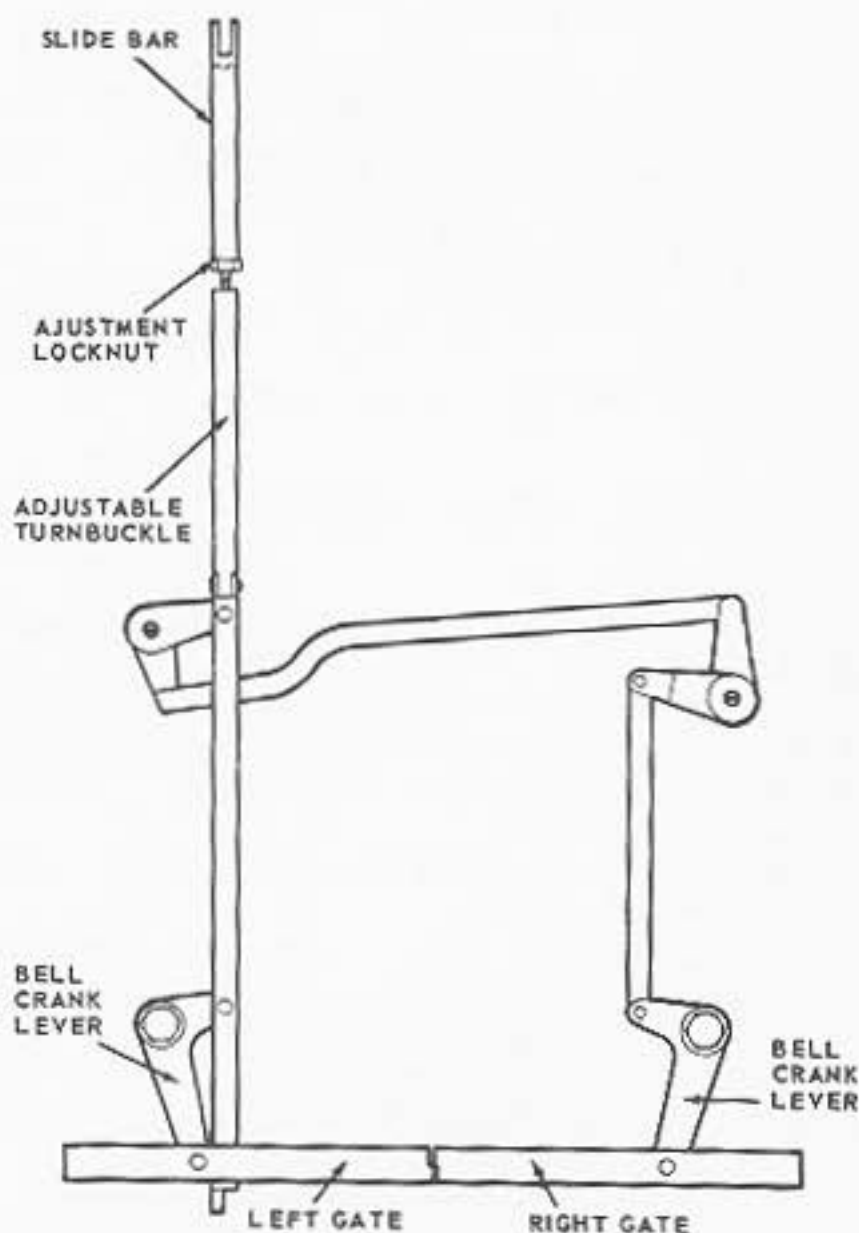
5.34

Figure 3-4.—Pivoting arrangement in a universal joint.

A CRANK is an arm (or pair of arms) keyed to a shaft in such a way as to impart or receive motion. The common exterior or side crank is manually rotated to introduce hand inputs into a mechanical system. As mentioned earlier, this is essentially one spoke of a wheel. Internal cranks take various forms. One of the commoner forms found in naval ordnance is the bell crank shown in figure 3-5. This type is used to carry push-pull motion around corners. Cranks may also be used to convert turning motion to back-and-forth (reciprocating) motion (for example, in certain types of motor-driven reciprocating pumps) or vice versa (for example, in internal combustion engines).

A LINKAGE is a system of bars, cranks, and other lever-like components, connected to fixed members and to one another in such a way that an input force causes a desired movement of the movable members. Figure 3-5 shows a linkage used in the loader for the 3-inch rapid-fire gun. When the vertical shaft moves upward, the horizontal gates are pulled together to close; when it moves down, they open.

Of all the mechanical components used in ordnance machinery systems, few are more numerous or more varied than the gears. They are used to transmit motion, to change the direction or type of motion, and to increase or decrease



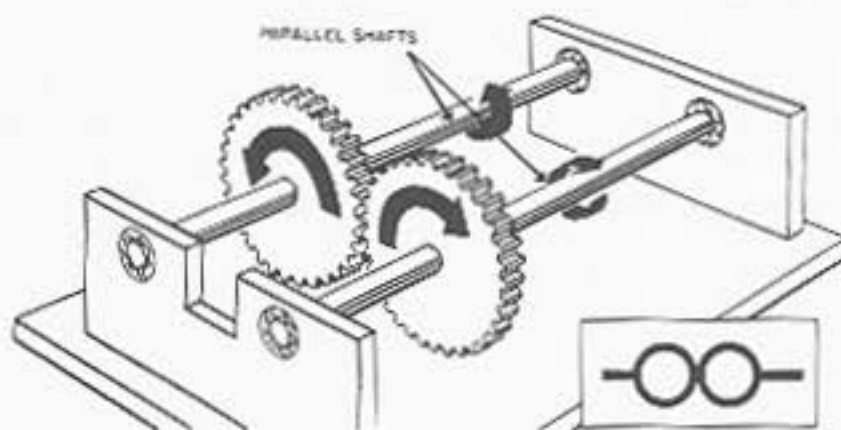
110.5

Figure 3-5.—A typical ordnance linkage (gate-operating linkage, 3-inch rapid-fire gun loader).

speed. Also, as a later article will explain, they are used to perform the four arithmetical processes (addition, subtraction, multiplication, and division). The serious student will regard the discussion of gears in this chapter as a mere introduction to a large and fascinating topic.

As has been said before, many (but not all) gears are wheels with teeth that mesh and permit one wheel (the driving gear or driver) to turn the other wheel (the driven gear) without slipping.

Figure 3-6 shows a simple gearing arrangement. Here the driver and the driven gear have the same diameter and the same number of teeth. Necessarily, therefore, they turn at the same speed, though in opposite directions (one clockwise and one counterclockwise). The shafts,



5.22.1

Figure 3-6.—Spur gears with a 1:1 ratio.

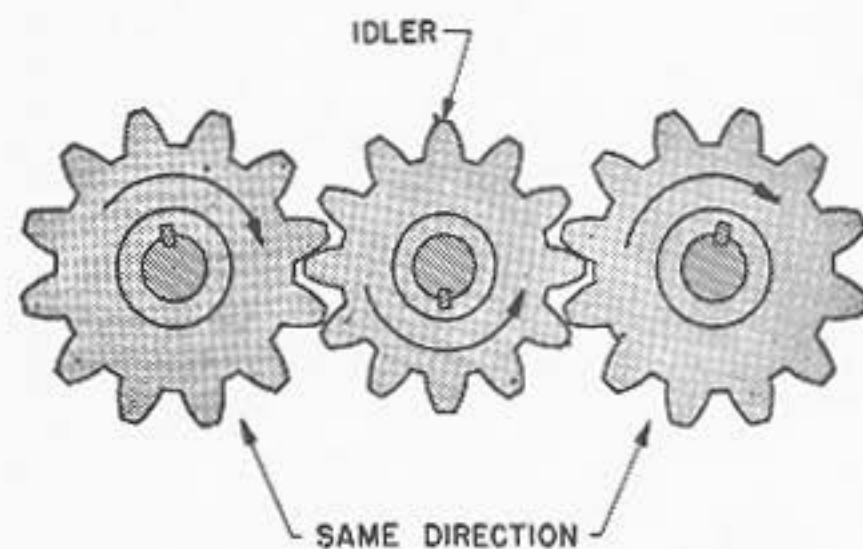
likewise, turn at the same speed and in opposite directions.

The ratio of the number of teeth on the driver to the number of teeth on the driven gear is called the gear ratio. In figure 3-6, the gear ratio is 1:1.

Gears that have radial teeth, as in figure 3-6, are called spur gears.

A designer may wish two parallel shafts to turn in the same direction. They will do this if he places an idler between the driver and the driven gear, as shown in figure 3-7. This idler serves only to change the direction of motion; it has no other use in the system.

To produce a difference in speed between two gears (and the related shafts) the designer makes the driven gear larger or smaller than the driver, as required. If the driven gear has four times the circumference (and four times the number of teeth) of the driver, it will take four times as



12.55

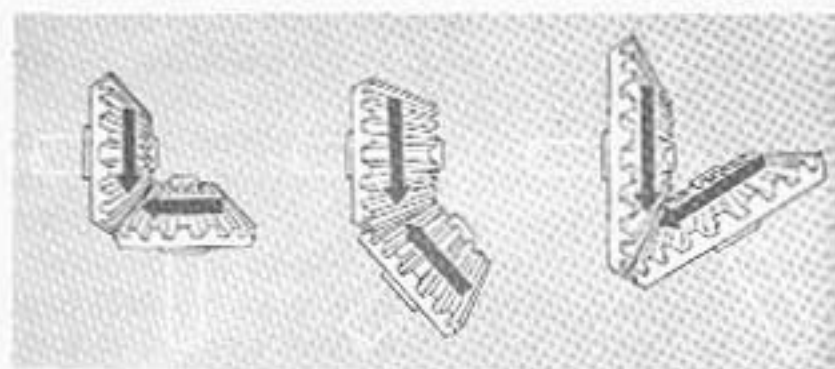
Figure 3-7.—The principle of the idler gear.

many seconds to make a complete revolution; that is, its speed will be a quarter of the speed of the driver.

To turn a driven gear and shaft faster than a driver, as is frequently desired, the designer makes the driven gear smaller than the driver. The smaller gear of a meshing pair is frequently called a pinion.

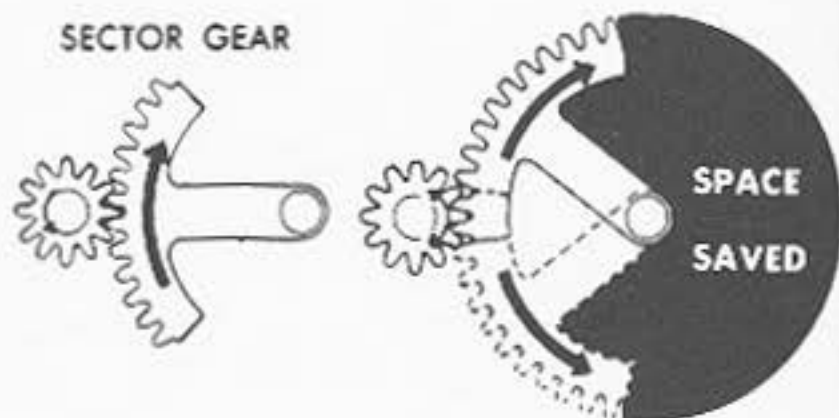
The shafts in a gearing system need not be parallel. As figure 3-8 shows, they may be placed at right angles or at some other desired angle. Bevel gears (fig. 3-8) can be designed to transmit motion at almost any angle. Bevel gears that are at right angles are called miter gears.

Some gears do not need to turn through a complete circle. The mechanism may have limit stops that restrict the travel of a pinion to a certain number of revolutions clockwise and an equal number counterclockwise. To save space and weight, the gear driven by this pinion can be a segment, or sector gear, rather than a circle. Figure 3-9 shows a sector gear.



5.22.4

Figure 3-8.—Bevel gears.



5.24.6

Figure 3-9.—How a sector gear saves space.

Under some conditions a limited-travel gear need not be an arc. Sometimes it can (and indeed **MUST**) be a straight bar with gear teeth, or a rod with a specially designed screw thread. The bar-type gear is called a rack (fig. 3-10); the screw-type gear is called a worm, and its mating gear is called a worm wheel (fig. 3-11).

A single-thread worm turns its worm wheel one tooth for each turn of the worm, and a double-thread worm turns its wheel two teeth for each turn of the worm. Worms may have three, four, or more threads. The number of wheel teeth turned for each revolution of the worm always corresponds to the number of threads on the worm.

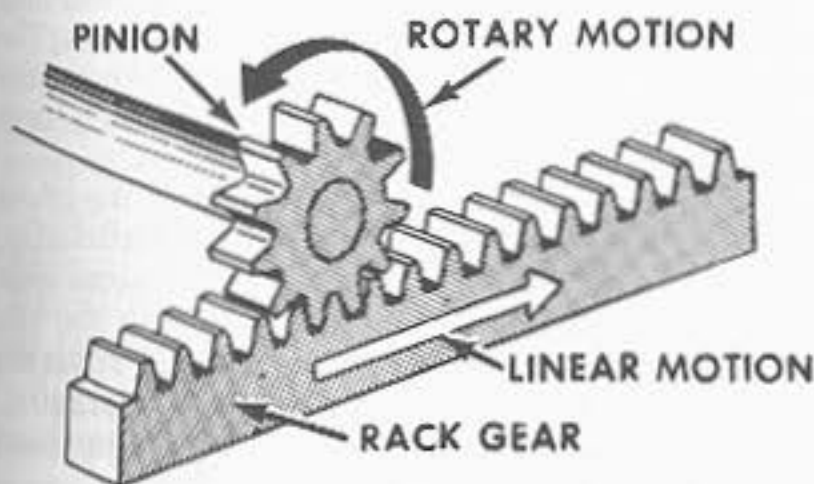
Worms are often used where great reductions in amount of rotation are needed, because the ratio of rotation between the worm and its wheel is usually large. Since each thread of the worm moves only one tooth of the wheel the gear ratio between worm and wheel is:

$$\frac{\text{The number of threads in the driving worm}}{\text{The number of teeth in the driven wheel}}$$

In a single-thread worm with a 100-tooth wheel, the worm must make 100 revolutions for one complete turn of the worm wheel. (The gear ratio is 1:100.)

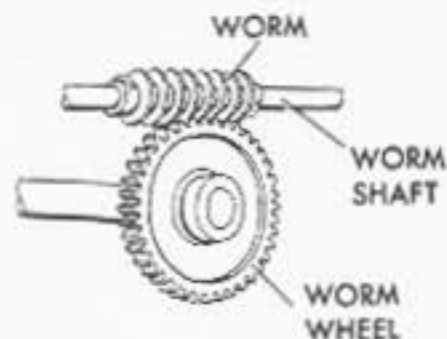
Sometimes the worm wheel drives the worm. This is possible only when the slope of the worm threads is greater than 5° .

The rack converts rotary motion to linear motion when it is driven by a pinion. A rack with two sets of teeth may serve simultaneously as a driver and a driven gear. When the rack drives,



5.22.13

Figure 3-10.—A rack makes conversions between rotary motion and linear motion.



5.22.9

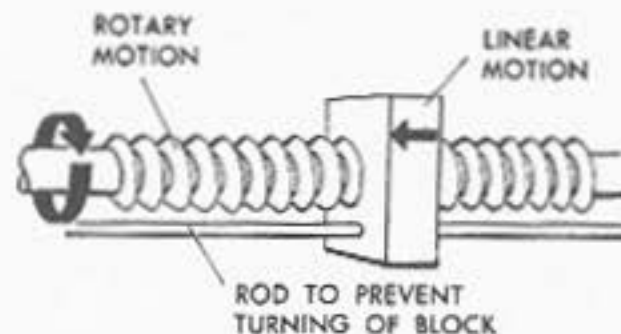
Figure 3-11.—A worm and worm wheel.

the mechanism converts linear motion into rotary motion.

Another device for converting rotary motion to linear motion is a screw with a traveling block (fig. 3-12). The block is restrained in such a way that it cannot turn with the screw. As the screw turns, the block walks along the threads. Screw-type elevating gear in older gun turrets uses this principle, which has other ordnance applications.

Figure 3-13 shows spur gears of several sizes, bevel gears, a screw with a traveling block, a rack (the T-shaped member) moved backward and forward by this block, and, finally, a gear that converts the straight-line motion of the rack to rotary motion. For the sake of simplicity, the draftsman has not shown the teeth on the various gears.

The input enters this system through the handcrank. The designing engineer has assigned an arbitrary input value of 400 knots to each complete revolution of the handcrank. Numerals indicate the gear ratios other than the 1:1 ratio of the first pair of bevel gears. The figure is introduced at this time to show a representative but fairly simple example of the gearing and shafting used in naval ordnance. Somewhat later,



110.6

Figure 3-12.—The principle of the travelling block.

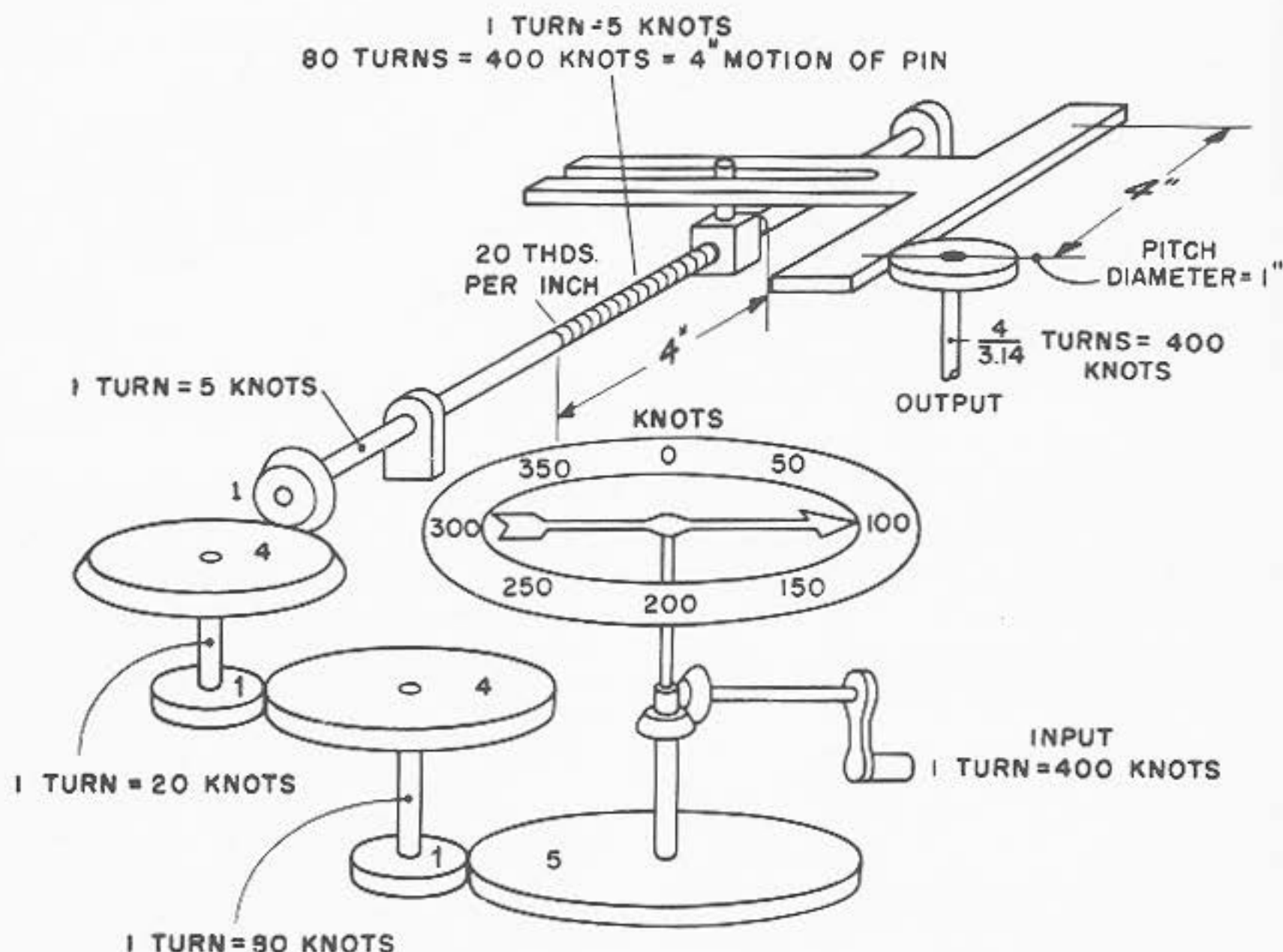


Figure 3-13.—A representative gearing system used in naval ordnance.

the mathematical aspects of the figure will receive some attention.

A DIFFERENTIAL is an arrangement of gears and shafts that accurately and continuously combines two variable inputs to produce a single output or, conversely, as in the rear end of an ordinary automobile, breaks a single input into two outputs that vary as required.

In figure 3-14 a typical differential has been partially cut away to show the four bevel gears and the spider shaft that are the heart of the mechanism. This is a common differential design, though there are others.

The simplified drawings in figure 3-15 will clarify the relationships within the differential.

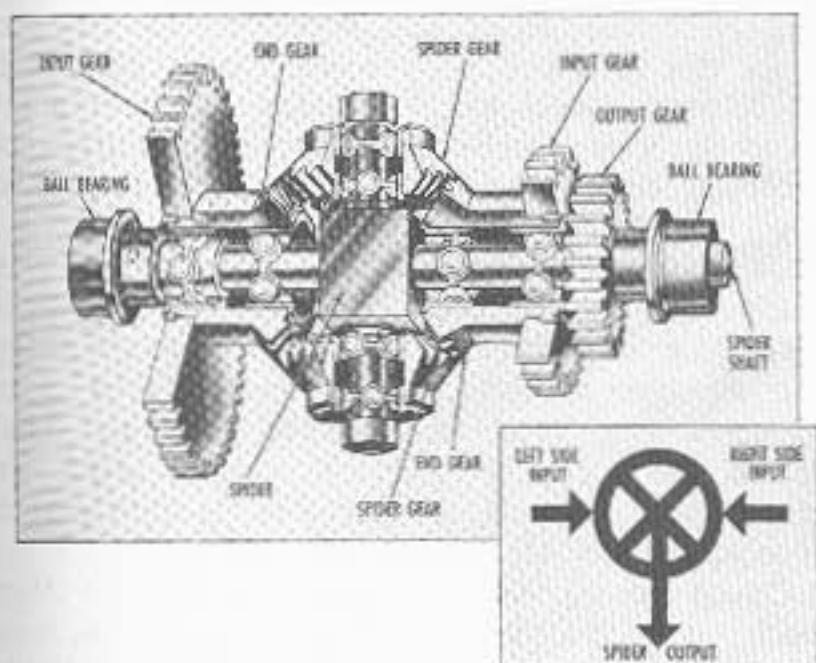
The two bevel gears on the sides of the differential are its end gears. Each end gear is firmly joined to a corresponding spur gear. This spur is the input gear through which inputs from

another part of the mechanism enter the differential. Each end gear and its input gear make up a side of the differential.

The two bevel gears above and below, meshing with the end gears, are the spider gears. The cross shaft and the spider gears make up the spider. The cross shaft is pinned to a long shaft called the spider shaft.

The spider gears are not pinned to the cross shaft in the usual gear-and-shaft relationship. Instead, these gears are free to rotate about their shaft on precision bearings. Likewise the two sides are free to rotate independently about the spider shaft. The output gear of the differential, however, is securely pinned to the spider shaft and rotates with it.

Figure 3-16 shows how the spider gears work. When a side receives an input, the input gear and its attached end gear turn. This action



12.87

Figure 3-14.—A typical differential.

drives the two spider gears, and in so doing turns the spider and the spider shaft, with its attached output gear.

If only one of the two sides receives an input, the opposite end gear will remain stationary while the two spider gears walk around it. The output will then vary with the single input.

If both sides receive inputs in the same direction, the movement of the spider will be proportional to the sum of the two inputs.

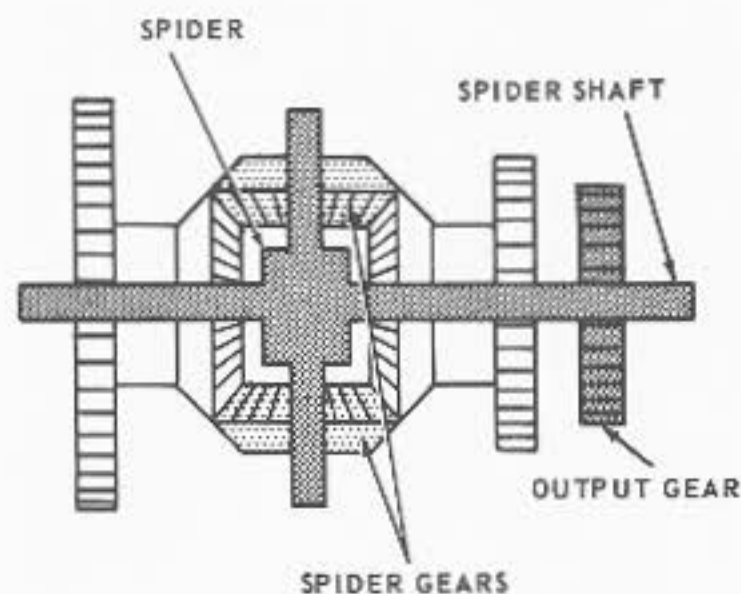
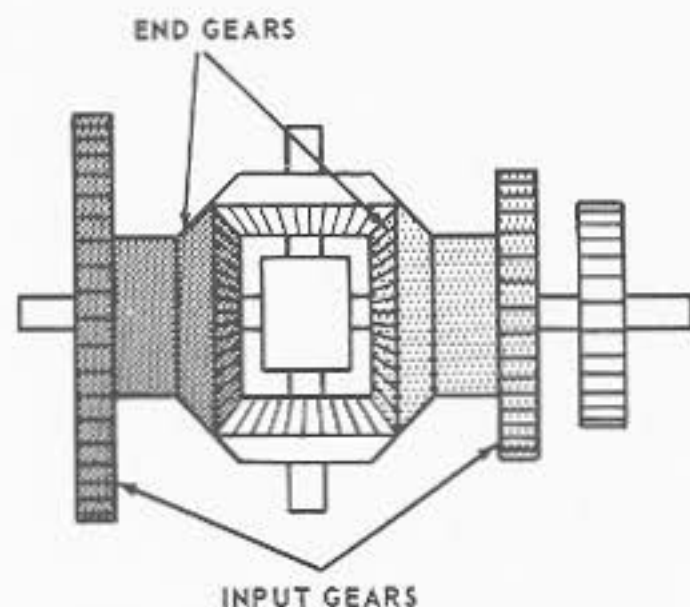
If the two sides receive inputs in opposite directions, the movement of the spider will be in the direction of the larger input, and will be proportional to the difference between the two inputs.

If the two inputs are equal and opposite, the spider gears will turn, but the spider shaft will not move.

Because the spider gears are free to roll between the two end gears, the revolutions of the spider always represent half the sum (or difference) of the two inputs.

This short description has shown that the differential can be used to perform additions and subtractions. In fire control devices it is used for that purpose.

Like a gear and shaft, a CAM is a mechanical device for receiving inputs and transmitting outputs. As will be shown later, cams are capable of showing mathematical relationships that cannot be expressed in terms of simple gearing and shafting.



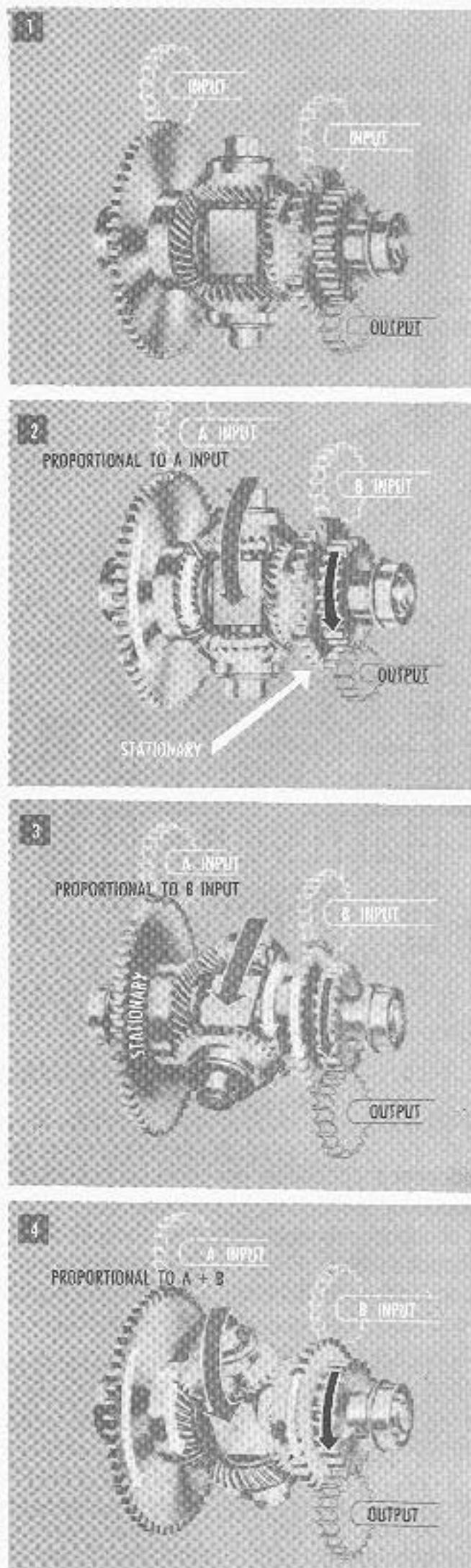
110.8

Figure 3-15.—Gear relationships within a differential.

Cams vary greatly in design. Every cam, however, has some sort of shaped surface—a groove, a ridge, or a contour—that is positioned by the input force. Every cam has also an output device, called a follower, that bears against the shaped surface and is positioned by it.

One type of cam has a uniform spiral groove. Each point on this spiral corresponds to an output that is directly proportional to an input from the driving pinion shown at the lower right in figure 3-17. The cam follower is the small cylinder shown as a phantom in the illustration.

The cam shown in figure 3-17 can rotate either clockwise or counterclockwise, depending on the direction of the input. Rotation in one direction forces the follower (and with it the



110.9

Figure 3-16.—How a differential works.

attached follower block and the output pin) outward from the center, along the straight-line slot. A reversal of the direction of rotation forces the follower back toward center. Though the follower itself never touches the zero position at the exact center of the cam, the output pin is offset enough to allow a zero reading to be taken.

This cam is a positive-action type. This means that its follower is keyed to the groove in such a way that it is forced to move every time the cam moves. Some cams, however, have followers that move only when they are held against the cam by gravity, spring action, or some other force that is free to operate only at some stages of the mechanical action.

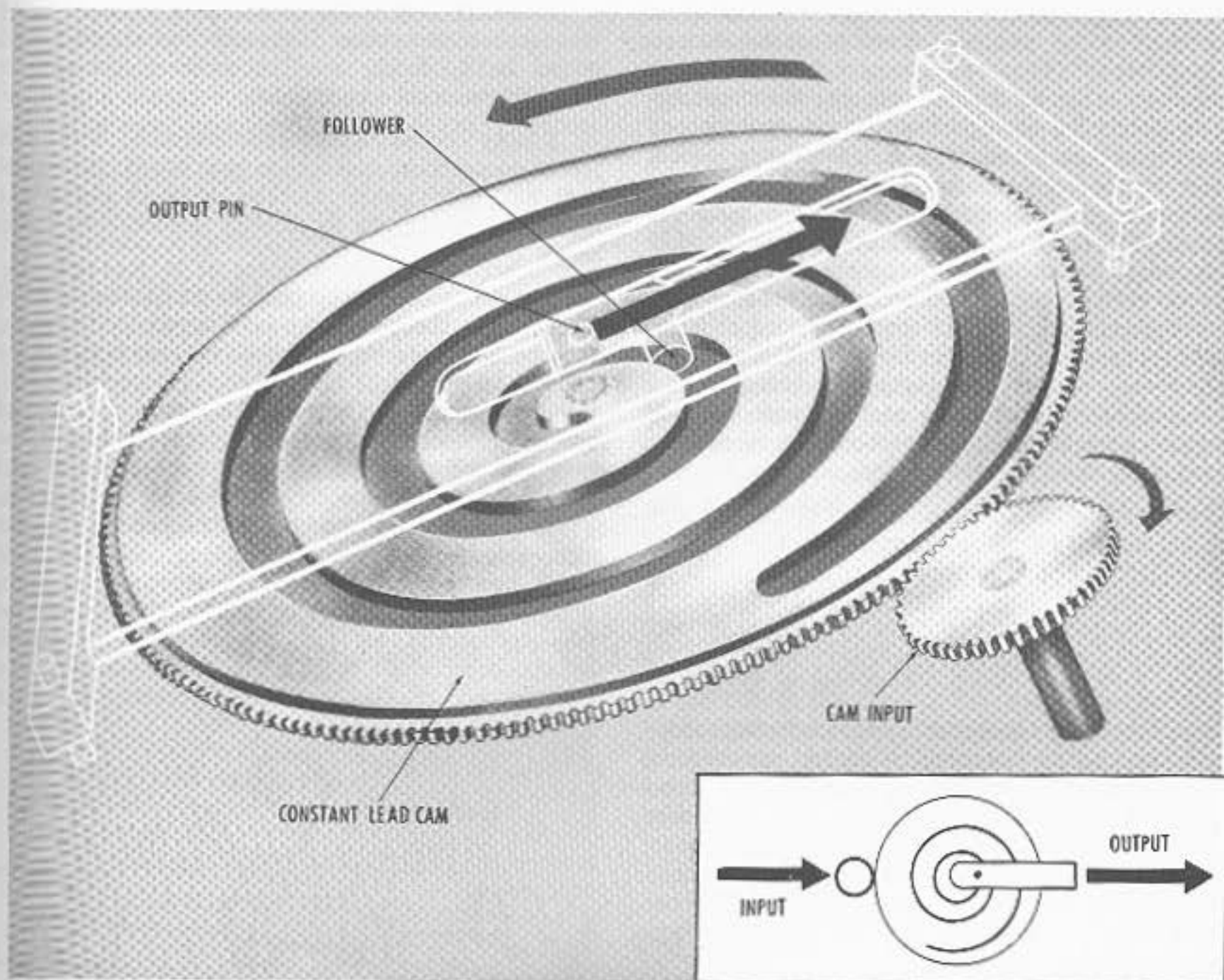
Cams can be used to control or position other mechanisms. Shipboard guns, for example, have firing cutout cams that act to interrupt firing when the gun is pointing in a direction that endangers permanent shipboard installations. But many cams are special-purpose mathematical devices. As such, they will be discussed in the next section.

MECHANICAL COMPUTING DEVICES

The problem of hitting a distant, rapidly moving target from a maneuvering ship is much too complicated to be solved by mental arithmetic, or even by hand-operated slide rules. When a conventional gun is fired, some two dozen factors may enter into the fire control problem. (For a discussion of the fire control problem see chapter 6.) If the weapon is a guided missile and the target is a manned aircraft or a guided missile moving at supersonic speed, the problem is still more complex and the futility of longhand methods is obvious.

MACHINES CAN SOLVE THE PROBLEM. As the reader has probably noticed, certain basic mechanisms can hardly be described, even in their simplest terms, without some reference to their potentialities as problem solvers.

In figure 3-13 the designer of the gearing and shafting decided arbitrarily that one revolution of the input crank should represent 400 knots. He could have selected any other figure, had he found it better suited to his purpose; a crank revolution, as such, has no mathematical significance until one has been assigned. When an input value has been selected, however, every



110.10

Figure 3-17.—A positive-action spiral cam.

transmitted value in the entire gearing system varies with the input, following the fundamental law of proportion:

$$a:b = c:d.$$

A GEAR TRAIN, then, is one means of representing mathematical relationships.

Unfortunately, many factors in the fire control problem do not vary in accordance with the laws of direct proportion. These factors, too, can be expressed in terms of mechanical motion. By using the basic mechanisms described thus far, plus certain specialized modifications of those mechanisms, the Navy's mechanical computers set up and solve problems that involve

algebra, trigonometry, and even calculus. Related mechanisms either position the gun or launcher automatically or give operating personnel the information they need.

TYPES OF COMPUTERS. A computer may be of the digital or the analog type. It may be mechanical, electrical, or a combination of both. We are here concerned only with mechanical computation. (For some further discussion of fire control computers using electrical or electronic elements, see chapter 6.)

A digital computer essentially performs the basic arithmetical processes—addition, subtraction, multiplication, and division—by counting. The ordinary office calculating machine is a mechanical digital computer.

An analog computer represents mathematical relationships by analogous mechanical motions and positions. These may vary from moment to moment by large or small amounts, but the solution is produced continuously. Its output at any given instant measures the values at that instant of the two or more changing quantities in the problem it has been designed to solve. A simple example will help to make this clearer. Suppose the hypotenuse of a right triangle remains constant in value but the two acute angles are continuously changing. One of the computing devices described later in this section will tell the operator (or the related computing mechanism) the exact values of the base and altitude of this triangle, whenever these values are needed in the solution of a larger problem.

For solving the fire control problem, the mechanical analog computer is much faster than any combination of mechanical digital units. It is not as versatile as a digital computer, but a fire control computer is required to deal only with fire control problems. The fact that it is not adapted to other problems is not a drawback.

The following tabulation lists some of the shipboard computing devices (usually mechanical or electromechanical analog types) that a junior officer is likely to encounter. In gun systems:

- Fire control computers
- Gun directors
- Gun elevation indicators
- Gun train indicators
- Parallax correctors
- Rangefinders
- Rangekeepers
- Receiver-regulators
- Sightsetter's indicators
- Stable elements
- Stable verticals
- Star-shell computers
- Wind transmitters

In torpedo and ASW systems:

- Course directors
- Depth computers
- Attack directors
- Range recorders

Later chapters will explain the functioning of many of these computing devices. The paragraphs following will take up a number of their representative mechanical components and tell briefly how they work.

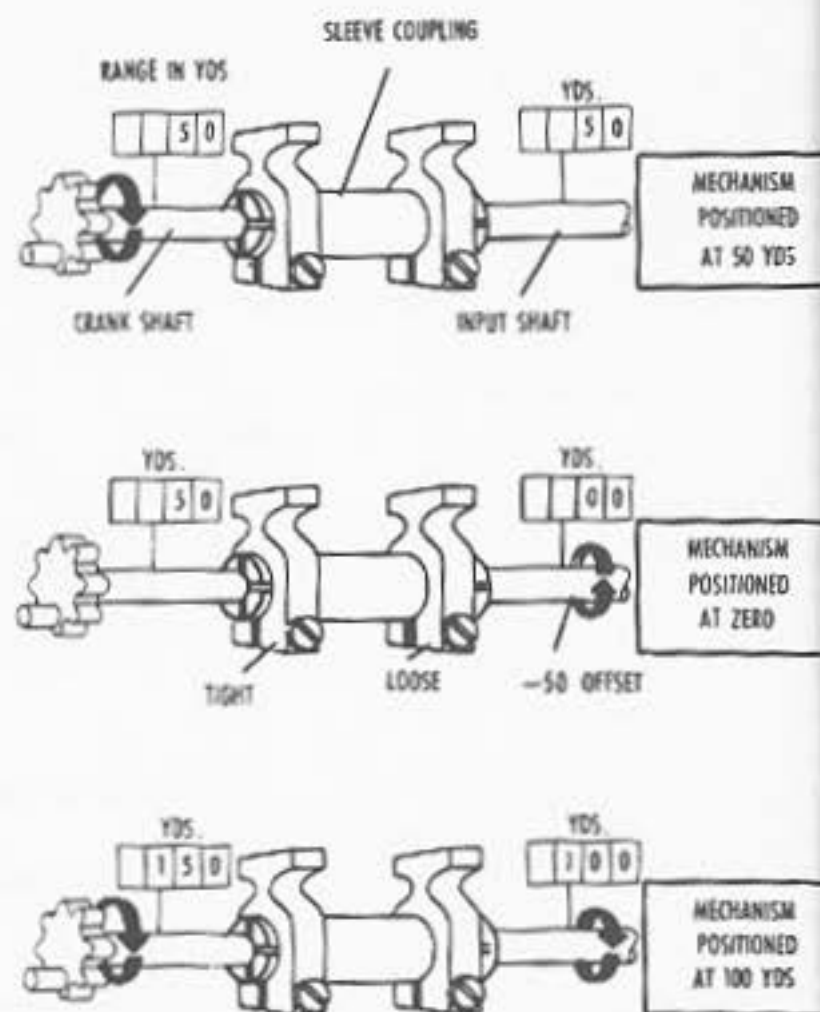
ADDING AND SUBTRACTING DEVICES. As was explained earlier, the output of a differential (figs. 3-14, 3-15, 3-16) measures the sum or the difference of two inputs.

Finely constructed mechanisms with light loads sometimes use a compact jewel differential that has spur gears instead of bevel gears. The operating principle is exactly the same as in the bevel type.

A shaft can be designed to add some selected constant to the value it would normally transmit. Figure 3-18 shows a two-shaft combination arranged to transmit an output of range-minus-50.

Each shaft in figure 3-18 has a mechanical counter showing its output. In the first view, the two shafts have been zeroed, coupled, and turned as a unit until the output of each is 50 yards.

In the center view, the crankshaft remains clamped to the sleeve coupling, but the input shaft has been unclamped and reset at zero. When the loose clamp is tightened again and the two shafts turn as one, the variable introduced by the crankshaft will be reduced by 50 when the input shaft transmits it. For example, in the



110.11
Figure 3-18.—A coupling used to introduce a constant.

lower view, a crankshaft reading of 150 yards is transmitted by the input shaft as 100 yards.

This use of a sleeve coupling is called "putting a constant offset on the line." The offset can be either negative, as here, or positive.

CAMS, MULTIPLIERS, AND DIVIDERS. The use of shafting and gearing in solving problems in ratio and proportion has already been explained, and it is an extremely important use.

By the use of cams, quantities that vary according to other laws can frequently be introduced into the gearing, either for transmission to a dial or for further use in solving the problem.

A great many mathematical relationships can be expressed, accurately and compactly, as graphs on squared paper. It is possible to construct cams that reproduce these graphs. The spiral cam in figure 3-17 is only one of a great variety

of possible types. Three commonly used cams are shown in figure 3-19.

In computing cams, such as the three shown in figure 3-19, the output is a function of the input; that is, it varies with the input, but not in direct proportion. The output of the reciprocal cam is one-divided-by the input. The input of the secant cam is the value of a given angle; the output is the secant of that angle. Cams can, of course, be cut to represent other trigonometric functions. The square cam multiplies the input by itself. The subject of cams is much broader and more complex than this necessarily limited paragraph would indicate.

Sometimes cams cannot be designed to show the output values for all possible inputs; but they can still be used to take care of inputs within certain ranges that are adequate for the needs of the system.

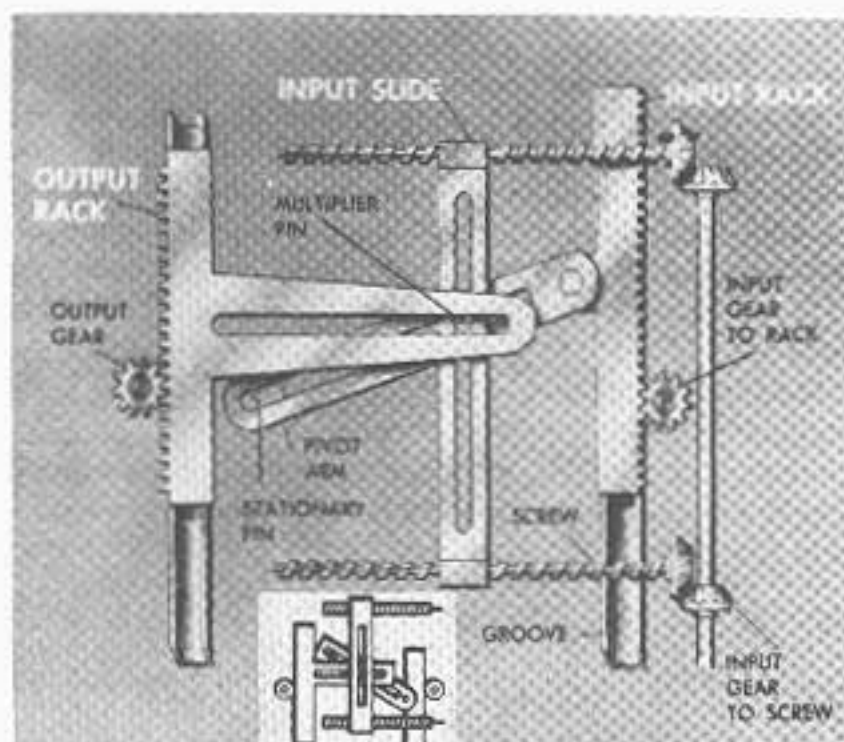
The **SCREW-TYPE MULTIPLIER** shown in figure 3-20 is a device that computes, continuously and accurately, the product of two continuously changing input values. Actually there are several types of multipliers, but all of them make use of the laws of proportion as exemplified by a pair of similar triangles.

The multiplier illustrated here receives one of its inputs through a slotted slide that is walked out from (or back toward) its zero position by two screws that are turned by bevel gears. The second input enters through a slotted arm that pivots on a stationary pin, and is joined at its opposite end to an input rack.



5.29

Figure 3-19.—Some representative computing cams.



12.91

Figure 3-20.—A screw-type multiplier.

In its zero position, the pivot arm is perpendicular to the input slide. The pivot arm is forced away from (or back toward) its zero position whenever the input rack is moved by the input spur gear.

A multiplier pin passes through the slots in the input slide and the pivot arm. This pin also passes through a third slotted member—the T-shaped output rack.

Whenever the input to the slide, the input rack, or both is zero, the multiplier pin will lie at some point along the zero line shown in figure 3-21. The slot in the output rack will also lie along the zero line. This is correct, since any quantity multiplied by zero equals zero.

Whenever the input slide and the input rack BOTH move from their respective zero positions, the multiplier pin will be above the zero line by a vertical distance that, as will be shown in the next paragraph, measures the product of the two inputs. The output rack will be displaced by this same amount, and will transmit the measured product as its output.

Figure 3-22 shows how this particular multiplier utilizes geometric truths. In this figure, the constant K is the distance, along the zero line, from the stationary pin to the vertical line of travel of the right end of the pivot arm. Solid line a is the distance the input rack has moved from zero. Dotted line b is the distance the input slide has moved to the right of zero. Dotted line x is the distance the multiplier pin and, with it, the input rack has moved up from zero.

Notice that these relationships define two similar right triangles, one superimposed on the other. Since the corresponding sides of similar triangles are in proportion,

$$\frac{x}{a} = \frac{b}{K}$$

and

$$x = \frac{ab}{K}$$

That is, x , which represents the output, is the product of the two inputs, divided by a constant. A proper choice of gearing ratios can remove the effect of the constant.

In actual practice, to save space, a multiplier is often designed to deliver a fixed fraction (say a tenth) of the whole product. Gearing converts this fraction to the full value.

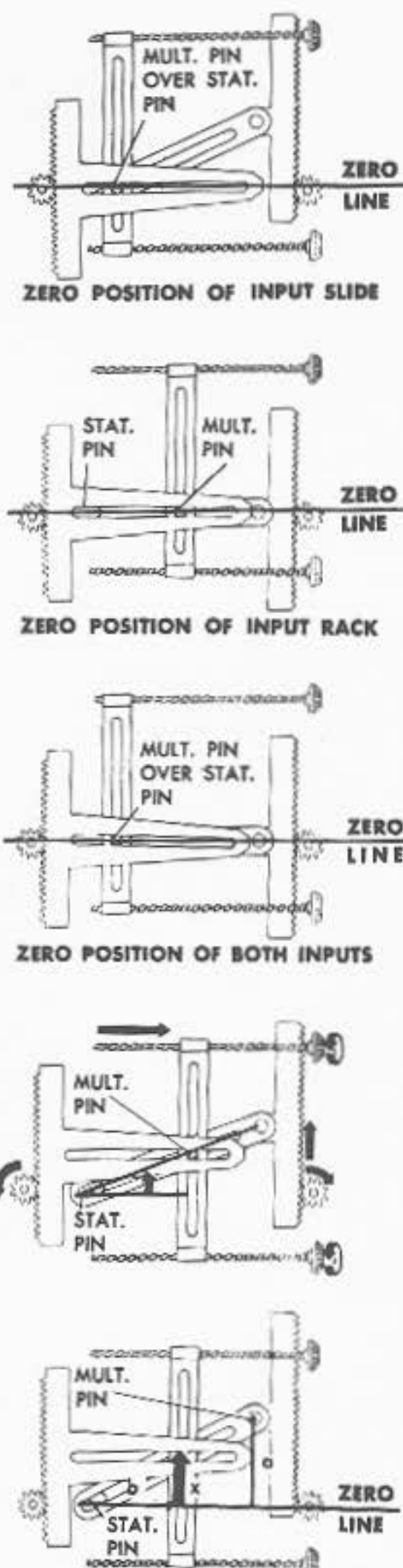
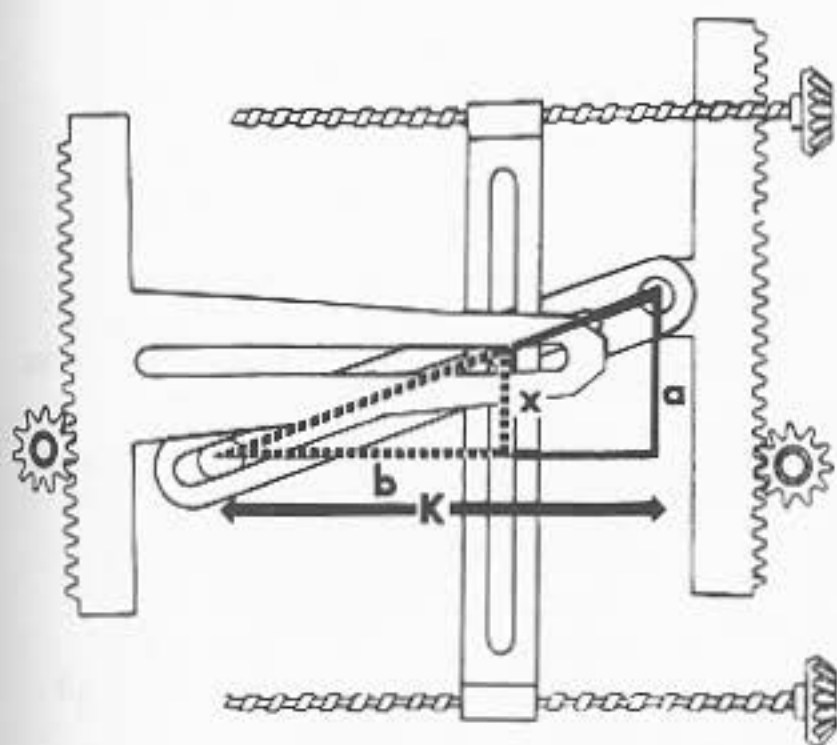


Figure 3-21.—How the multiplier works.



12.93

Figure 3-22.—Similar triangles in the multiplier.

INTEGRATORS. In some phases of the broad fire control problem—and in many other situations as well—a quantity that obeys the laws of proportion (and therefore can be transmitted by a gear) must be multiplied by a second quantity that varies at a constantly changing rate of change. We say that the second quantity accelerates, or decelerates, or changes by increments. The integrator, one type of which is shown in figure 3-23, is a device that performs this special kind of multiplication.

The horizontal disc is driven at a constant speed that measures the non-accelerating input. A gear-and-rack arrangement receives the accelerating or decelerating input and uses this input to drive a movable carriage backward or forward along a selected diameter of the disc. The carriage contains two balls, one directly above the other, that are free to turn.

Except when it is above the dead center (zero point) of the disc, the lower ball rotates whenever the disc turns. The speed of the ball depends on two factors—the constant speed of the disc itself and the variable point at which the carriage is positioned at the given instant. The nearer the ball is to the edge of the disc, the faster it will rotate.

The lower ball drives the upper ball. (The designer uses a pair because the two balls roll more smoothly than a single one. In other designs a single ball or a roller can be used.) The

rate of rotation of the balls measures the product of the non-accelerating input and the accelerating input. The upper ball drives a roller which, in turn, transmits its constantly varying output to the next stage of the gearing system.

At one side of the center of the disc, the balls transmit positive values; at the opposite side, negative values.

COMPONENT SOLVERS. A vector is a line drawn to show both the direction and the magnitude of a force. Such quantities as target speed and wind motion are shown on graphs as vectors. For practical purposes, a vector can be treated as the diagonal of a rectangle that has one corner at the zero point of a conventional graph, one side along the x-axis, and one side along the y-axis. These sides of the rectangle represent the two components that make up the vector.

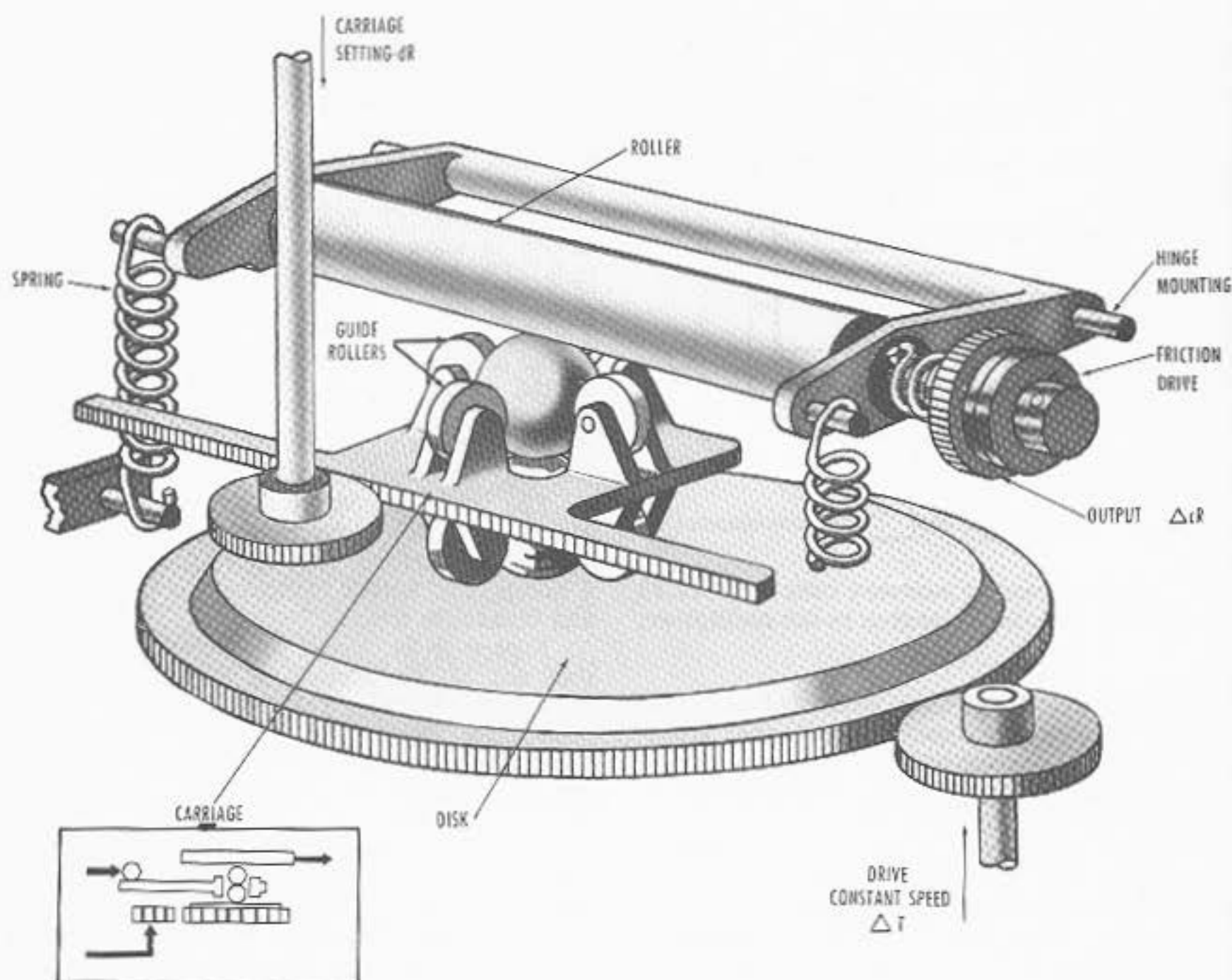
The two components can be computed by simple trigonometric methods. When it is desirable to perform this operation automatically, a component solver computes the desired values and transmits them.

Figure 3-24 shows the operating principle (but not all the structural details) of a typical component solver. The dial carrying the compass rose and own-ship outline can be rotated about the zero point of the graph. This dial is set at an angle representing the relative target bearing (angular offset of own ship's centerline from the line of sight). The vertical pin is positioned at a distance from center that represents own ship's speed. Thus the vector is established.

Two L-shaped slides, arranged as shown in the illustration, are slotted to receive camming action from the vertical pin. The slides move whenever the pin moves, but they are so mounted that the range slide always moves parallel to the line of sight and the deflection slide always moves perpendicular to the line of sight. The distances travelled by the two slides always measure the values X_o and Y_o , which are the two quantities this particular component solver is designed to transmit.

A mechanical component solver can resolve a vector rapidly; but a wire-wound resolver, constructed on the principles of the synchro, can receive an input that measures the vector and instantaneously transmit a pair of outputs that measure the components.

NOTE: In addition to elaborate gearing and shafting, and also in addition to a large number of electrical devices, the Mark 1 computer, a World War II design, contained 9 component solvers, 10 integrators (representing two types) 15 multipliers (both simple and complex types)



110.12
Figure 3-23. — A disc-type integrator.

8 cams, 24 handcranks, and more than 150 differentials.

GYROSCOPES

A gyroscope (colloquially called a gyro) is fundamentally a rapidly spinning wheel. Its rotational momentum gives it two useful properties:

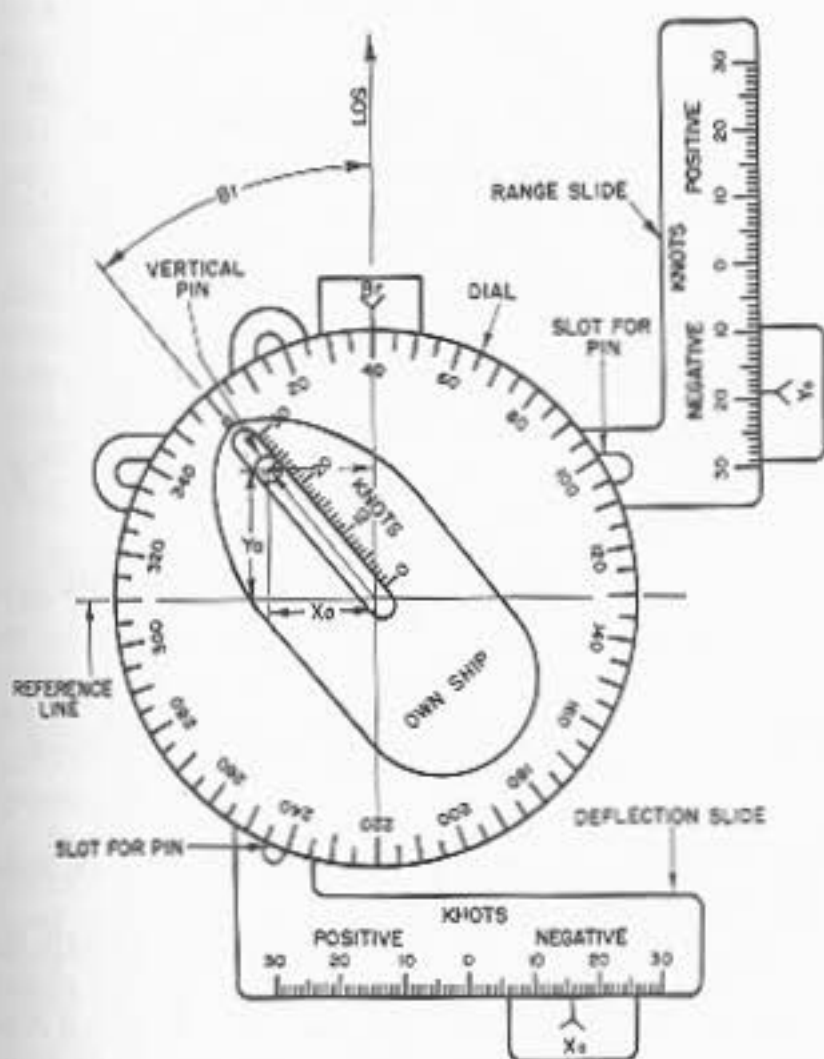
1. rigidity in space
2. precession

The first property was described earlier as being caused in any rotating body by its rotational momentum. It can be demonstrated easily

in a toy gyroscope (figure 3-25, part A) which, when spinning rapidly and supported at one end, will appear to defy the law of gravity by remaining horizontal while the other end is unsupported.

At the same time, though, the gyro will demonstrate the effect of the second property, precession, by rotation in a horizontal plane about its point of support, as shown in part B of figure 3-25. Gravity pulls the unsupported end of the spinning gyro wheel's axle vertically downward. But the axle doesn't move downward; instead it reacts by moving horizontally (i.e., at 90° to the pull of gravity).

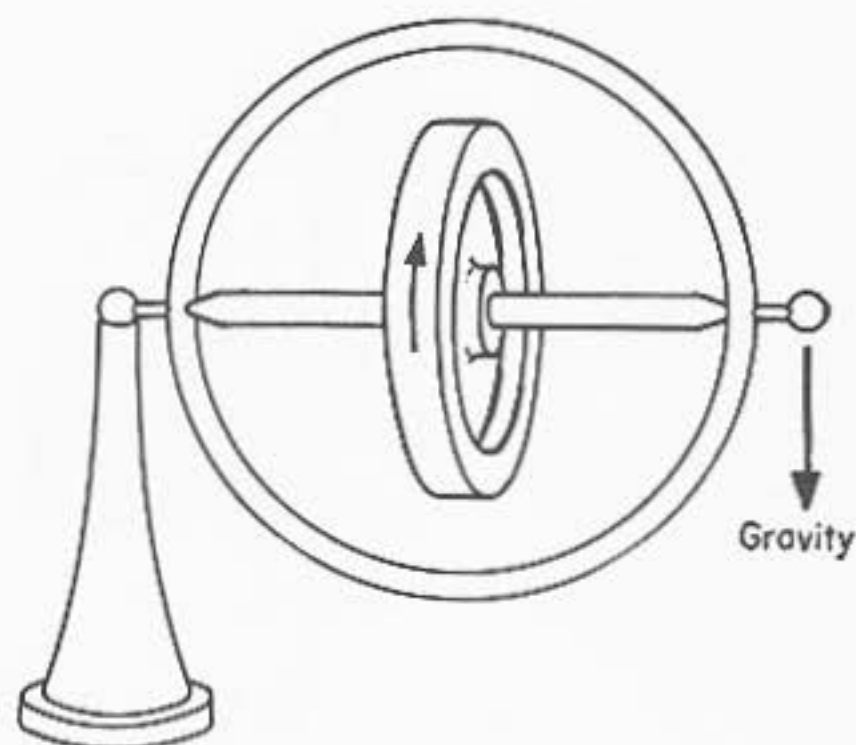
To understand precession, consider the spinning mass of the large wheel shown in figure



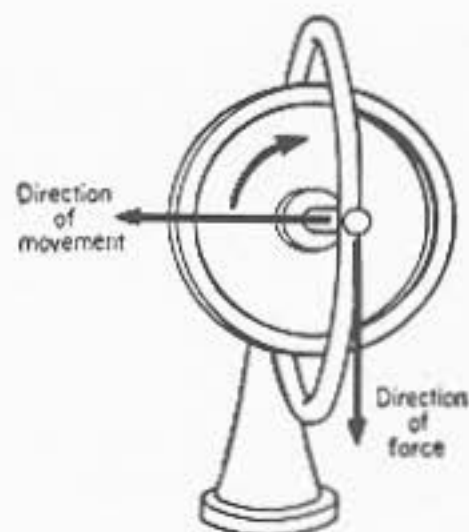
110.13

Figure 3-24.—The principle of the component solver.

3-26. An applied force symbolized by thick arrows labeled APPLIED FORCE (at the top and bottom of the wheel's axle) tends to tip the axle (i.e., rotate it about the axis Y-Y). Particle A is part of the spinning wheel's rim. At some instant its inertia is moving it in the direction AC. But the applied force tends to move it in the direction AB. It cannot move in two directions at once. It responds to the two forces acting simultaneously upon it by moving in the direction AD. But to do this the wheel's plane of rotation must shift as shown in the smaller diagram in figure 3-26. If the wheel's plane of rotation shifts, so does its axis of rotation (X-X). This shift is at an angle of 90° to the axis of the applied force (Y-Y). By turning figure 3-26 on its side and comparing it with figure 3-25, part B, you can see how the force of gravity pulling the axle downward can cause the axle to move horizontally.



A

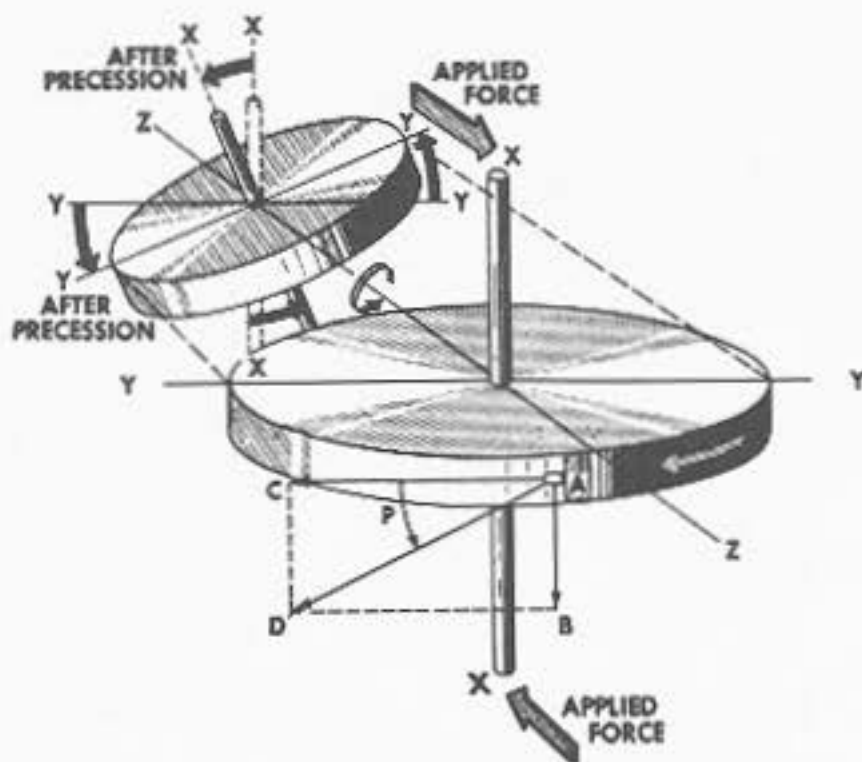


B

4.99:100

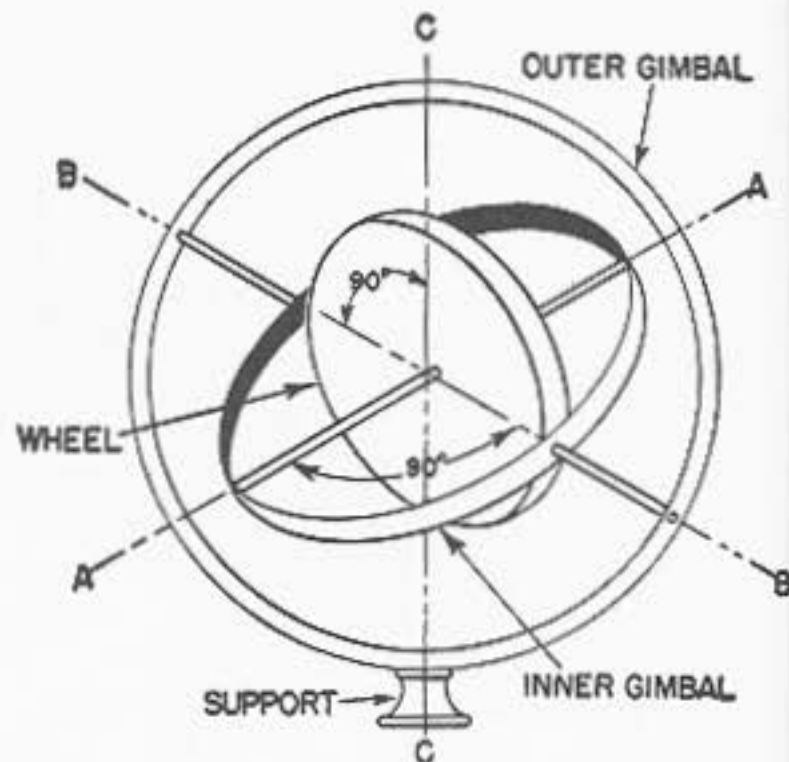
Figure 3-25.—Elementary gyro action. A. Rigidity in space; B. Precession.

The gyro's first property (rigidity in space) makes it desirable to use for establishing a reference direction (as in a torpedo or gyrocompass) or a reference plane (as in a stable element). In these applications the gyro wheel is so mounted that it will not be affected by changes in the direction of the vehicle that carries it. Since the precessional force is related to the deflecting force applied to the gyro, its second property (precession) is used (in lead-computing fire



88.6

Figure 3-26.—Gyro precession.



4.101

Figure 3-27.—The principle of gyro mounting.

control equipment) when it is necessary to determine the amount of lead required for a gun projectile to hit a moving target. These applications are discussed in later chapters of this text.

In these applications, it is necessary to mount the gyro wheel with the amount of freedom required in each case. This is done by using gimbals. A gimbal is a metal ring (or part of a ring) supported so that it can rotate about an axis formed by two points 180° apart on its circumference. Figure 3-27 shows a gyro wheel supported in two gimbals so that it has three degrees of freedom.

The gyro rotor is free to spin on its axis A-A. That's one degree of freedom. The rotor axis is supported in bearings in the inner gimbal ring, which is free to turn on the axis B-B. That makes two degrees of freedom. The outer gimbal, pivoted on the support, is free to turn on axis C-C. That gives the gyro its third degree of freedom. With three degrees of freedom, the gyro can maintain its rigidity in space no matter how its support moves.

PRINCIPLES OF HYDRAULICS

DEFINITIONS

Fluids are materials that continuously adapt their shape to fit their containers. Fluids include

both liquids and gases. In this section the main emphasis will be on liquids.

Hydraulics, in the strict sense, deals with the behavior of liquids in motion through a closed (that is, liquid-filled) system of connected containers. In its practical applications, hydraulics is concerned with the uses of fluid-filled systems in transmitting applied forces and producing or controlling mechanical motion.

A closely related science, called hydrostatics, deals with the behavior (including especially the pressure aspects) of fluids at rest in open containers. These may be such large "containers" as lake or ocean beds. In actual practice, the Navy man ordinarily expands hydraulics to include hydrostatics. Following are some definitions used in hydraulics.

HYDROSTATIC PRESSURE. Any liquid in an open container exerts pressure equally in all directions from any given point within the liquid. The degree of pressure on a submerged object varies directly with the depth the object has reached. At a depth of one foot in sea water, the bottom of a mine case is under hydrostatic pressure of 64.3 pounds for each square foot of its surface. At a 10-foot depth, the pressure is 10 times as great, or 643 pounds per square foot.

Underwater weapons—particularly mines and many depth charges—have various components that remain inactive until the hydrostatic pressure on the exterior of the device becomes great

enough to overcome a built-in resistance, such as that offered by a spring or an expanded bellows.

APPLIED PRESSURE. A liquid in a closed system also exerts hydrostatic pressure, but this is not a major consideration in any component except the storage reservoir. This reservoir must contain enough liquid (and exert enough pressure or head) to keep all the enclosed spaces filled during a complete cycle of operation.

The really important fact about pressure in a closed system is the capacity of the liquid for transmitting—rapidly and in all directions—a force that is applied to one component of the system. Because it can do this, an enclosed liquid can be used, much as a basic machine is used, to overcome resistances and move loads.

BASIC PRESSURE-MOTION RELATIONSHIP. The system shown in figure 3-28 is not equipped to produce a work output that has any practical value outside the classroom. It does, however, have teaching value in that it shows the basic principle behind many more elaborate and highly practical systems.

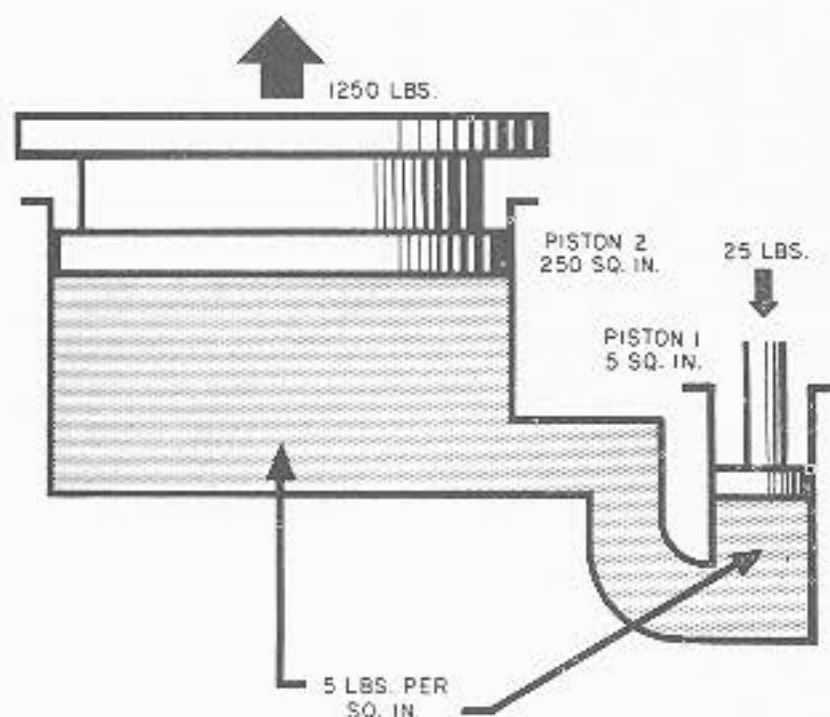
In figure 3-28 a total downward force of 25 pounds is applied to the small piston, whose head has an area of 5 square inches. The pressure applied through this piston to the enclosed liquid is 25 pounds for each 5-square-inch area of container surface. The unit pressure is, therefore, $25/5$ or 5 pounds per square inch. (This unit pressure may be abbreviated 5 psi; the letter symbol is pronounced p-s-i, not like the name of the Greek letter Psi.)

The input, transmitted equally in all directions throughout the liquid, acts on the large piston head with an upward pressure of 5 psi. The large piston head has an area of 250 square inches. It is, therefore, subjected to a total upward force of 250×5 , or 1250 pounds.

The system is similar, in effect, to a lever in which E is 25, R is 1250, and the theoretical mechanical advantage is 50. But, just as in the lever, the distances travelled by the effort and the resistance are in inverse proportion.

For example, if the small piston moves downward an inch, it displaces 5 cubic inches of practically incompressible liquid that must be accommodated somewhere unless the system is to burst. The large piston is the only component that can move to make room for the displaced liquid; but it needs to move upward only $5/250$ or $1/50$ inch to accommodate the 5 cubic inches of fluid.

This system lacks some of the essential components of a useful hydraulic mechanism. The



110,14
Figure 3-28.—The basic principle of hydraulic pressure.

next article will mention and briefly explain those components.

SYSTEM COMPONENTS

FLUID RESERVOIR. Because certain working members of a hydraulic system move up and down or in and out, the amount of space inside the system varies. To keep the available space filled at all times, the system must have a storage tank or reservoir to accommodate back-up fluid and return it to the system as needed. The depth (or the elevation, which amounts to the same thing) of the storage reservoir must be designed to furnish enough hydrostatic pressure or head to keep all enclosed areas filled during a complete cycle of operation.

PISTONS AND CYLINDERS. Figure 3-28 shows elementary examples of the working parts present, in one form or another, in all hydraulic mechanisms. These are the cylinders that accommodate varying amounts of fluid and the pistons (short, closely fitted interior cylinders) that move, in response to mechanical or hydraulic pressure.

Usually the piston is attached to a rod that projects through a leakproof opening in the capped end of the enclosing cylinder. The usual purpose of the rod is to receive a mechanical input or to transmit an output.

CONNECTING LINES. The system must have connecting lines joining the working components to one another and to the reservoir. These lines, like the one connecting the two cylinders in figure 3-28, may sometimes be part of a single casting. If the working elements are a distance apart, pipes are used to connect them.

VALVES. A workable hydraulic system must have valves that open and close to keep the fluid moving in the right direction, in the right amounts and at the proper pressure. The valves must also prevent the liquid from moving away from certain areas until it has accomplished its work. A lack of valves robs the device in figure 3-28 of practical value.

There are many types of valves, varying from extremely simple to fairly complex designs. Some have stems that permit an operator to admit fluid, to cut it off, or to allow flow at a reduced rate. Others are operated by the internal pressures that develop within the system. At this time only a few valves of the simpler sort will be considered.

The **COCK** is a plug-type valve permanently seated within a pipe. A cylindrical opening in the plug can be turned at will, to permit flow or to block it. Figure 3-29 shows the top view of a typical cock.

A **GATE VALVE**, like a cock, can be turned by an operator to admit or obstruct flow. Instead of staying within the pipe in its open condition, the gate valve occupies a projecting "bonnet," as shown in figure 3-30.

A **NEEDLE** valve has a tapered point to permit gradual opening or closing in an area where a more sudden change of pressure would be dangerous.

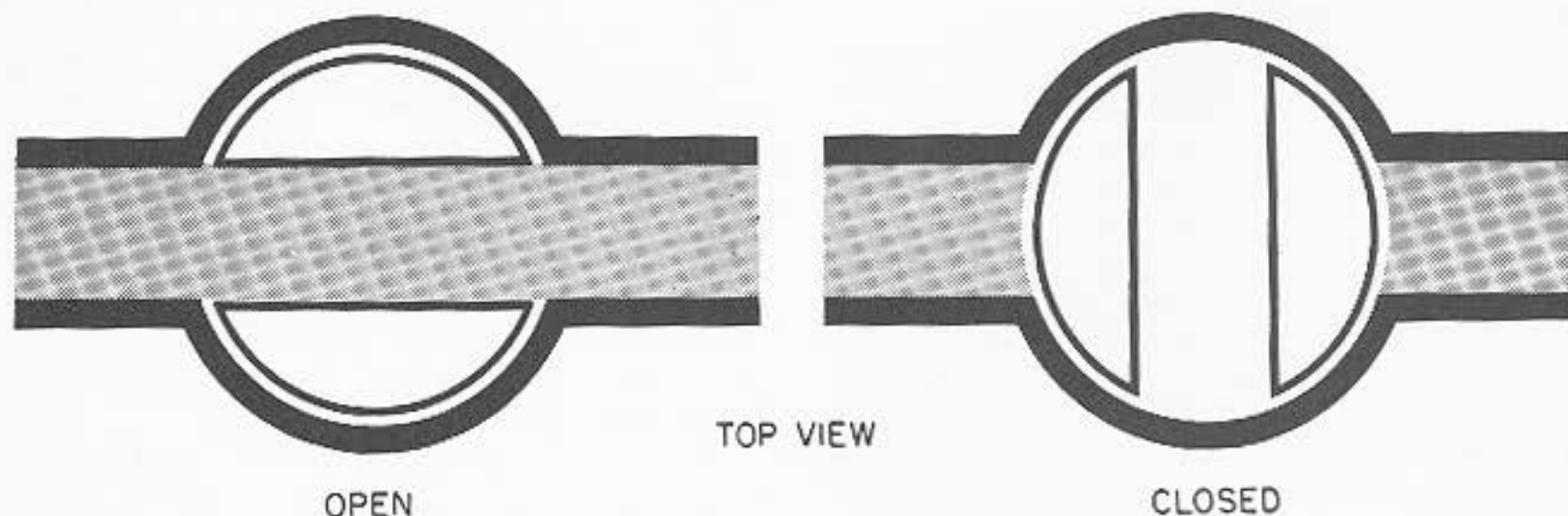
A **CHECK** valve, responding automatically to pressure changes within the system, opens to permit flow in one direction and closes to check or prevent flow in the opposite direction. Spring or gravity action sometimes hastens the closure of this valve. Figure 3-31 shows a check valve hinged at the top to allow flow toward the right and prevent flow toward the left. A check valve is sometimes called a directional valve.

A **SAFETY** or a **RELIEF** valve (the two types are similar but not identical) is a spring-loaded check valve that keeps an exhaust or bleeder pipe closed until an excessively high pressure within the main line overcomes the built-in spring resistance and opens the valve.

SPOOL valves and **ROTARY** valves may, depending on design details, be operated by hydraulic or electrical actuators, or may (less frequently) be hand-operated. These valves are used in more complex hydraulic systems to direct fluid flow as desired for system operation.

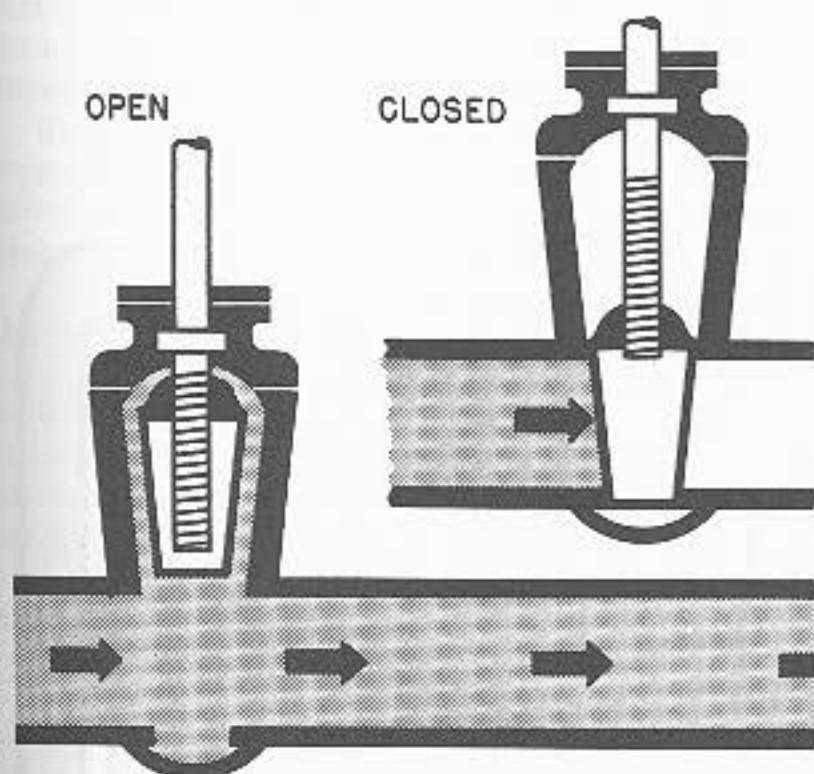
SIMPLE PRACTICAL APPLICATION

Before taking up the pump, the reader may be interested to see that the addition of devices described thus far—a storage reservoir, a connecting line, two check valves, and a gate valve—can turn the device shown in figure 3-28 into the highly useful hydraulic jack shown in figure 3-32 and, somewhat later, in figure 3-33.



110.15

Figure 3-29.—How a cock controls flow.



110.16

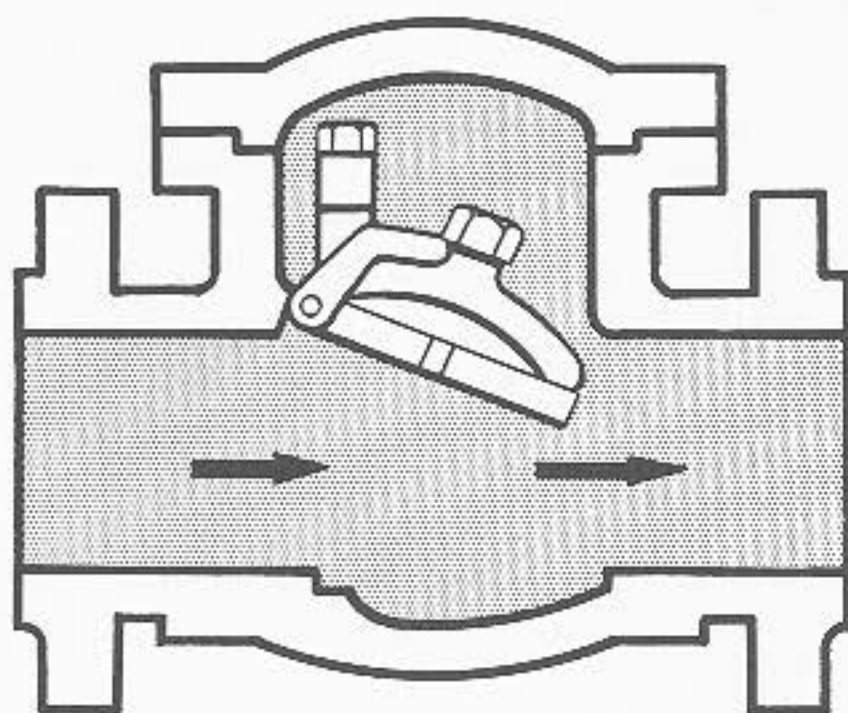
Figure 3-30.—How a gate valve opens.

The valves numbered 1 and 2 in the illustration are check valves. Valve 1 is hinged at its left-hand side. It is open because fluid under pressure has been forced against its lower face by the down stroke of the small piston. When open, this valve admits displaced fluid to the large cylinder. Valve 1 cannot swing downward beyond its horizontal or closed position.

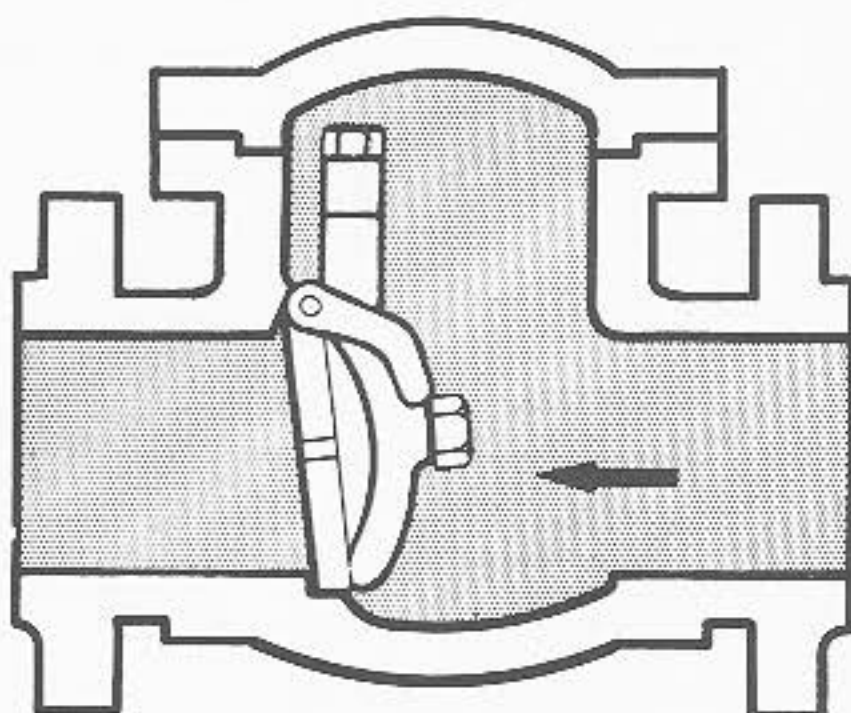
Valve 2, shown closed in figure 3-32, is hinged at the top. It opens by swinging toward the small cylinder. It cannot swing open in the direction of the storage tank. This valve is closed by the pressure exerted during the down stroke of the input piston, for this applied pressure exceeds the hydrostatic pressure exerted on the opposite face of the valve by the liquid in the storage tank.

Valve 3, the GATE valve, is kept closed while the operator is using the jack to lift a load. Acting as a pair, valves 1 and 3 keep the displaced fluid trapped in the large cylinder. Upon completion of his work, the operator opens valve 3, thus allowing the displaced fluid to return to the reservoir as the large piston sinks by gravity to its normal position.

Figure 3-33 shows the relationships within the jack during the up stroke of the input piston. As this piston is pulled upward, the pressure within the small cylinder drops, and a partial vacuum is formed. The hydrostatic pressure of



OPEN



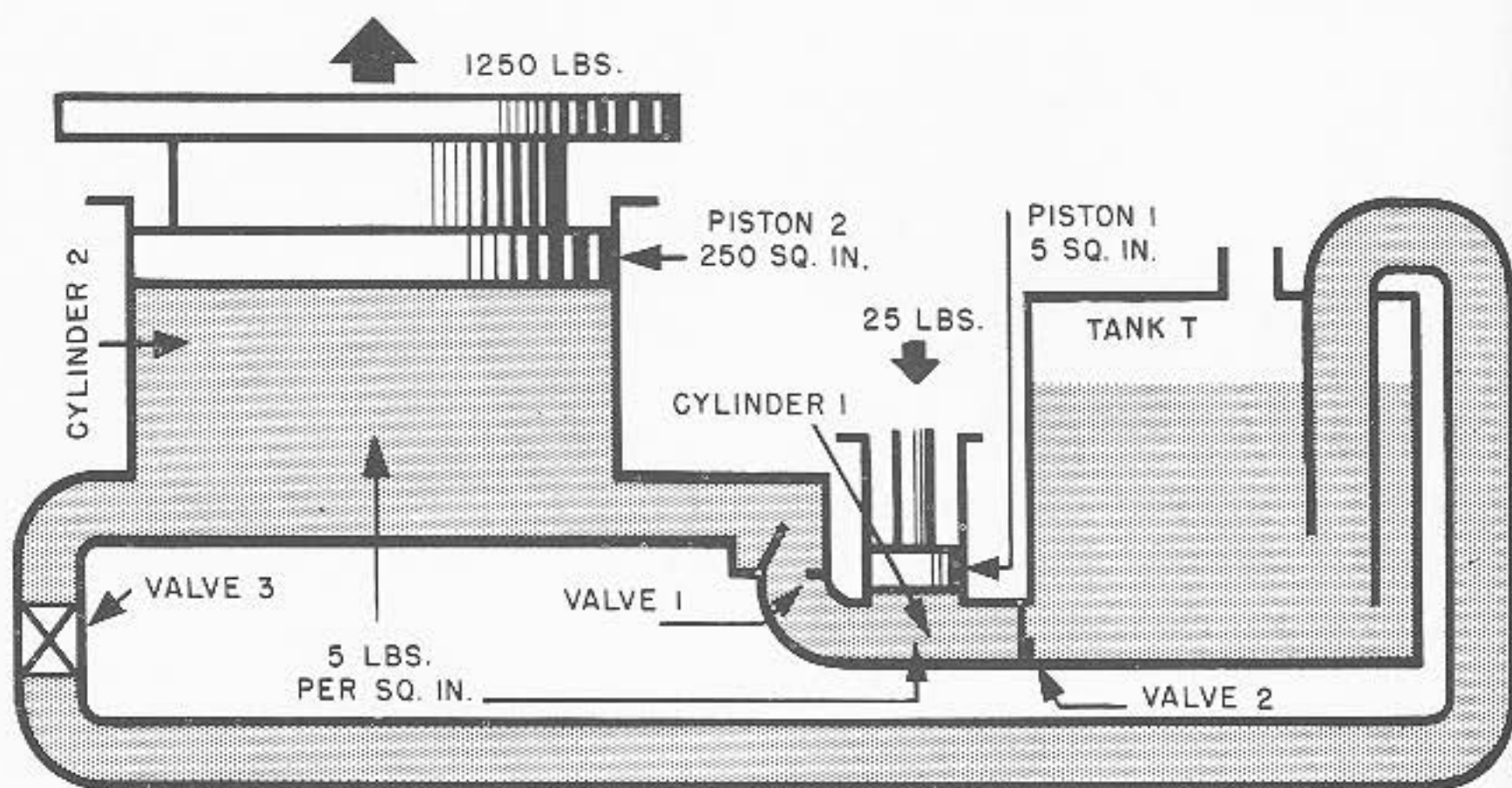
CLOSED

11.319(110)

Figure 3-31.—The operating principle of the check valve.

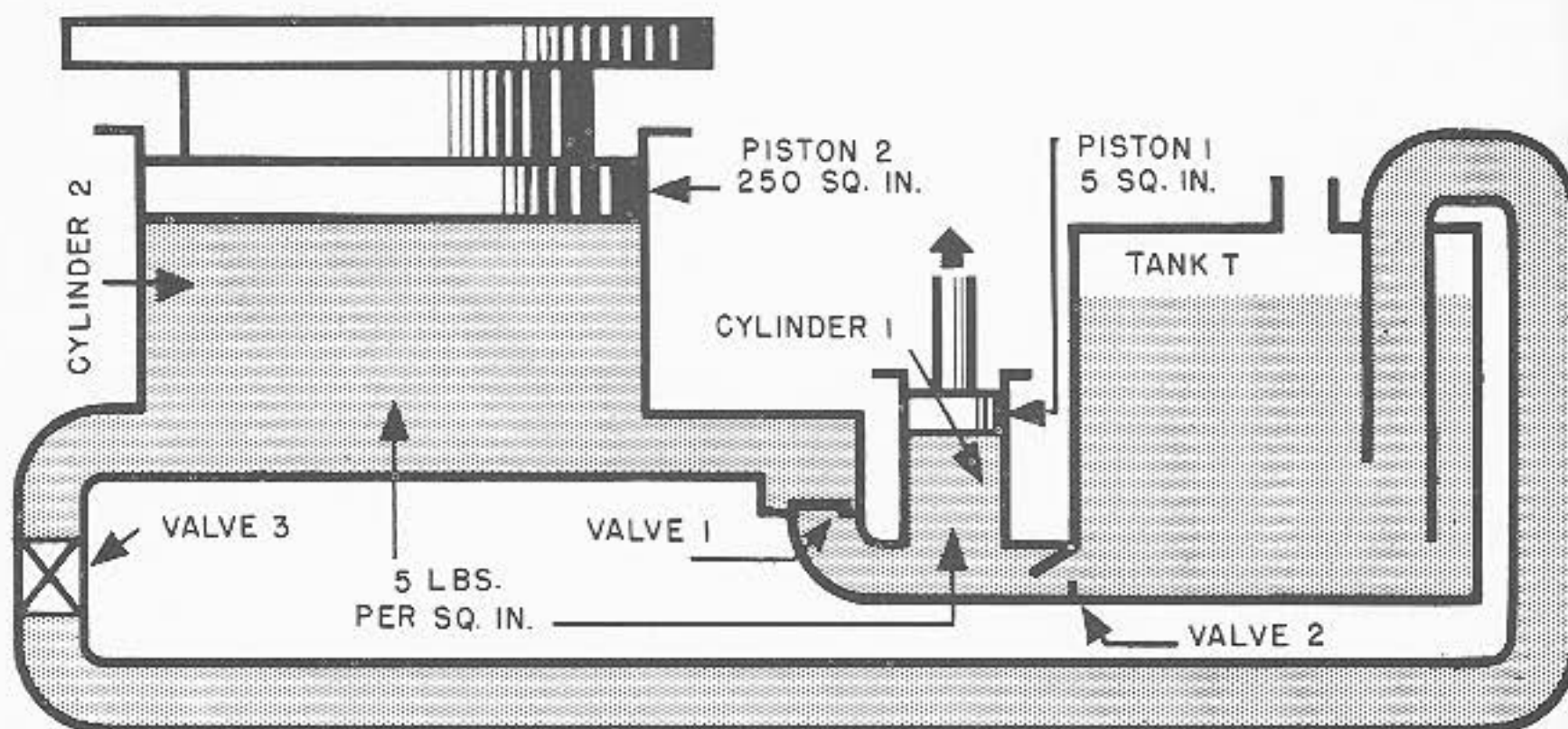
the fluid in the storage tank forces valve 2 open and lets fluid enter the small cylinder as long as the piston is rising.

Because the pressure in the small cylinder has dropped below that in the large cylinder, the large piston tries to drop and restore balance; in technical language, the large piston exerts back



110.17

Figure 3-32.—A hydraulic jack—down stroke of the input piston.



110.18

Figure 3-33.—A hydraulic jack—up stroke of the input piston.

pressure, forcing valve 1 downward to its horizontal or closed position. Because this valve cannot swing below the horizontal, it simply remains closed until it is opened (and valve 2 is closed) by the next input stroke.

The cycle shown in figures 3-32 and 3-33 is repeated until the liquid trapped in the large piston has lifted the load as high as the operator wishes, within the capabilities of the jack.

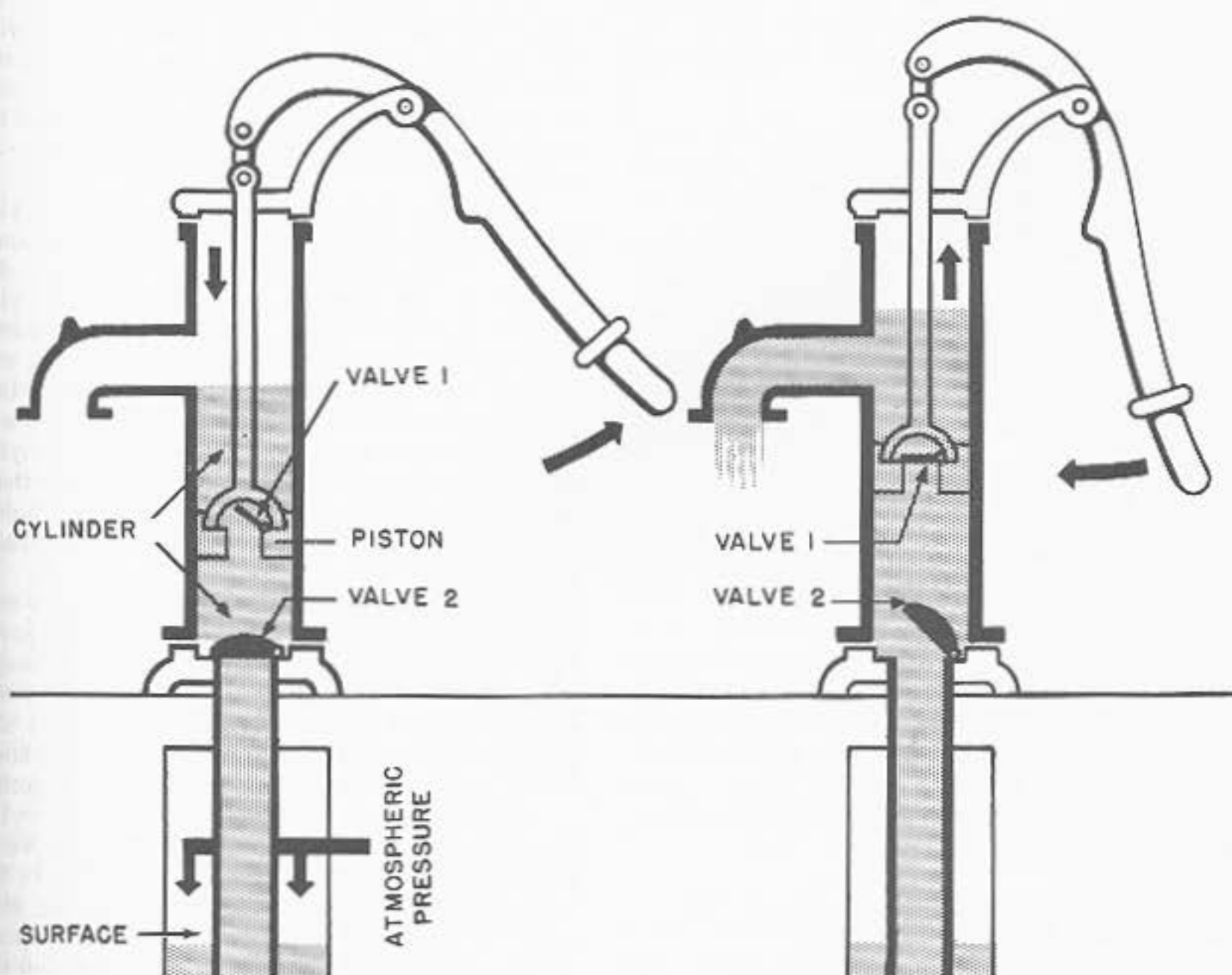
THE SIMPLE PUMP. A pump is a mechanism that uses an external source of power to apply force to a fluid. All pumps in open hydraulic systems take advantage of the fact that the earth's atmosphere, a gaseous fluid, exerts a static pressure whose existence becomes noticeable whenever a partial vacuum is created.

Anybody who drinks through a straw is making use of this phenomenon. By sucking on the

straw, he creates a partial vacuum. Atmospheric pressure, acting on the liquid in the tumbler, forces enough of it up the straw to dispel the partial vacuum.

In a common hand pump, figure 3-34, the lever-type pump handle is joined to a piston rod with a simple upward-opening check valve (numbered 1) in the piston. The downstroke of the piston applies pressure to the water in the pump, opening valve 1 and closing another check valve (numbered 2) at the base of the pump.

On the up stroke of the piston, pressure is reduced, and a partial vacuum is created, in the area between the two valves. Valve 1 closes. Atmospheric pressure in the well forces water up the pipe. The upward thrust of the water opens valve 2 but is not strong enough to open valve 1 as long as the piston continues to rise. The



110.19

Figure 3-34.—How a simple hand pump operates.

excess water thus drawn into the pump flows from the spout.

There is a great difference in structure, though not in fundamental operating principle, between the simple hand pump in figure 3-34 and the Waterbury constant-speed, axial-piston, variable-delivery pump that constitutes the A-end of a gun's electric-hydraulic train or elevation power drive. The summary below will prepare the way for the description of the A-end in the next section.

SOME FACTS ABOUT PUMPS. Pumps that are designed to perform work operations are installed as integral parts of closed hydraulic systems in which fluid from a reservoir is repeatedly circulated by pump action. These pumps are divided into two main classes—the reciprocating and the rotary type.

RECIPROCATING pumps deliver liquid by a back-and-forth movement of mechanical parts. **ROTARY** pumps deliver liquid by a circular (or other curved) motion of mechanical parts. The A-end is a reciprocating pump. The following numbered statements apply to it.

1. By lengthening or shortening the work stroke of its piston(s), a reciprocating pump can be made to deliver a larger or smaller volume of liquid per stroke.

2. Reciprocating pumps can be constructed to utilize two, three, or even many piston-and-cylinder units arranged in a cylinder block and driven by an ordinary power motor.

3. An **AXIAL-PISTON** reciprocating pump has a cylinder block that rotates on a central shaft in such a way that the pistons move back and forth in a direction parallel to the shaft.

4. A **VARIABLE-DELIVERY** axial-piston pump contains a means of varying the piston stroke (and thereby varying the output of the pump) automatically in response to control signals.

ACCUMULATORS. An enclosed hydraulic system usually contains an accumulator that stores a certain amount of fluid under air pressure. When there is a sudden heavy demand for fluid, in excess of the capacity of the pumps, fluid from the accumulator enters the system and tends to equalize the flow.

ORDNANCE HYDRAULIC MECHANISMS

This article will take up, in rather general terms and without fine details, some of the hydraulic devices that are found associated with

gun mounts, turrets, and missile-launching systems. Because the way has already been prepared for it, the hydraulic pump or A-end will be described first.

HOW THE A-END WORKS. Instead of having a single piston like the ordinary hand pump, the A-end often has nine piston rods, each with its own cylinder. These cylinders are arranged in a cylinder barrel that rotates in a fixed plane perpendicular to its central shaft.

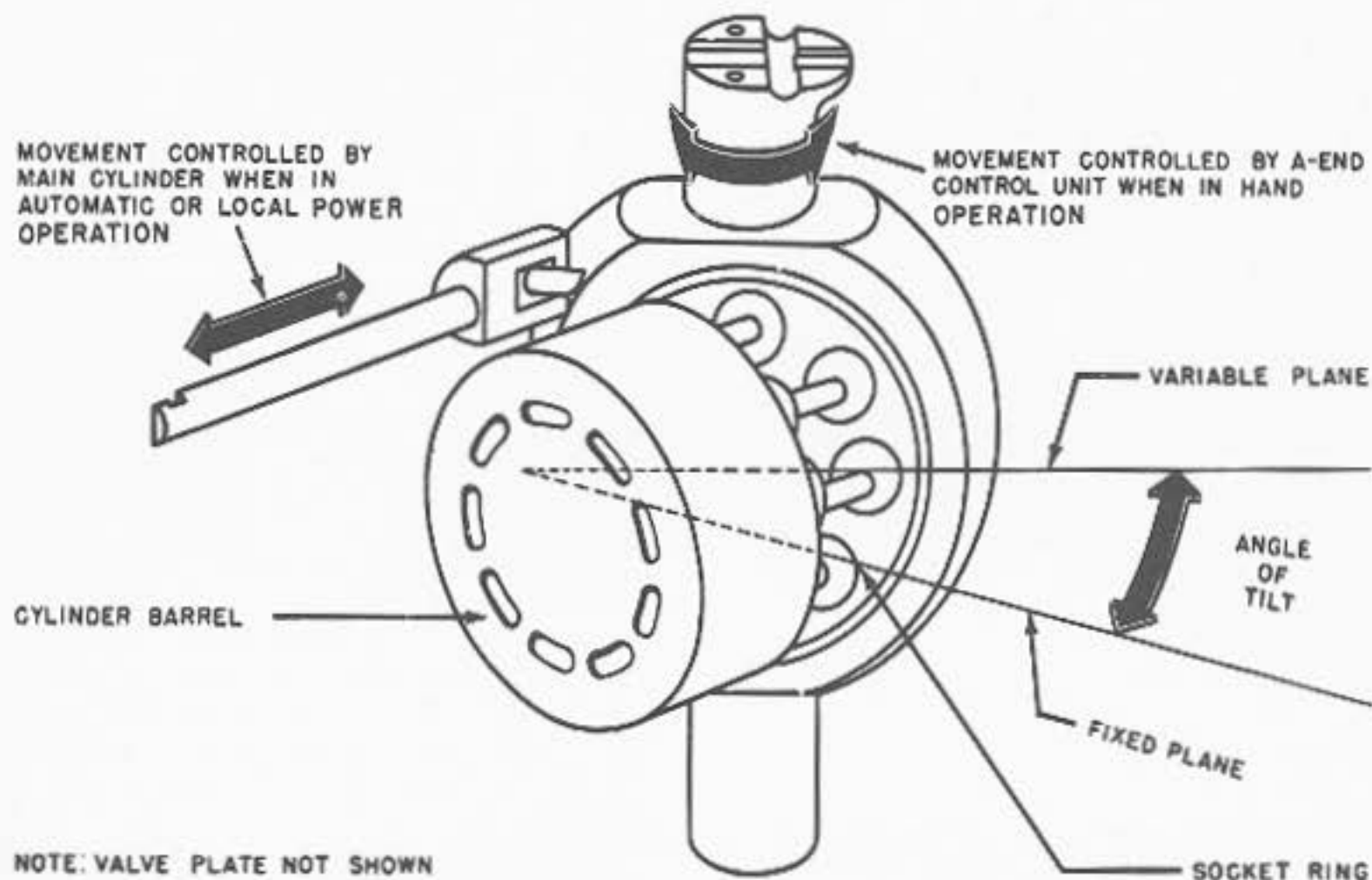
The ends of the cylinders are joined to a socket ring that rotates with the cylinder barrel, but at the same time tilts at an angle that can be varied from 20° on one side of the position of zero tilt to 20° on the other side. A universal joint, similar in principle to the one shown in figure 3-4, allows the socket ring to be driven and tilted simultaneously. The amount and direction of tilt depend on the control signal the A-end receives.

The simplified drawing in figure 3-35 shows one possible angle of tilt between the cylinder barrel and the socket ring. The yoke-like structure in which the socket ring is bearing-mounted is called the tilt box. The ring is tilted in accordance with signals from the indicator-regulator.

When the A-end is in operation, the cylinder barrel rotates in the vertical plane, and the socket ring rotates with it, at an angle determined by the input signal. Unless the cylinder barrel and the socket ring are exactly parallel, each piston rod, during a complete cycle, will be pushed into its cylinder (thus increasing the internal pressure) for a half-cycle and then will be drawn toward the opposite end of the cylinder (thus reducing the internal pressure) for the next half-cycle. The cylinder barrel as a whole will have a high-pressure side and a low-pressure side.

To get pumping action, then, it is only necessary to arrange pipe lines and valve ports in such a way that hydraulic fluid can always be drawn into the cylinders as the internal pressure decreases and can always be forced out as the pressure increases. The valve plate shown in figure 3-36 makes the necessary arrangements.

To minimize leakage, the rotating cylinder barrel bears closely against the fixed valve plate at all times. For the angle of tilt shown in figure 3-36, the lower pipe line is the intake and the upper line is the output. Lands, corresponding to the neutral-pressure (9 o'clock and 3 o'clock) positions of the cylinders (figure 3-36, part A) prevents short-circuiting of the two sides. When the angle of tilt reverses, the high-pressure side



110.20

Figure 3-35.—Angle of tilt in the A-end.

becomes the low-pressure one, and the direction of flow reverses. Figure 3-36, part B, shows the assembly in phantom.

In some installations, the B-end or hydraulic motor is separated from the A-end as shown in figure 3-37. In others, the B-end is directly connected to the valve plate. In either event, the action of the two ends is the same.

B-END. The B-end, shown as a phantom in figure 3-38, is much like the A-end in design, except that the angle of tilt is built in and cannot be changed. The valve ports on the intake side receive oil under pump pressure from the A-end. This oil exerts forces at right angles to the faces of the pistons open to the intake ports. These forces can each be broken into two components—(1) a thrust component along the axis of rotation that serves no useful purpose and is neutralized by bearings and (2) a turning component that rotates the socket ring and, with it, the cylinder barrel and the output shaft.

After a given piston has taken all the fluid it can from the intake side of the valve plate, it passes the land and begins to discharge fluid

through the outlet ports of the B-end to the intake (suction) side of the A-end.

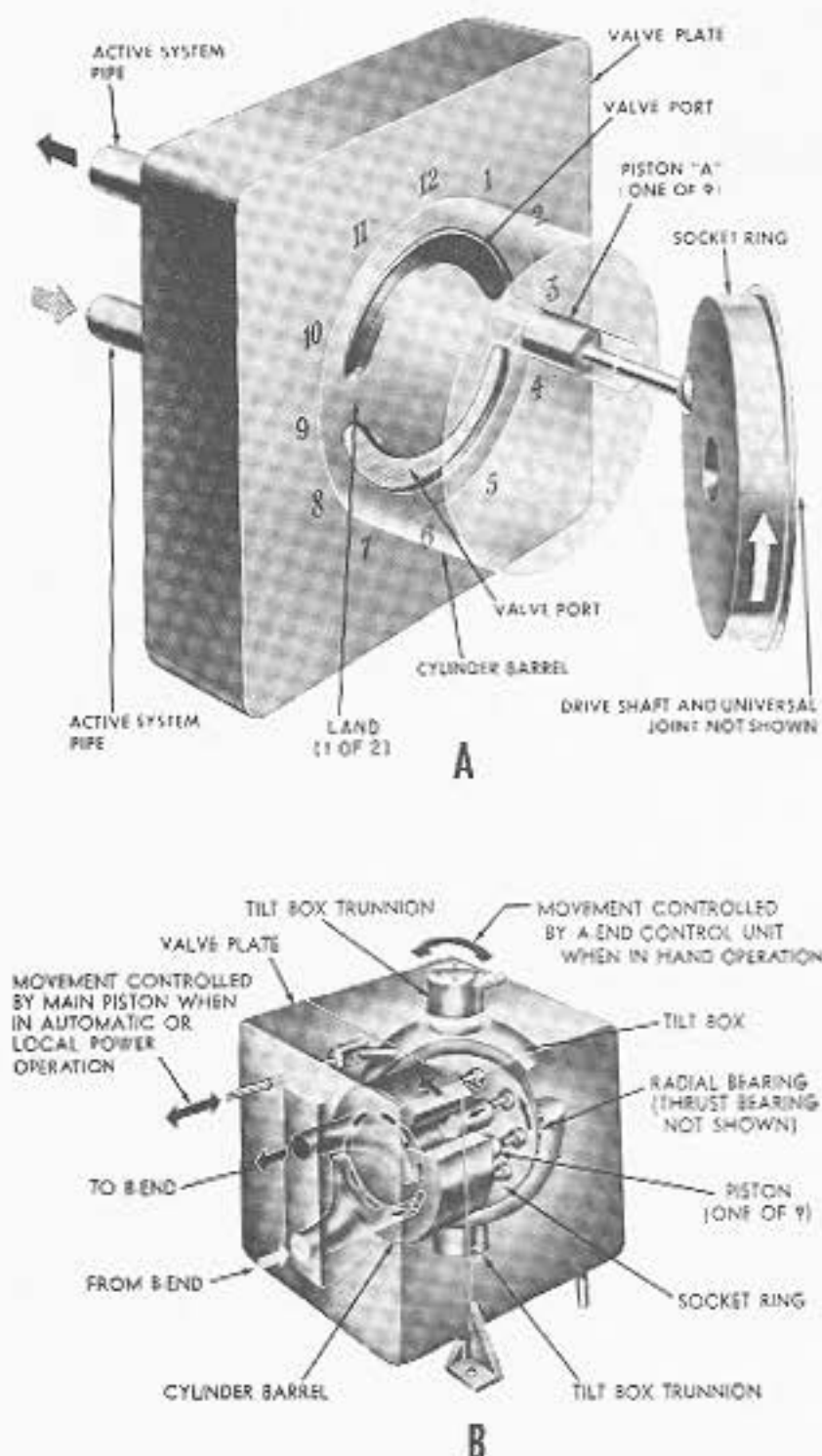
The direction of turning of the B-end and its output shaft depend on the direction of turning of the A-end.

RECOIL AND COUNTERRECOIL DEVICES. The recoil and counterrecoil systems of naval guns operate without pump or motor action. Details of these piston-and-cylinder systems vary with the sizes and types of guns. Figure 3-39 is a representative sketch, based on a conventional 5-inch gun.

The recoil cylinder contains fluid and has a piston whose head is precision-fitted to the cylinder wall. The counterrecoil cylinder contains air (or some inert gas) under pressure and has a partially hollow plunger whose outer end extends through an airtight fitting in the end of the cylinder.

The recoil and counterrecoil units work together to keep the "kick" of the gun within reasonable bounds, to restore the gun to battery, and to hold it there until the next round is fired.

If the student understands two simple and useful hydraulic devices—the hydraulic recoil brake



110.21
Figure 3-36.—A-end operation. A. Cylinder barrel, valve plate, and socket ring. B. Phantom view of assembly.

and the differential cylinder—he should be able to study, with little difficulty, the specific recoil-counterrecoil mechanisms in any naval gun.

In a hydraulic recoil brake, the head of a piston fits closely within a fluid-filled cylinder. The passages from one side of the piston head to the other are few and small. These passages may be holes through the piston head, or they may be grooves in the cylinder wall. If an applied force (such as the shock of firing) acts to move

the piston with respect to the cylinder (or vice versa) the movement can take place only as fast as the small passages allow fluid (which is practically incompressible) to flow from one side of the head to the other. Movement, therefore, is throttled, because much of the applied force has to be used up in overcoming resistance.

This principle is applied in the gun's recoil cylinder. The design features may vary from one gun to another, but the purpose remains the same.

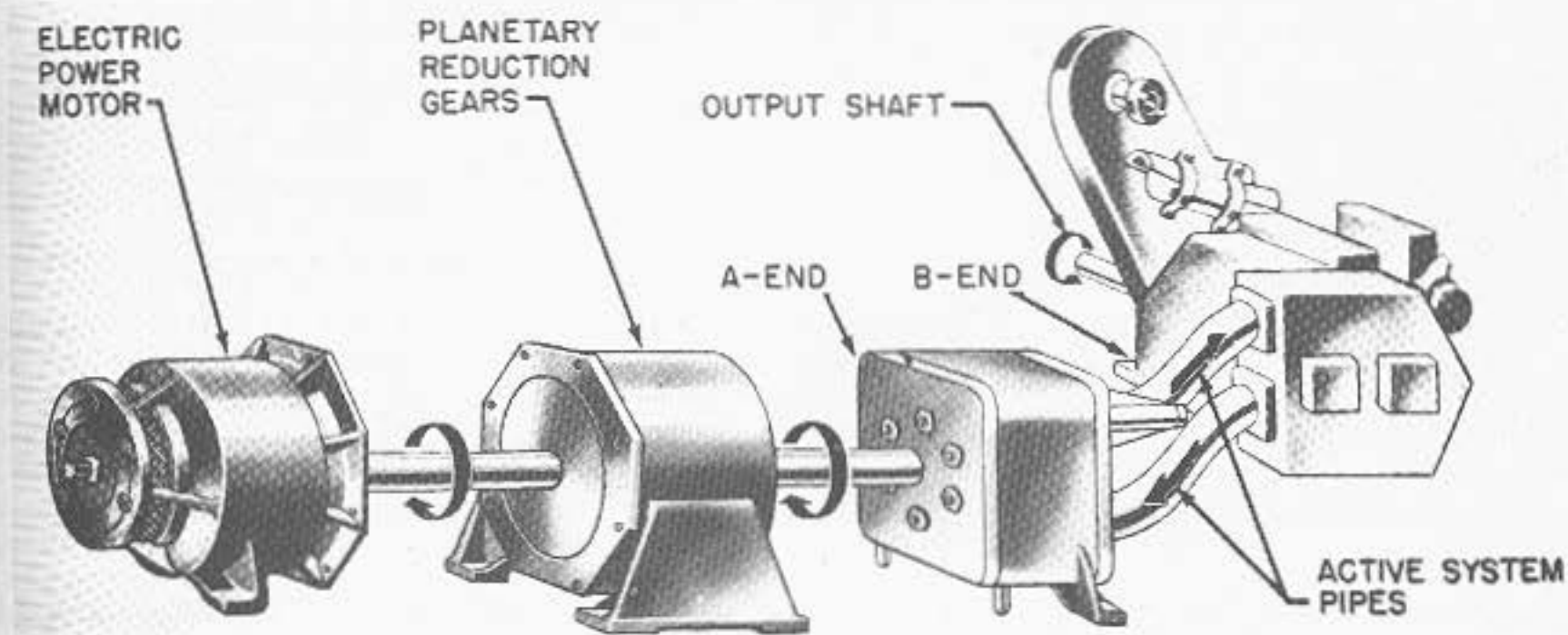
A number of other ordnance braking devices, including, for example, the dashpots that delay the operation of certain linkages in moored mines, make use of the throttling effect of small orifices.

To absorb the final shock as the gun returns to battery, some guns have a dashpot-type counter-recoil buffer that is physically associated with the recoil cylinder.

As previously mentioned, the counterrecoil cylinder contains air or possibly some inert gas. Gases, of course, are fluids; but unlike liquids, they are capable of being compressed under pressure. When the pressure is removed, they expand. As can be seen in figure 3-39, recoil movement decreases the amount of space in the counterrecoil cylinder, thus putting the air under greater than normal pressure. In many guns, the increased internal pressure would tend to cause an air leak, except for the sealing effect of a comparatively small differential cylinder that acts to tighten the packing through which the plunger end extends. The next few paragraphs will take up the differential cylinder.

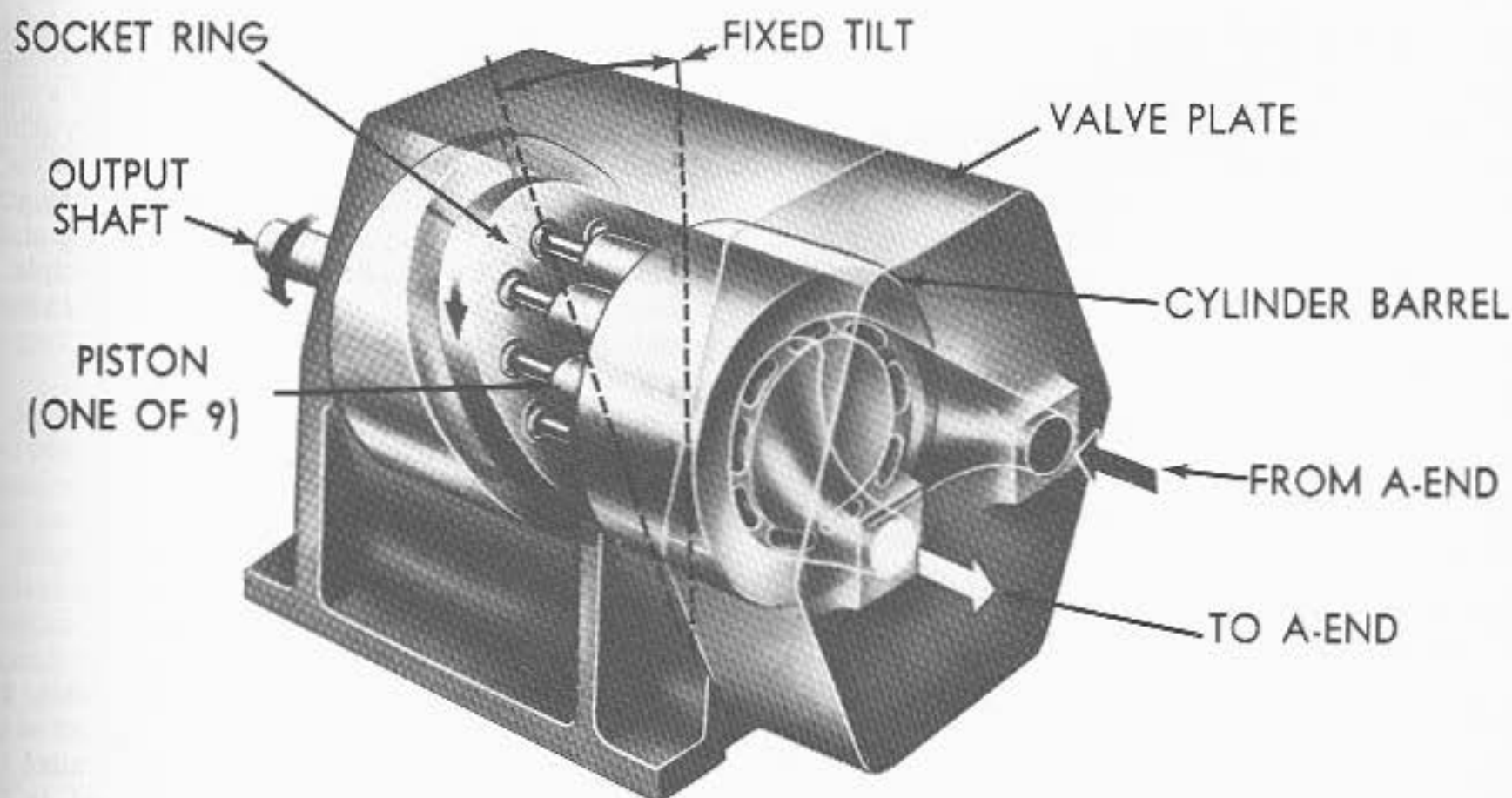
The device in the lower part of figure 3-40 is a typical differential cylinder. The free-floating piston in this cylinder always takes a position where the thrust of the air (directly connected to the air in the counterrecoil cylinder) exactly counterbalances the thrust of the oil (directly connected to the oil gland at the center of the chevron packing). But part of the area of the oil side of the differential cylinder head is occupied by the end of the piston rod, and therefore cannot receive thrust from the trapped oil, whereas the entire area of the air side of this head receives thrust from the trapped air. Therefore, at all times, the pressure in terms of pounds per square inch on the oil side must be greater than the corresponding pressure (in psi) on the air side.

Whenever recoil action raises the air pressure, the unit pressure of the oil—including, of course, the oil in the packing gland—rises proportionately. Thus the oil at the center of the specially shaped packing acts to "inflate" it and



110.22

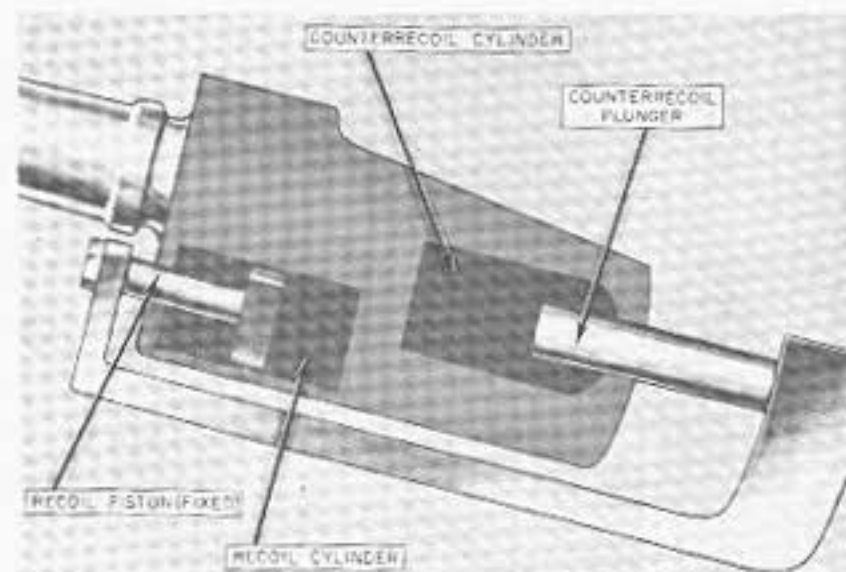
Figure 3-37. — The hydraulic speed gear.



NOTE: SOCKET RING,
UNIVERSAL JOINT,
THRUST AND RADIAL
BEARINGS NOT SHOWN

110.23

Figure 3-38. — A phantom view of the B-end.



84.147

Figure 3-39.—Representative recoil and counter-recoil systems.

prevent leakage of air. Any leakage that occurs will be an oil leak, not an air leak.

As soon as the recoil action is completed, the air in the counterrecoil cylinder begins to expand and return the gun to battery. The oil side, of course, continues to exert greater unit pressure than the air side, and therefore acts to seal the counterrecoil plunger.

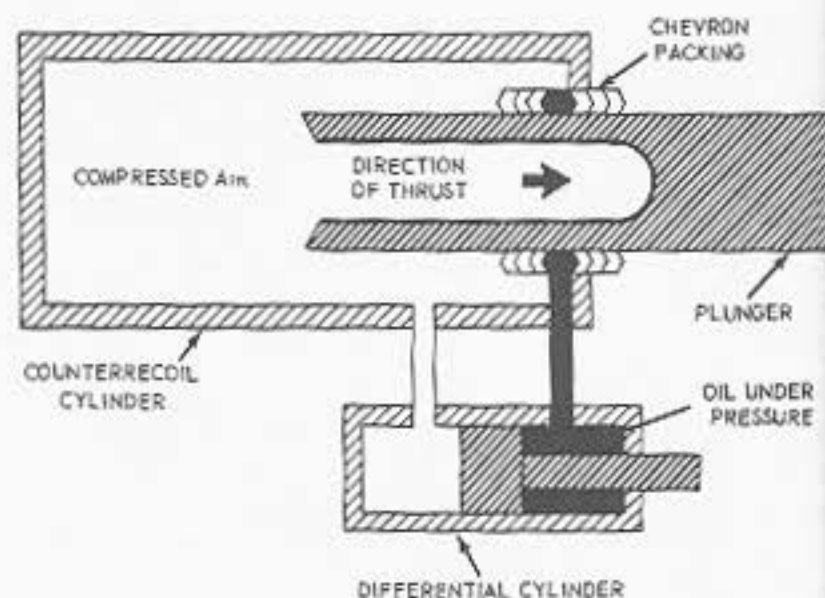
BASIC PRINCIPLES OF ELECTRICITY

Electricity is a form of energy. As such, it can be harnessed to do work.

Electrons make electricity available for use. Normally an electron revolves within a parent atom, somewhat like a planet within a solar system. Every electron bears an electric charge. If set free from its atom—whether by chemical action or by other means—the electron takes its charge with it.

All substances have resistance, which is a tendency to block the movement of free electrons. Conductors have a relatively low resistance; insulators, a high resistance. The unit of resistance is the ohm. In electrical equations, R represents resistance in ohms.

CURRENT is a stream of free electrons moving through a conductor. Current flows when (and only when) there is a closed circuit from the current source back to the source. Current is measured by the number of electrons that pass a given point in a second. The unit of



84.148

Figure 3-40.—Principle of the differential cylinder.

current is the ampere. In equations, I stands for current in amperes.

Each point in an electric circuit has a potential or an electromotive ("electron-moving") force that corresponds roughly to head in a water system. Electromotive force is commonly abbreviated emf; its unit is the volt. In equations, E stands for an emf in volts. The emf at any point is mathematically equal to the product of the current and the resistance; this principle is called Ohm's law. It may be expressed in three equations:

$$E = IR, \text{ or by simple algebra,}$$

$$I = \frac{E}{R}, \text{ and}$$

$$R = \frac{E}{I}.$$

The unit of electric power is the watt. The power in watts is equal to the product of the current and the voltage. P is the symbol for power in watts. It may be expressed in the equation:

$$P = EI, \text{ or, by substitution from Ohm's law}$$

$$P = E \times \frac{E}{R} = \frac{E^2}{R}, \text{ and}$$

$$P = IR \times I = I^2 R$$

Electric current is of two types—direct and alternating. In direct current (d-c) the electrons move continuously in one direction, though not necessarily at a constant speed. In alternating current (a-c) the direction of electron movement reverses rapidly and repeatedly. The number of times the electrons reverse in one second is called the FREQUENCY. Navy ships commonly use frequencies of 60 Hz (Hertz) or 400 Hz. One hertz is equal to one cycle per second.

Electricity and magnetism are closely related. Any conductor carrying electric current is surrounded by a magnetic field.¹ Furthermore, a magnet will induce a voltage in any conductor that is moved in its magnetic field. Conversely, if a current-carrying conductor is placed in a magnetic field, the conductor will tend to move at right angles to the field.

When a conductor is twisted into a coil and energized by current, the coil, as a unit, has a magnetic field. When the field of an energized coil is changing in strength (because of a change in current), it can induce a voltage in a second coil that is not physically joined to the first one.

A TRANSFORMER is designed to make practical use of induction. In the transformer a current-carrying coil, called the primary, induces a voltage in another coil or group of coils, called the secondary.

An induction device called the synchro is taken up later in this chapter.

SOURCES OF ELECTRICAL ENERGY

Batteries and generators are the two usual sources of electric current. A battery uses chemical energy to produce electrical energy that becomes usable when an external conductor is joined to the two pole pieces of the battery. Batteries are used to energize the small, self-contained electrical systems in flashlights, independent mines, some depth charges, and numerous testing devices. Larger batteries are used to operate electrically driven torpedoes. (See

chapter 13.) Very large installations are designed to furnish propulsive power for submarines. Batteries produce direct current only.

A GENERATOR uses mechanical energy (as from a steam or gasoline engine) to produce electrical energy by causing relative motion between an armature and a powerful magnetic field.

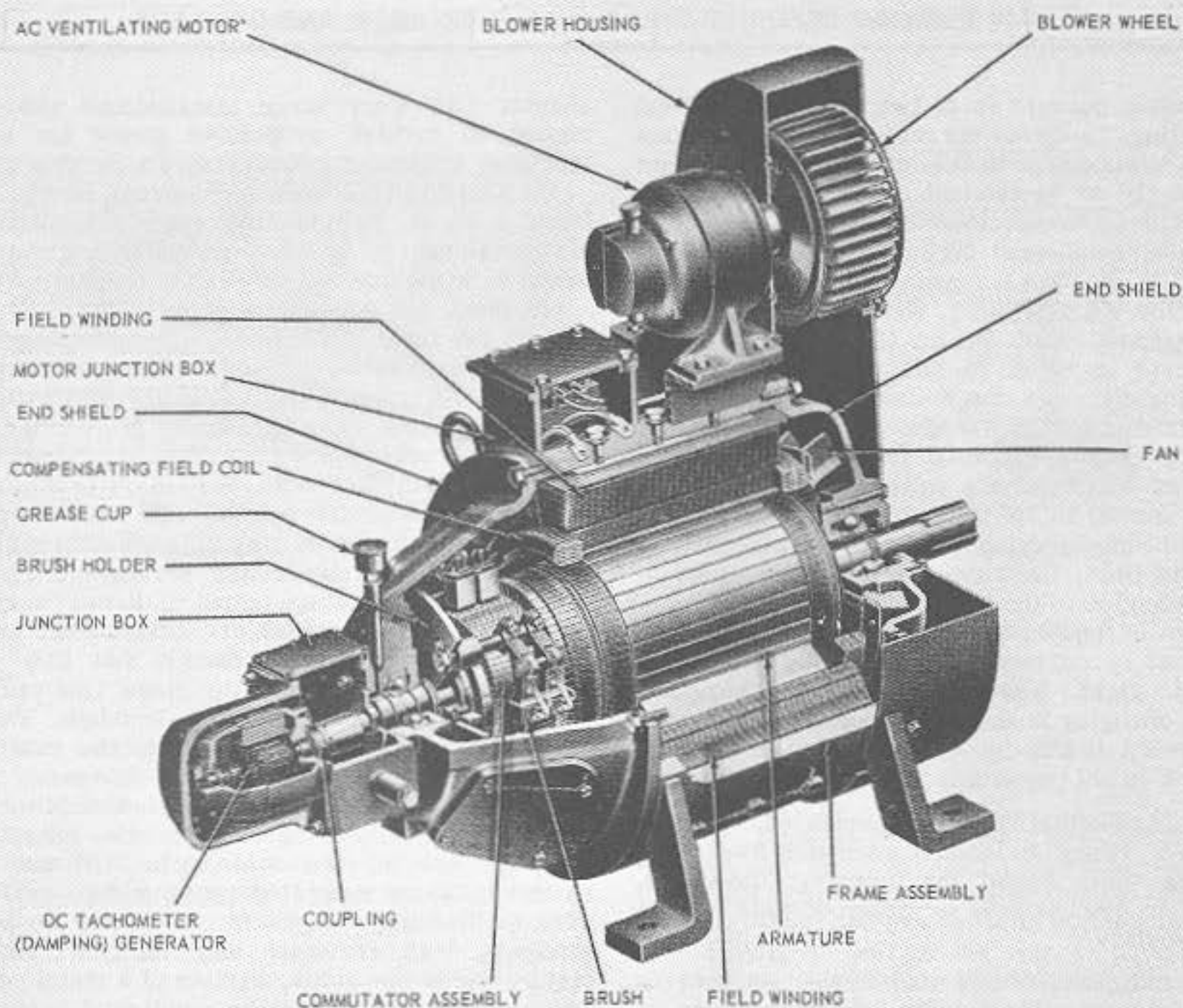
In most d-c generators the armature is the rotor, or turning member, and the magnetic field is furnished by the stator, or stationary member. Alternating current is always produced in the armature windings. In d-c generators the armature windings are connected to a commutator on the armature shaft. Stationary brushes on the stator contact the rotating commutator so as to receive electrons moving in one direction only. Thus the commutator-brush arrangement converts the a-c armature output to direct current.

Some a-c generators are constructed much like the d-c generator, except that they use solid annular insulated slip rings (instead of segmented commutators) and brushes. These directly transfer the a-c output to the external circuit. Larger a-c generators, however, use rotors with d-c excited electromagnets fed through brushes and slip rings, while the armature windings are in the stator. In still another variation, some special-purpose a-c generators have neither slip rings nor brushes; in these all windings, both armature and field, are in the stator, while the rotor consists of a metal core. The a-c damping generator mentioned below is of this kind of construction.

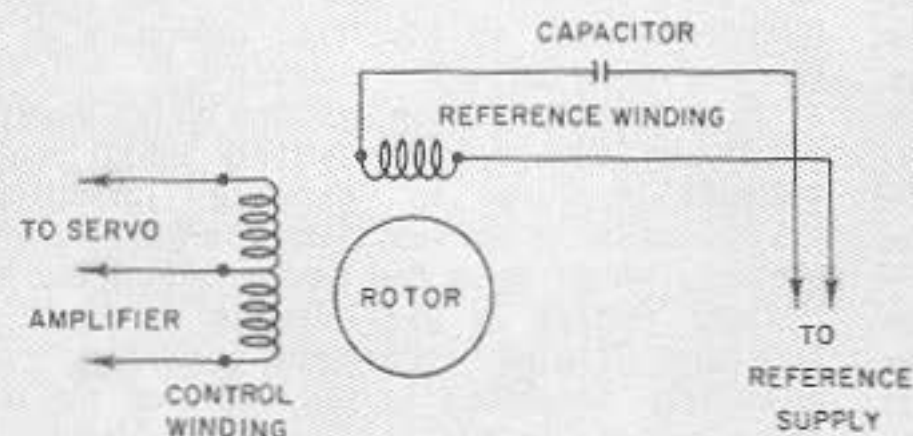
Figure 3-41, part A, shows the amplidyne train drive motor assembly on a 5-inch gun mount. The amplidyne system will be described in a later section, but this part of the figure is intended chiefly to illustrate examples of two types of motor and a d-c generator.

In general, ordnance systems do not generate electricity except for relatively small control voltages employed in "damping" (stabilizing) the operation of servosystems. In the amplidyne system, which is a d-c servosystem, the stabilizing voltage is generated by a small d-c generator (labeled "tachometer generator") mechanically connected to the shaft of the main drive motor. As you can see in the figure, the generator possesses the armature, field, commutator, and brushes mentioned above. In this illustration the tachometer generator is too small to show all these features clearly, but the student can inspect the corresponding features (which are similar in appearance and construction, though larger) in the main d-c drive motor.

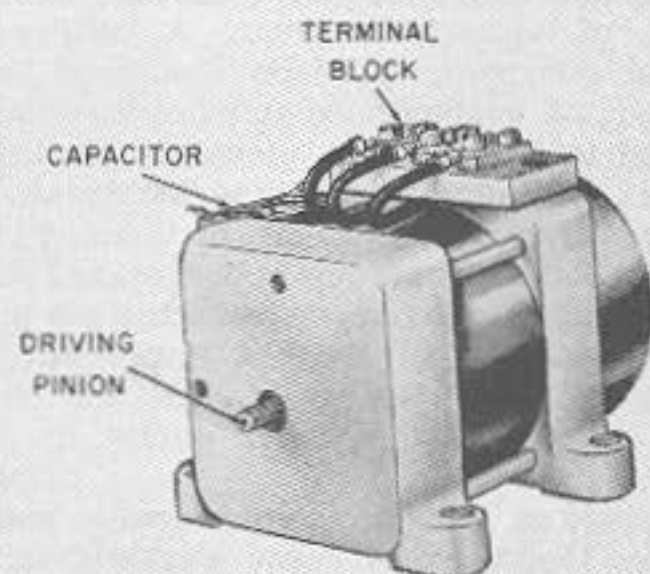
¹A piece of iron or other magnetic material may have its own permanent magnetic field independent of any electrical current. This phenomenon, as distinct from the magnetic field surrounding a current-carrying conductor, is discussed further in chapter 12 in connection with degaussing.



A



B



73.161

Figure 3-41. —Generators and motors. A. Ampidyne train motor assembly. (Note the d-c tachometer (damping) generator on the left and the a-c ventilating motor on the top of the assembly.) B. Typical small a-c instrument servo motor and its circuit diagram.

Small a-c damping generators (not illustrated) are used in some a-c servosystems. In external appearance as well as internal construction they resemble the servomotor illustrated in figure 3-41, part B; or they may be built on cylindrical rather than square-ended frames.

MOTORS

Structurally, motors in general resemble generators. A motor has a fixed stator and a rotor that can revolve. Instead of producing current, the motor receives current and uses it to energize its windings and produce torque. In nearly all types of motors, the torque normally causes the armature to revolve. In all large motors (i.e., larger than a fraction of a horsepower) locking or stalling the rotor so that it cannot turn when the motor is energized by its rated voltage will burn out either the motor or its current source, if not protected by fuses (and burnouts can often occur even with fuse protection, too). Some small specialized types of motors are designed to withstand locked-rotor currents. In one such type of motor, called a torque motor, the rotor can turn only a few degrees in normal operation; in other types it is expected that the rotor will stall for a time in normal service.

Motors used in ordnance gear always have the field winding in the stator; if there is an armature winding, it is in the rotor. With the rare exception of some machines that use permanent-magnet fields, d-c motors always have armature windings, commutators, brushes, and field windings. The main train drive motor shown in figure 3-41, part A, is a d-c motor with these components.

In all motors, the rotor is driven by the interaction between the magnetic fields produced by the stator and those produced by the rotor. In nearly all d-c motors and many a-c motors the interacting magnetic fields are produced by currents fed to the rotating armature windings and to the stationary field windings. In some a-c motors, however, currents are fed only to the field. The fluctuating magnetic fields produced by the a-c field currents induce other currents in the rotor; in turn, the induced rotor currents develop magnetic fields that interact with those of the field to develop motor torque. Motors that function on this principle are called INDUCTION MOTORS. The armature for such a motor may consist of a cage-like copper structure imbedded in a laminated soft iron core (these are

called "squirrel-cage" motors), or of an aluminum or copper cup surrounding an iron core. Large a-c induction motors may have rotors with coil windings (these are called "wound-rotor" induction motors).

There are, in contrast to the restricted number of fundamental types of electric generators, a great variety of types of electric motors (including a-c, d-c, and "universal" motors operating on either type of current), some of them quite different in principle from others. The types most frequently encountered in ordnance equipment are:

1. Polyphase a-c induction motors. These are the large motors, developing from 5 to over 100 horsepower, used to operate gun power drive electric-hydraulic and amplidyne systems, hoists, rammers, and the like. Figure 3-37 shows such a motor. As a class they are characterized by high starting torque and fairly constant speed under varying load.

2. Single-phase a-c induction motors. These have different characteristics from polyphase motors, but work on similar principles. They comprise the fractional horsepower motors used to operate small blowers, windshield wipers, etc. The blower motor in part A of figure 3-41 is an a-c single-phase squirrel-cage induction motor.

3. Synchronous a-c motors. (Not illustrated.) Synchronous motors can be very large (they have been used to drive ship's screws) but in ordnance equipment you will find only very small induction-type units designed to drive light loads, such as computing mechanisms, at absolutely unvarying speed. On most ships a special a-c constant-frequency supply is provided to drive such motors since they can hold a constant speed only in so far as the frequency of their a-c supply remains constant.

4. Servomotors. The function of the servomotor will be explained later in this section. Its important characteristics are that (1) it must be reversible when its input is reversed, (2) it must develop (for its rating) substantial starting torque, and (3) its output torque must be at least roughly commensurate with its electrical input. (These characteristics are by no means applicable to all types of electric motors.) Servomotors used in ordnance equipment are nearly always of either of two main types:

- a. A-c instrument servomotors. These are small fractional-horsepower induction motors powered by two inputs—(1) the ship's a-c power supply and (2) the output of the servoamplifier.

Figure 3-41, part B, illustrates one type of a-c servo motor and its circuit. The motor is always directly geared to the load, which may be a small indicator or computing mechanism component, a synchro, etc. (Synchros will be discussed later in this section.) It may also be geared to an a-c damping generator. Conventionally, the motor has two windings. One, the reference winding, is continuously energized by the ship's a-c supply (which is often called the REFERENCE VOLTAGE.) A capacitor is usually in this circuit. The other winding receives the amplifier output, which is an alternating current of the same frequency as the reference supply, but differs in phase from the current in the reference winding. This means that at any instant, it will differ in magnitude and often in polarity from the reference supply. In most servomotor circuits the capacitor functions to develop this phase difference. When only the reference supply is fed to the motor, its rotor (which has no winding but is only an aluminum or copper cup, shell, or cage secured to the output shaft) will not turn. When the amplifier puts out a current, the motor will develop a torque whose direction will depend on the phase relationship between the reference and amplified output currents. Since the power developed by a-c servomotors is quite small, the motor output may itself be used to control a hydraulic servo which develops greater power.

b. Direct current mount power drive motors. These motors are high-powered units used as described below in conjunction with amplidyne generators to drive gun mounts in train and elevation. The main drive motor shown in figure 3-41, part A, is of this type.

POWER TRANSMISSION

In a small electrical system, like that in a torpedo or mine, the power source, the transmission lines, and the simple or elaborate operating equipment must all be scaled down to fit a limited space. In an electrical system serving a city or a countryside, the power demands are heavy, and large-size components are necessary. Alternating current from huge generators may be transported for long distances over high-voltage lines. Transformer stations, making practical use of the principle of induction, convert the current and voltage to values safe for industrial and residential use.

Shipboard electrical systems occupy a position somewhere between these two extremes. The ship's main generators, connected to a

cable system through two or more switchboards supply current for many routine uses. The total power available must be great enough to meet the demands of varying conditions, including battle.

All possible safety precautions are observed. The cables pass through special packing glands between one ship unit and the next. Junctions and splices are made through special boxes and terminal boards. Tests are frequent and thorough.

Turrets and mounts have their own very elaborate wiring systems. Specific wiring systems are described in the NavOrd publications (C and OD) for the ordnance installations.

ALTERNATING CURRENT

In alternating current, as previously mentioned, the direction of electron movement reverses rapidly and repeatedly. Though still applicable, Ohm's law no longer deals with simple resistance as the single obstructive effect that limits current flow at a given voltage. In a-c circuits, specific types of circuit elements also have other obstructive effects on current flow and these effects vary with the a-c frequency. These effects are called CAPACITANCE and INDUCTANCE, and in any a-c circuit they must be taken into account along with resistance. These effects are not restricted to obstruction of current flow; as we previously noted in connection with the explanation of the capacitor in a-c servo motor operation, they can change the phase of one a-c voltage with respect to another.

In addition, there are still other ramifications to this subject. Though they are important, a detailed consideration of the functioning of electrically operated ordnance equipment, these aspects of a-c theory are beyond the scope of this course. Junior officers assigned to communications or fire control will find that the enlisted men specializing in these fields are well grounded in theory, as well as in its practical applications. The ordnance publications on specific items of equipment frequently cover those aspects of the theory that are assumed to be new in the reader's experience.

SYNCHROS

A synchro is an a-c energized device that looks like a small motor or generator, but is closer in operating principle to the transformer. All synchros have a wound rotor and a wound

stator, with slip rings and brushes to connect the rotor windings to the remainder of the system.

In terms of functioning principles, there are five types of synchro:

- Synchro transmitter
- Synchro receiver
- Synchro control transformer
- Synchro differential transmitter
- Synchro differential receiver

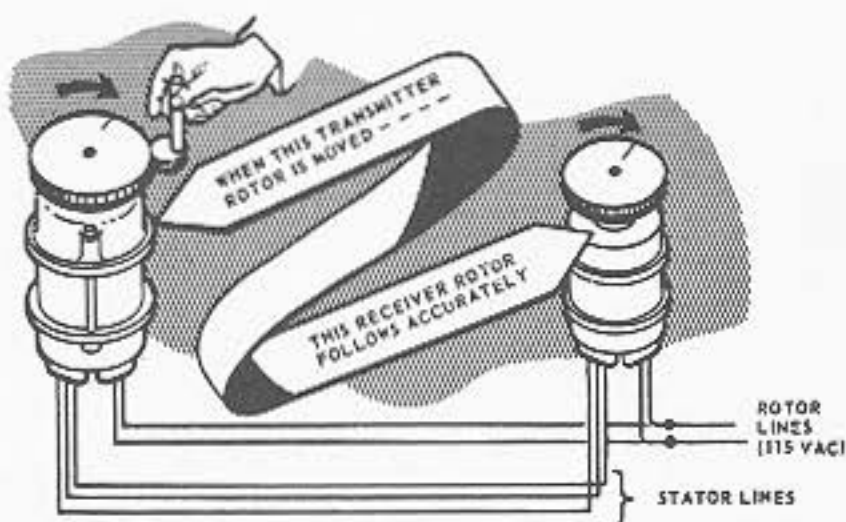
Any synchro system includes two or more of these units, one of which must be a synchro transmitter. Synchros are made in standard sizes and electrical characteristics, in two main varieties—one designed for operation at 60 Hz, the other variety designed for operation at 400 Hz. Principles of functioning apply regardless of difference in size and frequency rating. To understand these principles, we'll discuss first a system comprising a transmitter and a receiver, then go on to the other types.

SYNCHRO TRANSMITTERS AND SYNCHRO RECEIVERS. A synchro transmitter (also called a synchro generator) transmits an electrical signal that varies with the angle of rotation of its shaft. This signal goes through three conductors to a synchro receiver (also called a synchro motor). An additional pair of conductors furnishes excitation voltage from the a-c reference supply to both the receiver and the transmitter. See figure 3-42. The synchro receiver responds by causing its own shaft (if not too heavily loaded) to rotate through an angle corresponding to the signal. The two shafts turn through the same angle and in the same direction (for example, both 30° clockwise or both 15° counterclockwise, and so on). See figure 3-43.

The two drawings in figure 3-43 show how a transmitter or receiver (these are electrically similar) is constructed. The stator contains three evenly spaced, electrically connected coil windings. The centrally located rotor is also wound as a coil. The rotor winding is excited by the a-c reference supply.

When alternating current flows in the rotor, it creates a rapidly reversing magnetic field. This field induces currents in the stator coils; the stator currents produce fields whose total effect, or resultant, at any given instant, directly opposes the field of the rotor.

To form a conventional transmitter-receiver arrangement, two synchros are wired as shown in figure 3-44. Normally, however, the distance



12.156

Figure 3-42.—An elementary synchro system.

separating the synchros is much greater than the drawing indicates.

In their at-rest position, the two synchros are as shown in part A of the illustration. An input (through gearing or a handcrank) turns the rotor of the synchro transmitter as shown in part B. This upsets the balance of the magnetic fields throughout the system.

In restoring the system to magnetic balance, the electromagnetic forces acting on the synchro receiver turn its rotor to a position corresponding exactly to the position taken by the rotor of the transmitter. See part C of figure 3-44.

When the signal changes again, this sequence of events is repeated.

A synchro receiver of the type just described can be connected through shafting and gearing to turn a very light load, such as a dial. It is not powerful enough to turn a heavy load like a gun mount or a missile launcher. A special kind of synchro receiver called a control transformer can, however, act through a motor to turn a fairly heavy load.

SYNCHRO CONTROL TRANSFORMER. Like the basic synchro receiver, the control transformer receives an electrical input signal from a synchro transmitter. In the control transformer, however, the rotor is designed to produce an output voltage proportional to the incoming signal. After being amplified, as shown in figure 3-45, this output voltage drives a motor (called a servomotor) that operates a gearing system to turn the load.

SYNCHRO DIFFERENTIALS. Two types of synchros used in fire control are similar in

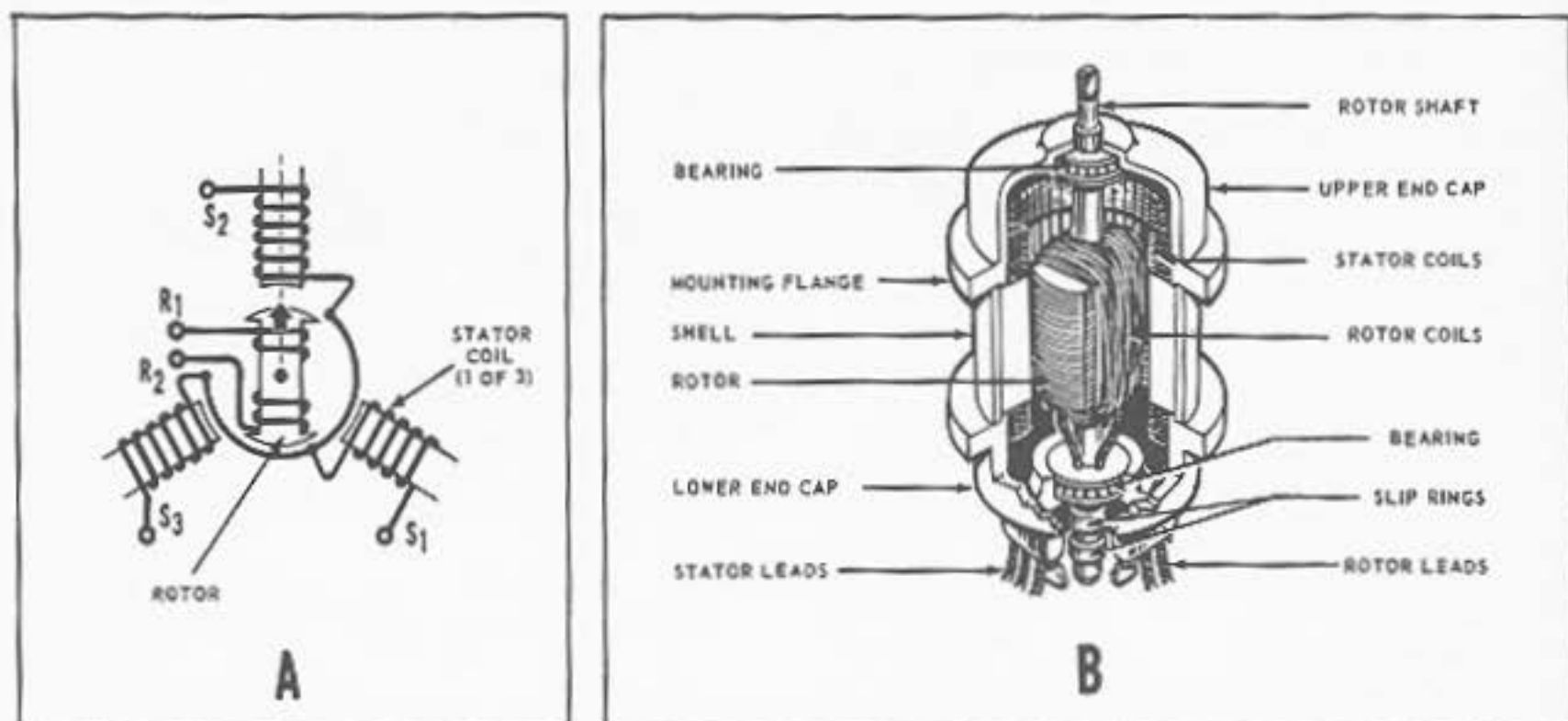
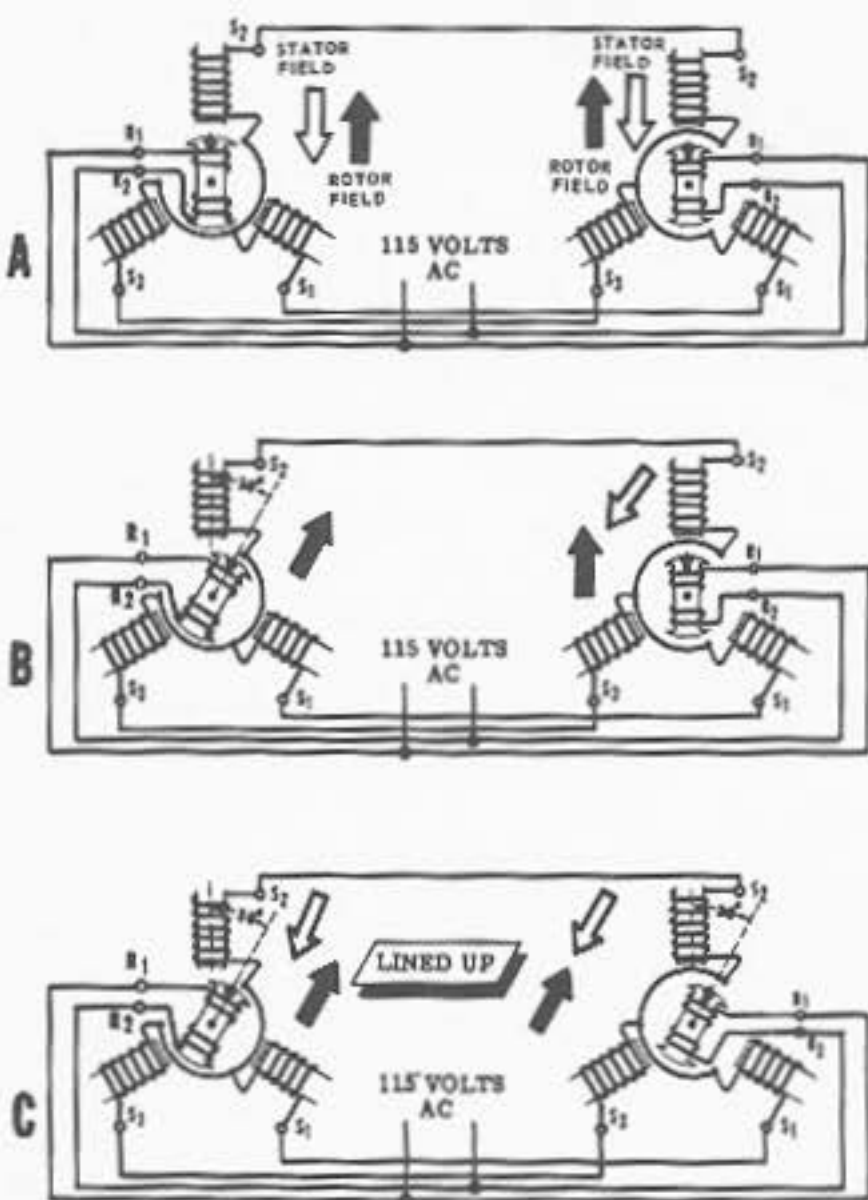


Figure 3-43.—Inside a synchro. A. Schematic drawing; B. Realistic drawing.

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12.170

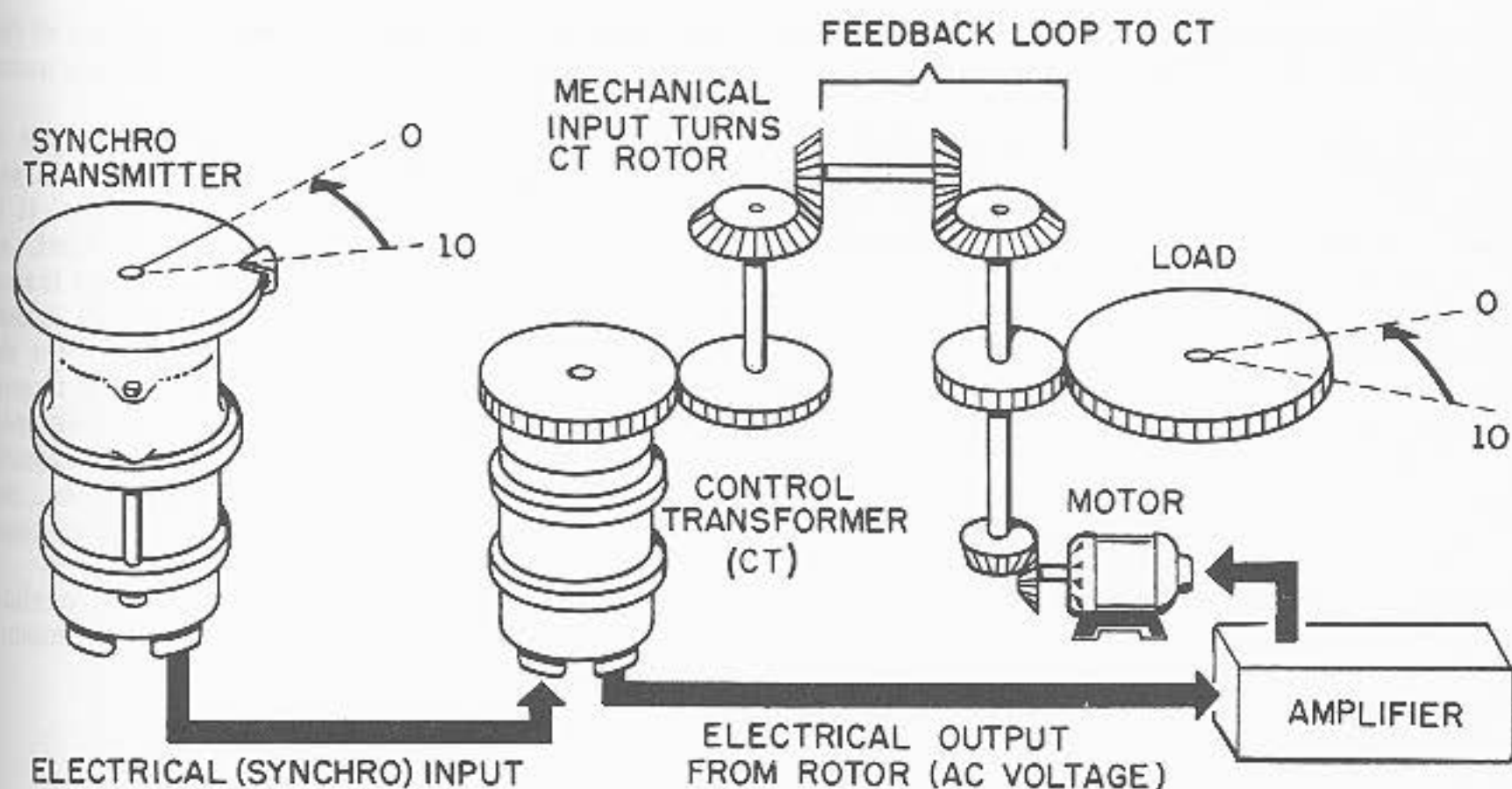
Figure 3-44.—A representative synchro system.

purpose to the mechanical differential that continuously adds or subtracts two changing inputs.

The synchro differential transmitter (also called a differential generator) receives two inputs: (1) a mechanical signal that turns its rotor and (2) an electrical signal that is fed into the stator windings. The output of this synchro is an electrical signal that exactly measures the sum (or, if wired for this purpose, the difference) of the two inputs.

The synchro differential receiver (also called a differential motor) combines two electrical signal inputs to produce a mechanical output. This output consists of a rotor torque or movement that accurately represents either the sum or the difference of the two inputs.

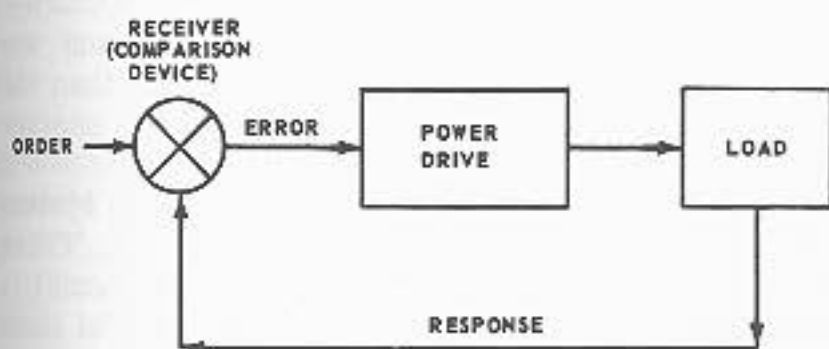
USING PAIRS OF SYNCHROS. The accuracy with which a synchro receiver or control transformer will duplicate the signal from the transmitter is on the order of a few minutes of arc difference between the signal as transmitted and the signal as received. In some applications, a few minutes' inaccuracy is not important, but in others it is. For high-precision applications, a pair of synchro transmitters is geared together in the ratio of 36:1, and is connected electrically to a pair of receivers or control transformers similarly geared together. In each pair, the unit that rotates more slowly is the low-speed or coarse unit; the other is the



12.157

Figure 3-45.—A-c instrument servomechanism. Pictorial functional schematic.

SERVOMECHANISMS



110.24

Figure 3-46.—Basic servosystem.

high-speed or fine unit. You can liken this arrangement to the hands of a clock, with the clock hands geared 36:1 rather than 12:1. The hour hand corresponds to the coarse or low-speed indicator, and the minute hand to the fine or high-speed indicator. When pairs of synchros are used, the coarse unit covers the full range with which the system deals, while the fine unit, which rotates a number of times for one rotation of the coarse unit, makes it possible to transmit with much better accuracy than would be possible with the coarse unit alone.

WHAT THEY ARE. Electrical arrangements that cause mechanical action to take place automatically in response to synchro signals are called followups or servomechanisms. A servomotor is one of the components of a followup.

A servomotor is a reversible motor that operates in a slave-to-master relationship with the synchro equipment from which it receives its input signals. There are both a-c and d-c types of servomotors. The one mentioned later in this chapter, in connection with amplidyne power drives, is a d-c type. Certain dials and mechanisms in computing equipment are turned by a-c types.

Figure 3-46 illustrates in a simplified schematic the elements of a servosystem. The functioning of such a system is described below with reference to how its principle is utilized in positioning a gun.

At a remote station, all available information about the target is collected and combined. To the gun mount is transmitted a pair of order signals telling, respectively, what values of train and elevation will put the gun in firing position. The gun has two power drive systems—one for train and one for elevation. One of these is shown in figure 3-46. Each system receives

its own order signal and performs, independently, the actions outlined below.

1. The order signal is compared with the actual position of the gun. The result of this comparison is a command (called the error signal) telling how far and in which direction the gun must move.

2. When properly amplified, the error signal operates the controls of a power drive.

3. The power drive moves the load in such a way as to reduce the error.

4. While the load is being driven, a response signal is sent back continuously and automatically for comparison with the order signal.

5. When the two error signals (train and elevation) have been reduced to zero, the gun is in the ordered position for firing.

A-C INSTRUMENT SERVOMECHANISM. Now consider how the servo principle is applied in a typical instrument servomechanism or "follow-up" using an a-c reference voltage. Compare figures 3-45 and 3-46. In figure 3-45 the parts in the mechanism corresponding to the diagram of figure 3-46 are a synchro control transformer which serves as the signal receiver and comparison device, an electronic amplifier and a-c servomotor which together correspond to the power drive, and gearing from the motor which drives the load and the synchro control transformer rotor. The amplifier may be of the tube, magnetic, or transistor type, or a combination. The load may be a dial, a computing device, a hydraulic valve, a synchro transmitter, etc. We omit a number of components used in many systems to improve the stability and response of the servo, such as damping generators, amplifier feedback and stabilizing circuits, discrimination circuits which automatically select the appropriate input signal, capacitors for improving electrical characteristics and for changing phase relationships, etc.

The input that starts the servomotor is the output voltage of the synchro control transformer. This voltage has to be amplified before it can be used. As the servomotor turns, in response to the input voltage, the rotor shaft furnishes a mechanical output to the gearing that turns the load.

The load in figure 3-45 is connected back, through gearing, to the rotor of the synchro control transformer. The result of this mechanical feedback is to drive the rotor in such a direction as to reduce the electrical output of the control transformer. When the load reaches

the position originally ordered, the output of the control transformer becomes zero, and the motor stops.

The example chosen is a common type of servomechanism, but many other varieties and combinations of components are possible. It is possible to use a mechanical differential, a electrical resolver, a synchro differential transformer, a special type of movable-core transformer, or any of several other devices for the error-sensing unit. The variety possible in amplifiers has already been hinted at, as well as in auxiliary circuits and devices. Several kinds of motors are available, and so on. But the servo principle underlies all these combinations.

Now let us consider larger and more elaborate servosystems used for a gun mount launcher, or fire control director.

AMPLIDYNE SERVOSYSTEMS

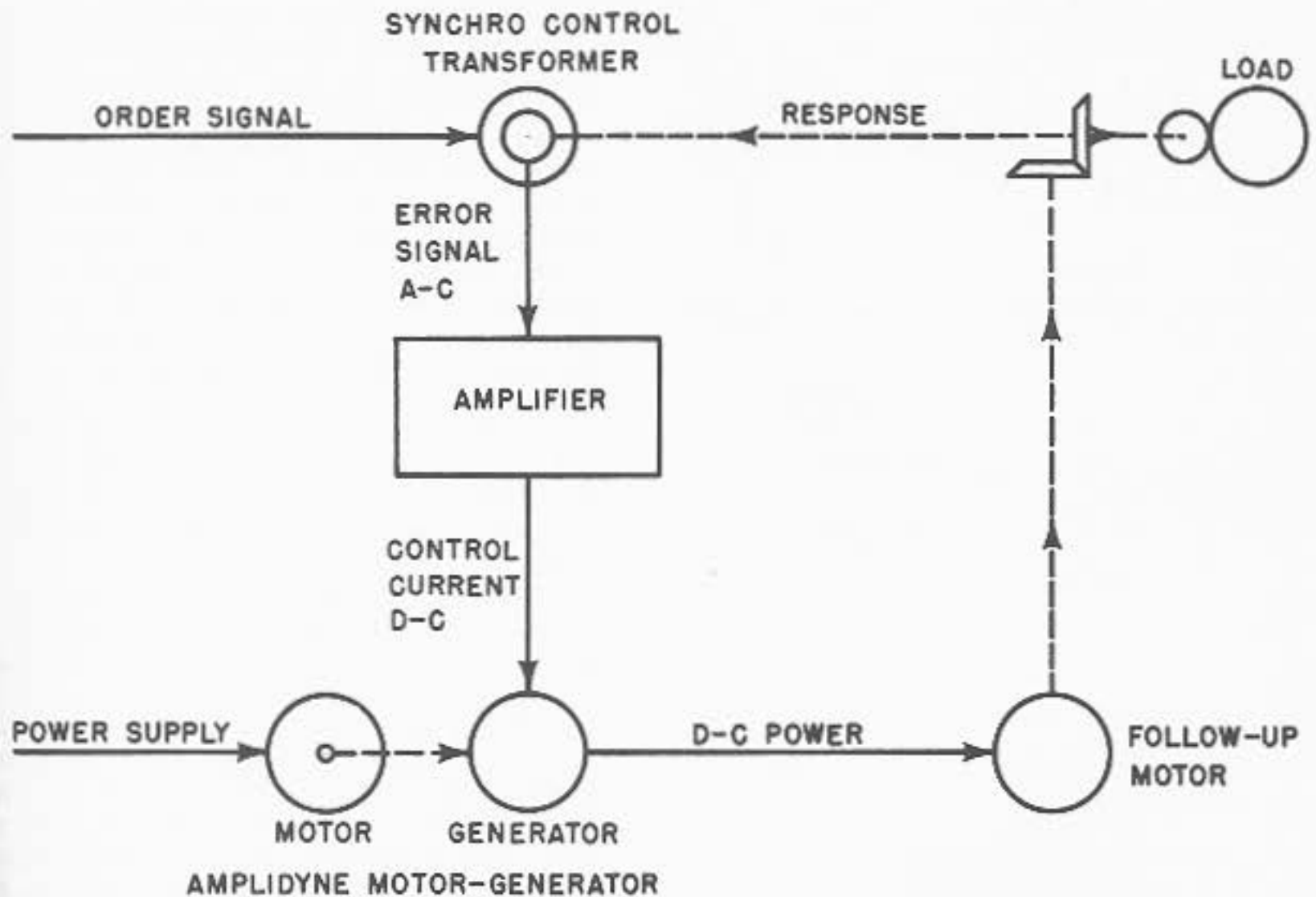
Heavy guns can be (and sometimes are) trained and elevated by direct handwheel action through the gearing system. Naturally this relatively slow and difficult method is not normally used in battle. But it is necessary for certain adjustment or maintenance operations.

For moderately light loads—such as 3-inch and smaller gun mounts and gun directors—amplidyne power drives are reliable and accurate. They are easier to maintain than the electric-hydraulic systems designed for heavier guns.

In figure 3-47 an amplidyne followup system has been reduced to its bare essentials. There are a pair of synchro control transformers (illustrated as a single unit for the sake of simplicity), an amplifier, an amplidyne motor-generator, and a followup d-c servomotor.

In the synchro control transformer the input to the stator is an order signal from a remote synchro transmitter. The position of the rotor represents the response of the load. The output of the synchro control transformer is the a-c error signal. Actually, two synchro control transformers—a coarse and a fine one—are used. When the gun is within 3° of its ordered position, the fine synchro is automatically connected to control the system instead of the coarse one.

The control amplifier uses gas-filled electron tubes (called thyatron) for two purposes. First it rectifies the a-c input; that is, it converts this input to a d-c output whose magnitude and direction measure the amount and direction of error. Second, it amplifies the signal and



110.25

Figure 3-47.— Essentials of an amplidyne followup system.

produces two d-c outputs that are fed to the control field windings in the amplidyne generator, as explained in the paragraphs following.

The amplidyne generator is a special adaptation of one type of ordinary commercial d-c generator. Such a generator has a wire-wound rotor that turns within the field of an electromagnet on the stator. The upper part of figure 3-48 shows a conventionally connected d-c field schematic. Excitation power to the field is 100 watts d-c to produce field FC. The arrow shows the direction of this field.

The larger circle between the two poles represents the rotating armature, which is driven at constant speed by a motor (not illustrated). Rotation in field FC induces an a-c voltage in the armature winding.

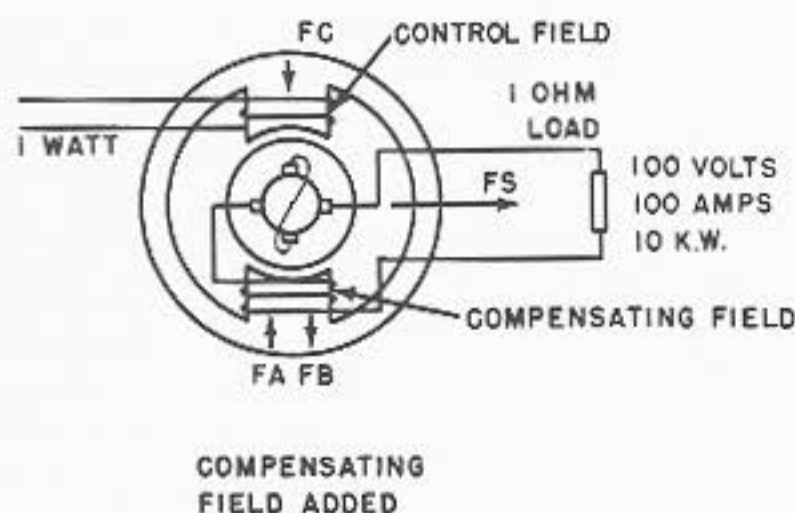
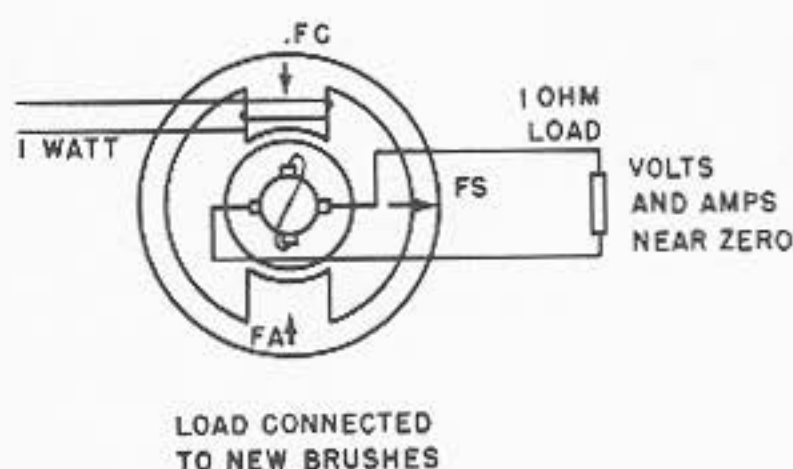
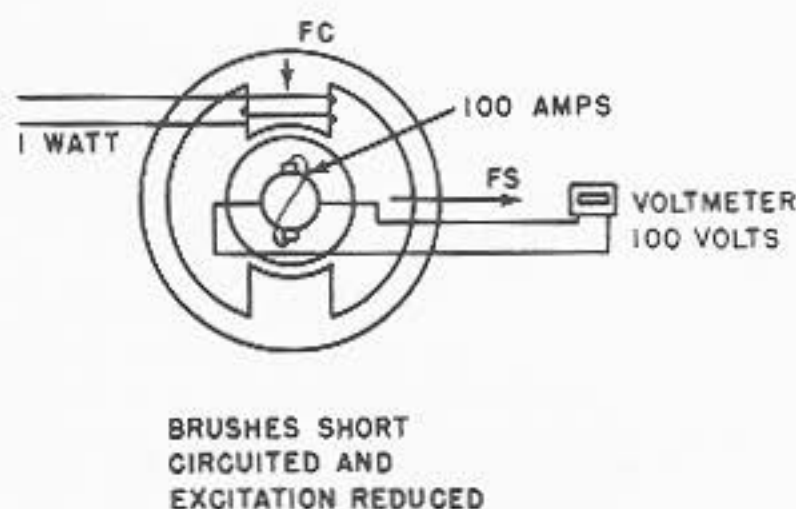
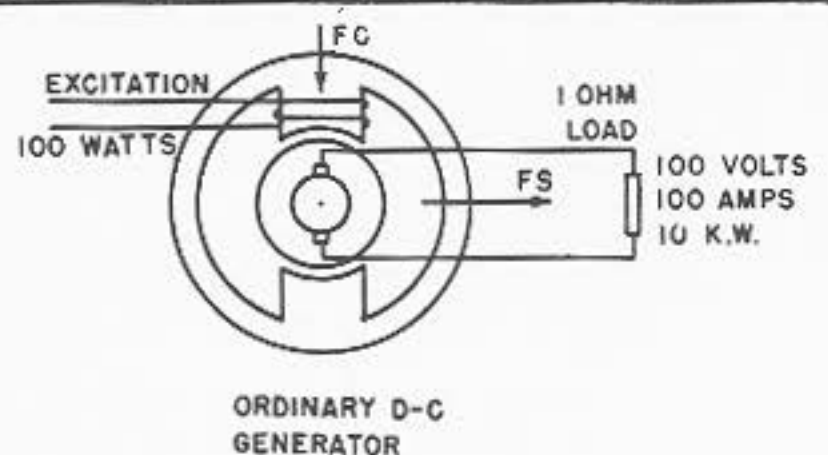
The inner circle in figure 3-48 represents the commutator. In the conventional d-c generator, the commutator connects the armature output to an external d-c load circuit by contact with a pair of stationary carbon brushes, 180° apart. The generated (or load) current as it

passes through the armature winding creates its own magnetic field, FS. This field, called armature reaction, serves no useful purpose; indeed, it is a nuisance.

Normally, other things being equal, the power output of the generator will be proportional to the excitation power. This generator is assumed to be a 10-kw machine (10,000 watts output), and the excitation required is about 100 watts. The "amplification," therefore, is 100 to 1.

The first step in transforming this ordinary d-c generator into an amplidyne generator is to short-circuit the two brushes as shown in the second part of figure 3-48. Now an immense armature current will flow, but if excitation is cut down to about 1 watt, FC is reduced, and 100 amperes again flow through the armature, producing the same armature reaction FS as before.

The next step is to add a second pair of brushes at right angles to the short-circuited pair, and to connect the load circuit over these brushes, as shown in the third part of the figure.



Now, however, the output voltage becomes very low, because the new output circuit has created its own armature reaction, FA, which opposes FC and greatly reduces its effect.

Now put a compensating winding, so connected that armature current passes through it, on the second pole of the electromagnet, as in the final part of the figure. This winding produces field FB to nullify FA thereby allowing FC to become fully effective again. The ordinary d-c generator has now become a basic amplidyne generator in which full-load output is developed with 1 watt excitation ("amplification" of 10,000 to 1). Thus it can operate on very low excitation (e.g., the output of the amplifier in figure 3-47) and still furnish enough power to drive a large servomotor (the followup motor in figure 3-47).

The amplidyne generator must control the direction of its followup motor's rotation, as well as its torque. To accomplish this, the amplidyne generator has two control fields instead of the one shown in the last part of figure 3-48. One of these is wound in the opposite direction to the other. The direction of FC and of generator output depend on which receives more current from the amplifier. If the amplifier supplies equal currents to both control windings, generator output is zero and the followup motor stands still. When control winding currents differ, the followup motor will develop a torque whose direction depends on which current is greater, and whose magnitude depends on the amount of the difference.

The followup motor operates in a slave-to-master relationship with the amplidyne generator. Under a given load, its speed and direction of turning depend on the amount and direction of its d-c input from the generator. Its output is mechanical power to drive the load in the right direction until the error signal has been reduced to zero.

ELECTRIC-HYDRAULIC SERVOSYSTEMS

The electric-hydraulic power drive has been developed to perform heavy gun laying reliably and rapidly. Previous portions of the chapter have taken up the components of electric-hydraulic power drives. What remains to be done is to show how the several types of components work together in a unified system. These paragraphs will not go into fine details, but will limit themselves to summarizing major functions.

Figure 3-48.—The development of an amplidyne generator.

The order signals to an electric-hydraulic system normally originate at a remote station. They enter through a complex unit sometimes called an indicator-receiver-regulator, but more often shortened to indicator-regulator. This unit contains synchros and related devices for (1) receiving the order signal and the response, (2) computing the error signal, (3) amplifying the error signal, and (4) transmitting this signal to the hydraulic system through an arrangement of valves and pistons.

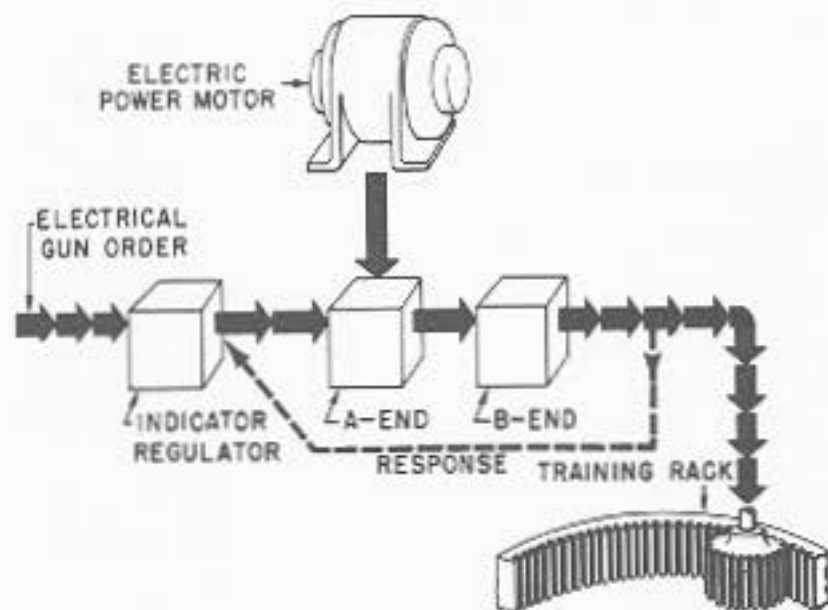
Figure 3-37 has already shown a typical gun mount electric-hydraulic power drive. The student should now be able to see how the various units—whether mechanical, hydraulic, or electric in nature—work together.

A conventional a-c electric polyphase induction power motor, connected to the ship's regular power supply, through a system of reduction gears drives the hydraulic pump (A-end) at virtually constant speed, regardless of A-end output.

The output of the A-end is hydraulic pressure to drive the B-end. The output of the B-end is mechanical action through a shaft and pinion. The input the B-end receives from the A-end determines the direction and duration of its output. In turn, the direction and amount of motion in train or elevation depend on the output of the B-end to the gun's gearing system.

To meet varying conditions, a gun mount's electric-hydraulic system allows a choice of several methods of control. Ordinarily the responsible officer or petty officer selects the most completely mechanized method that will work. The four methods of control that may be applied to a representative medium-caliber gun mount, the 5"/38, are designated as AUTO (automatic), LOCAL, HAND, and MANUAL.

Figure 3-49 shows the sequence of operations when the mount is trained in AUTO. (The train drive is illustrated, but the same principles apply to the elevation drive.) The gun order signal from a remote source enters the indicator-regulator. There the order signal is compared with the response, and the error signal is generated and amplified. The amplified error signal positions the A-end socket ring, thus regulating A-end output. A-end output drives the B-end, which drives the training pinion and rack. Mechanical response from the gearing is an input to the indicator, where with the order signal it helps to generate the error signal. As gun position approaches synchronism with the



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Figure 3-49.—A train power drive in automatic control.

gun order signal, the error signal decreases, becoming zero or null when gun position equals gun order.

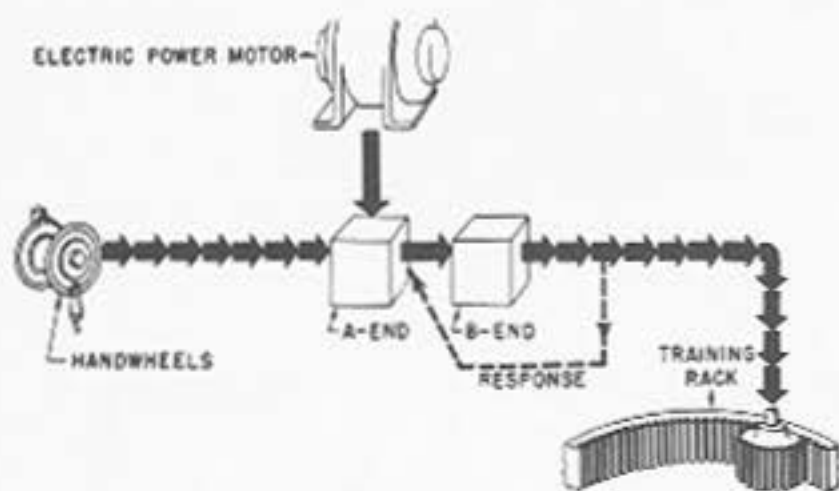
In LOCAL control the trainer's handwheels, rather than a remote source, transmit the order signal to the indicator-regulator. As before, the indicator-regulator compares the order signal with the response and transmits the error signal to the A-end. From that point on, as shown in figure 3-50, the sequence of operations is the same as in AUTO control.

In HAND control (not available in all mounts) the trainer bypasses the indicator-regulator completely. The handwheels are geared to a mechanical followup on the A-end control unit, which still receives power from the electric motor. In response to the handwheels, the A-end operates the B-end until the trainer's dial system (or, alternatively, his optical equipment) assures him that the gun is at the ordered position. Figure 3-51 shows this sequence.

The fourth method, MANUAL control, is used chiefly to train the mount when repairs, alterations, or adjustments, are in progress. In this method the handwheels are geared directly to the training rack, bypassing the entire electric-hydraulic system.

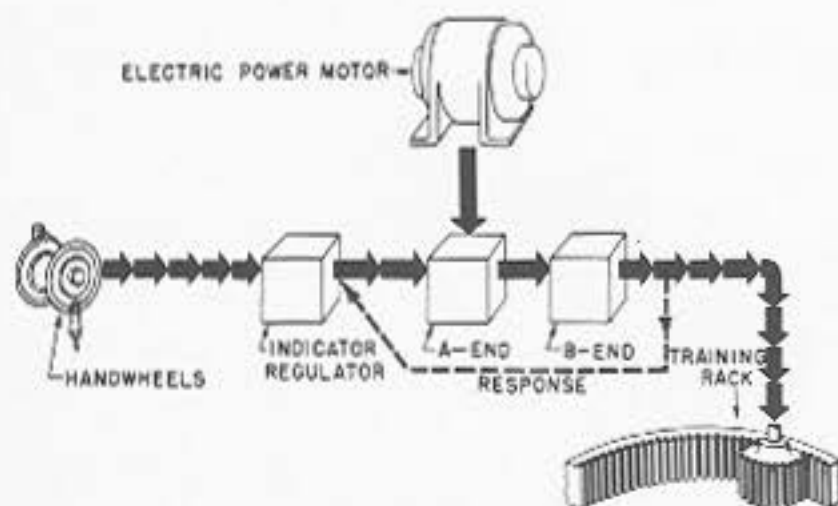
OTHER CONTROL SYSTEMS

The foregoing examples of amplidyne and electric-hydraulic control systems have been taken from gunnery. Guns, however, are far



110.28

Figure 3-50.—A train power drive in local control.



110.29

Figure 3-51.—A train power drive in hand control.

from being the only military equipment that must be moved smoothly, rapidly, and accurately in response to incoming signals. Missile launchers and certain types of projectors have control arrangements similar, in many features, to those used with conventional guns. By their nature, systems designed to launch guided missiles must be capable of operating even more swiftly, accurately, and dependably than any except the newest gun systems. As in conventional guns, the designer's choice of amplidyne or electric-hydraulic drives is governed largely by the weight and other physical features of the given system.

Many types of lightweight equipment, both in the field of ordnance and outside it, contain electronic amplifier-rectifiers, synchros, servomotors, and simple or elaborate computing devices. Naturally this chapter cannot take up these types of equipment one by one. A reader

who understands the basic mechanisms used in gun fire control, however, should have little trouble in following an instructional pamphlet that tells how similar mechanisms are designed to set a fuze, to train an antenna, or to steer a ship.

BASIC PRINCIPLES AND APPLICATIONS OF ELECTRONICS

All principles that apply to electricity also apply to electronics. Electrical principles are concerned mainly with d-c voltages and a-c voltages with frequencies of 400 hertz and below. Electronics deals with voltages of all frequencies and with devices involving the emission, behavior, and effects of electrons in vacuum tubes, gases, and semiconductors. Technically speaking, electronics extends into many occupational fields. In ordnance some of the places where electronic principles are used are in gun, torpedo, and missile fire control systems and sonar sets. Radars use numerous electronic circuits. Although most circuits are too complex to discuss in this text, some basic electronic circuits and devices (both analog and digital) are discussed here.

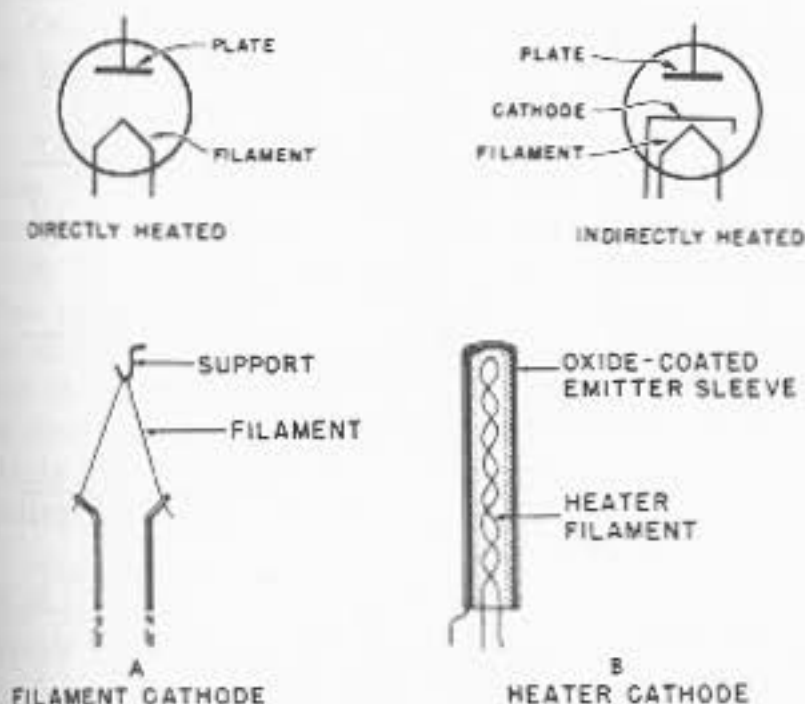
ELECTRON TUBES

An electron tube is an airtight envelope in which the conduction of electrons takes place. Electron tubes are classified as vacuum or gas-filled. The vacuum tube's envelope is a highly evacuated glass or metal shell, which encloses two or more elements (electrodes). The gas-filled tube contains a specific gas—usually nitrogen, neon, argon, or mercury vapor—and normally has two or three elements.

Vacuum tubes are used more widely than gas-filled tubes. There are many types of electron tubes, each of which can be made to perform many functions. Some applications are converting a-c voltage to d-c voltage (rectification), amplifying weak signals, and generating frequencies that are much higher than those that can be produced by conventional a-c generators.

Vacuum Tubes

All vacuum tubes have at least a cathode, an anode (plate), and a cathode heater (filament). In most applications, the filament is separate from the cathode, but in some cases the filament and cathode are common as shown in figure 3-52.



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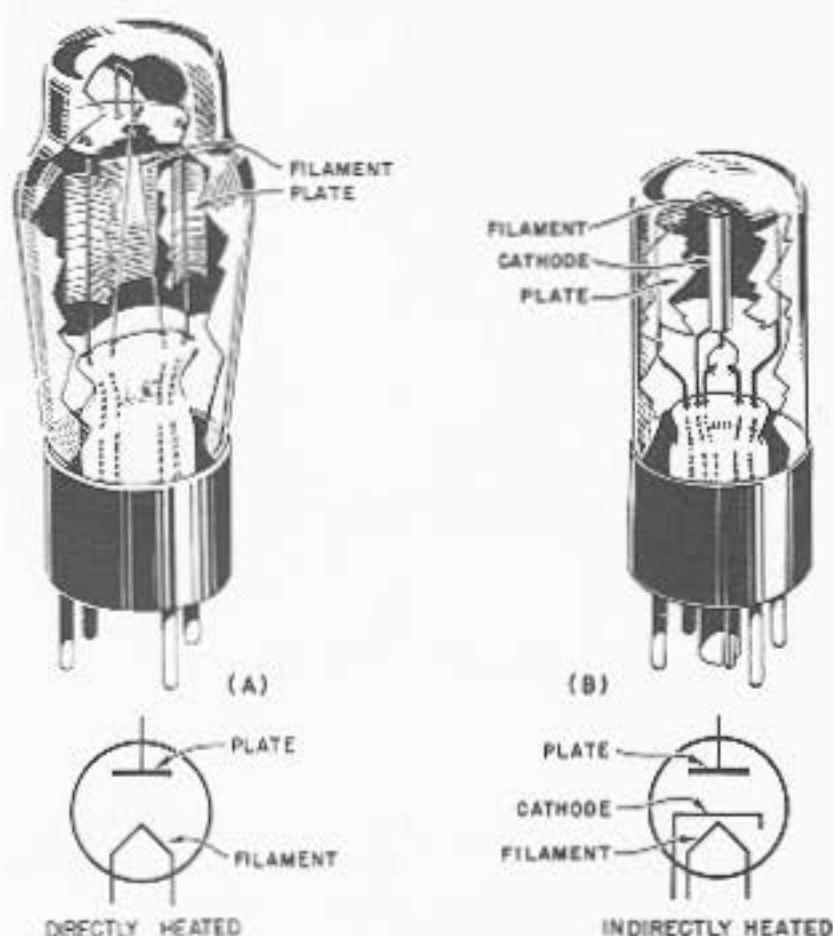
Figure 3-52.—Methods of heating the cathodes of electron tubes.

DIODE.—The simplest vacuum tube is the diode (fig. 3-53). As its name implies, it has two elements—the cathode and the plate. The filament serves only as a heater for the cathode and is not considered to be an element. One version of the diode is shown in figure 3-53A; another version is shown in figure 3-53B. The diode in figure 3-53A has a directly heated cathode, and the one in figure 3-53B has an indirectly heated cathode.

In an electronic circuit the two electrodes of a diode act in the same manner as a flow valve in a water pipe. (The British refer to the electron tube as a valve instead of a tube.)

The operation of a diode is best illustrated by connecting the plate and cathode in series with batteries and a milliammeter as shown in figure 3-54. First the cathode is brought up to normal operating temperature by applying the rated voltage across the heater terminals. If the battery is connected so that the plate is positive in respect to the cathode (fig. 3-54A), the meter will indicate current flow. If the battery is reconnected so that the plate is negative in respect to the cathode (fig. 3-54B), the meter will indicate no current flow.

As long as the plate remains negative in respect to the cathode, no plate current will flow in the circuit, although the cathode is emitting electrons. Whether the tube is conducting or not, at a given heater temperature, the number of



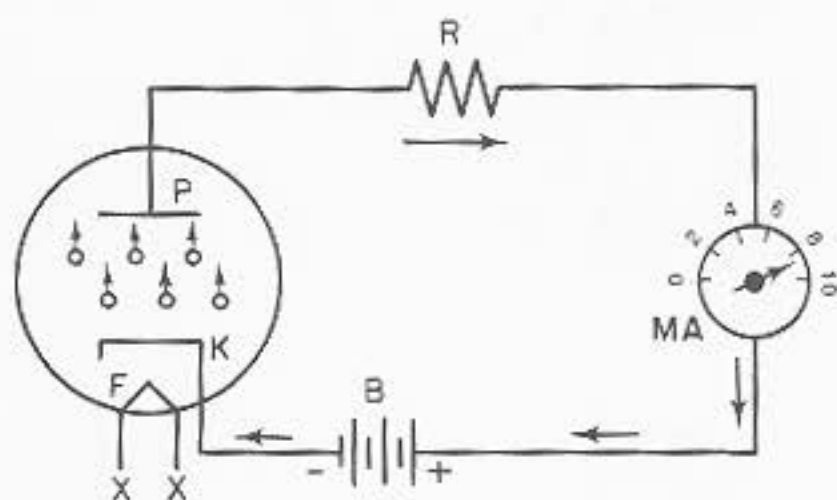
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Figure 3-53.—Cutaway of 2-element tubes.

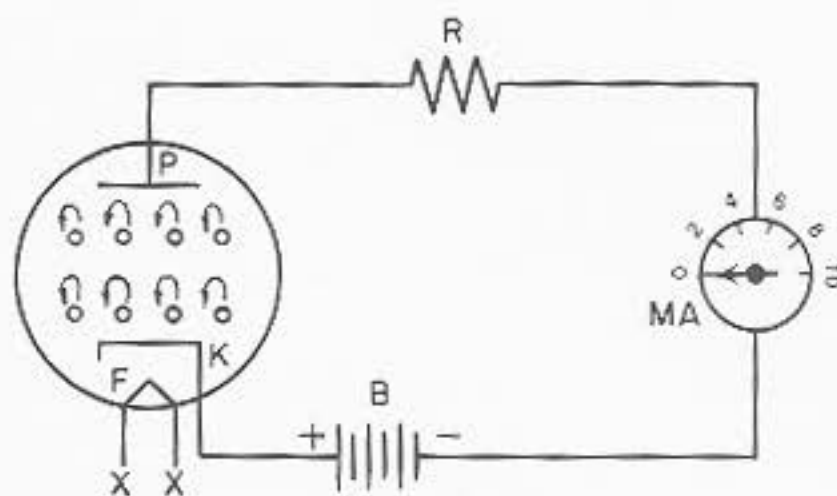
electrons emitted by the cathode remains constant regardless of the plate voltage (assuming that the tube is operating within its designed limits, of course). The total number of electrons attracted to the plate (thus plate current) depends on the relationship of plate voltage to cathode voltage. As plate voltage becomes more positive in respect to the cathode voltage, plate current flow increases until saturation (maximum current flow) is reached. As it becomes less positive, plate current flow decreases until the tube's cutoff (no current flow) point is reached. (Cutoff is reached when the plate voltage goes negative in respect to the cathode voltage.)

Because current can flow in only one direction through a diode its basic use is as a rectifier. If the battery in figure 3-54 is replaced with an a-c voltage source, current will flow through load resistor R only on alternate half-cycles—when the plate is positive with respect to the cathode. The rectified output is half-wave pulsating d-c voltage (fig. 3-55).

By modifying the circuit as shown in figure 3-56, full-wave rectification (and twice the average d-c voltage output) can be obtained. In this application, on one alternation V_1 conducts



A
PLATE POSITIVE



B
PLATE NEGATIVE

20.1

Figure 3-54.—Action of diode.

(passes current) up through R while V_2 is cutoff. On the next alternation V_2 conducts up through R while V_1 is cutoff. This type circuit rectifies both the negative and positive alternations of a cycle of a-c voltage.

With the addition of a filter circuit, comprising energy-storing devices (capacitors) and devices that resist changes in current (coils), either the half-wave rectifier or the full-wave rectifier may be used as a d-c power supply for various ordnance equipments. The type of power supply filter circuit used depends on the requirements of the circuit. Some equipments require smooth d-c voltage whereas others do not. Some equipments require large amounts of current, but

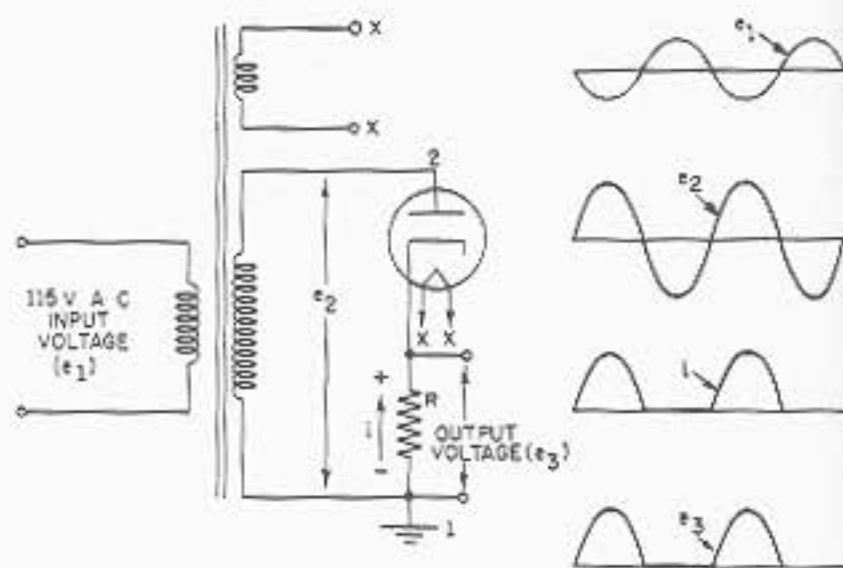


Figure 3-55.—Simple half-wave rectifier circuit and waveforms.

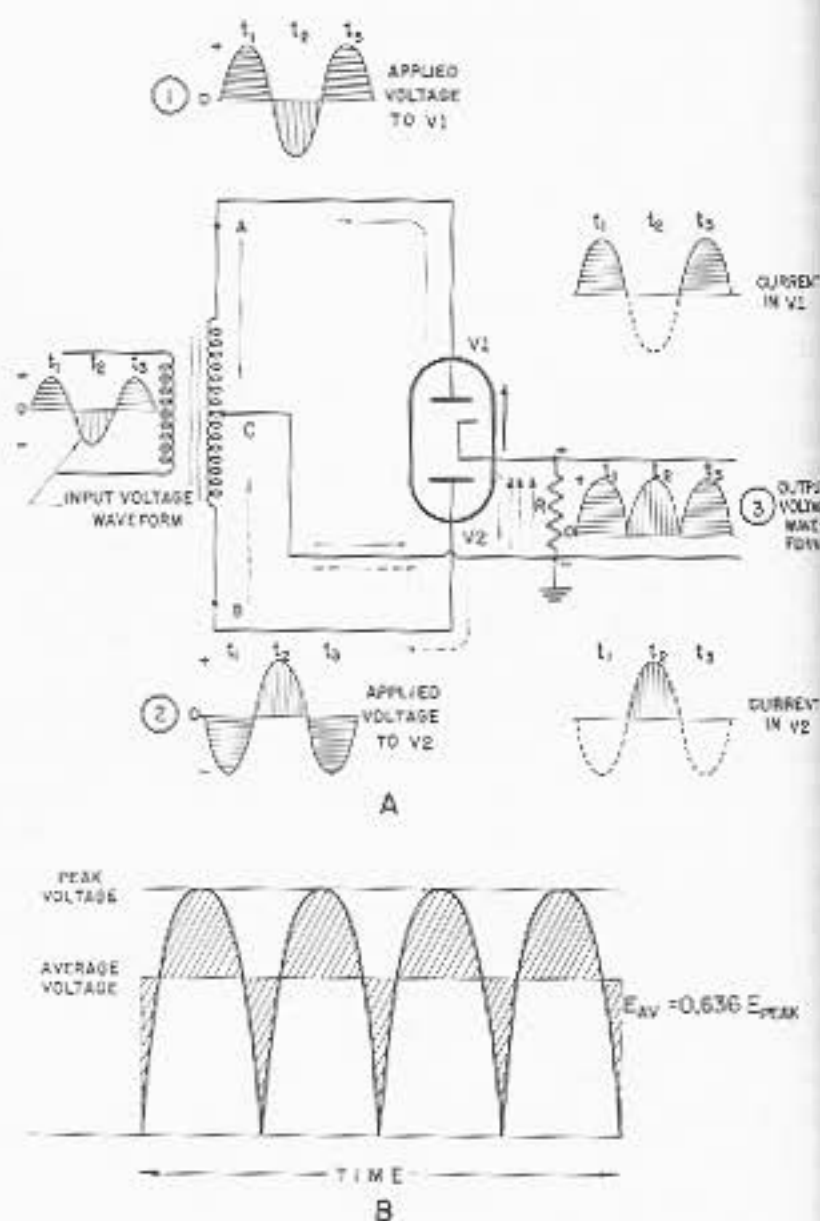


Figure 3-56.—Simple full-wave circuit and waveforms.

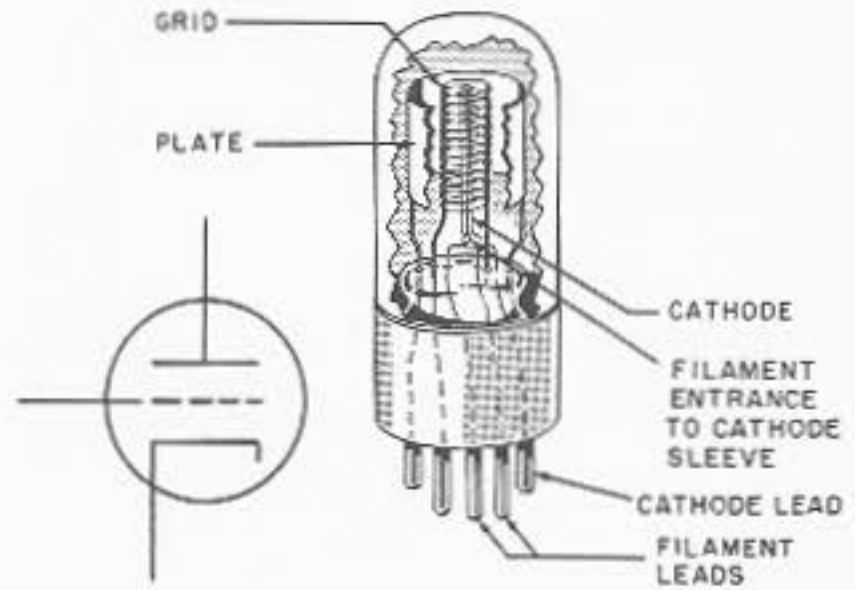
others do not. An example of a full-wave rectifier and filter is shown in figure 3-57.

Other applications of the diode are discussed in Basic Electronics, NavPers 10087 series.

TRIODE.—The triode, a 3-element electron tube, is similar in construction to the diode, except that a grid of fine mesh wire (the control grid) is added between the cathode and the plate. The space between the meshes is large enough to allow electrons to flow from cathode to plate. But the space is sufficiently small and the grid is close enough to the cathode to control effectively the flow of plate current when the proper voltage is applied between the cathode and grid.

The schematic representation and construction features of a typical triode are shown in figure 3-58. Electrical connections to the electrodes are made through wires to the base pins. The cathode sleeve surrounds the filament, and is insulated from it. The control grid is placed closer to the cathode than to the plate.

Although they have other uses, triodes are used mainly as amplifiers. Plate current in a

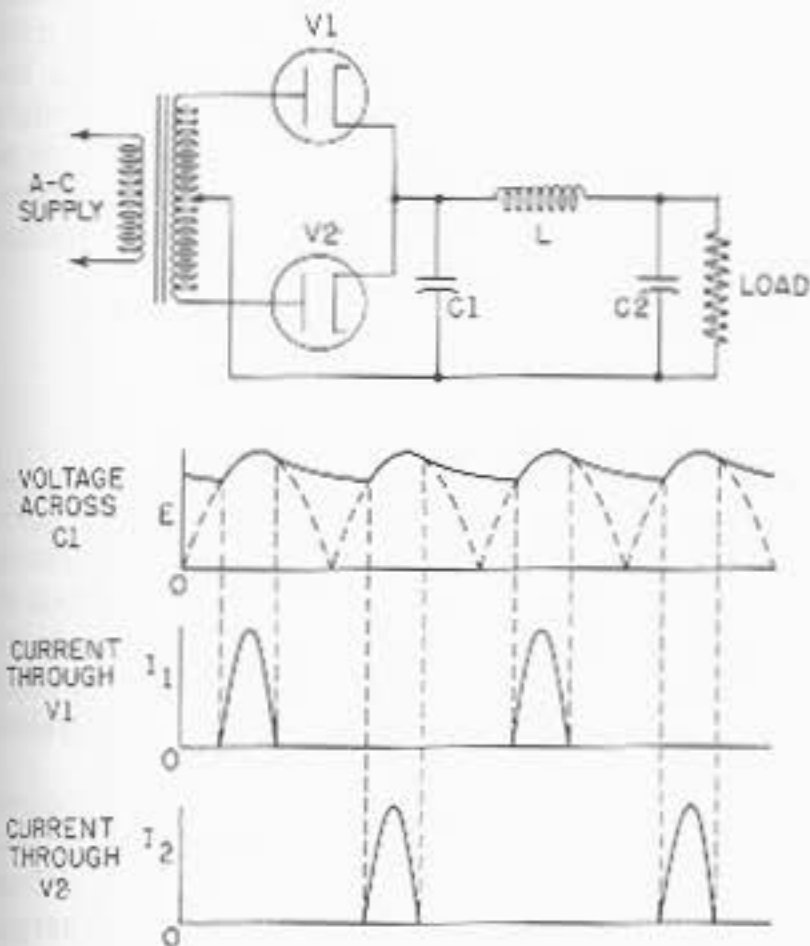


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Figure 3-58.—Cutaway and schematic of a triode tube.

triode amplifier is controlled by the grid-to-cathode voltage—whether a-c or d-c. A small change in grid voltage produces a relatively large change in plate current. This grid voltage can be either the a-c signal voltage or the negative d-c voltage referred to as the bias and applied between the control grid and cathode. Figure 3-59 illustrates the effect on plate current of making the control grid voltage progressively less negative with respect to the cathode. When the negative bias is high (cutoff or above), as in figure 3-59A, no plate current flows, because the negative charge on the control grid is sufficient to repel the electron back to the cathode. As the bias is reduced (fig. 3-59B), current begins to flow, and with zero bias (fig. 3-59C) current flow is maximum. The grid may be considered an electronic control valve that regulates the flow of electrons through the tube and through the load in the plate circuit. Thus an a-c signal added to (or subtracted from) the grid bias causes the plate load current (i_p)—and, therefore, the plate voltage (e_p)—to vary in the same manner (fig. 3-60). This is true, of course, only as long as the input signal is small enough that it does not cause the tube to saturate or cutoff. The relatively large variations in plate current and plate voltage, which constitute the output signal, are caused by small variation in the input signal to the control grid. Thus the control grid signal is said to be amplified in the plate circuit.

In all triode amplifiers the plate voltage (and current) does not vary in the same manner as



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Figure 3-57.—Waveforms of current and voltage in rectifier with pi-section filter.

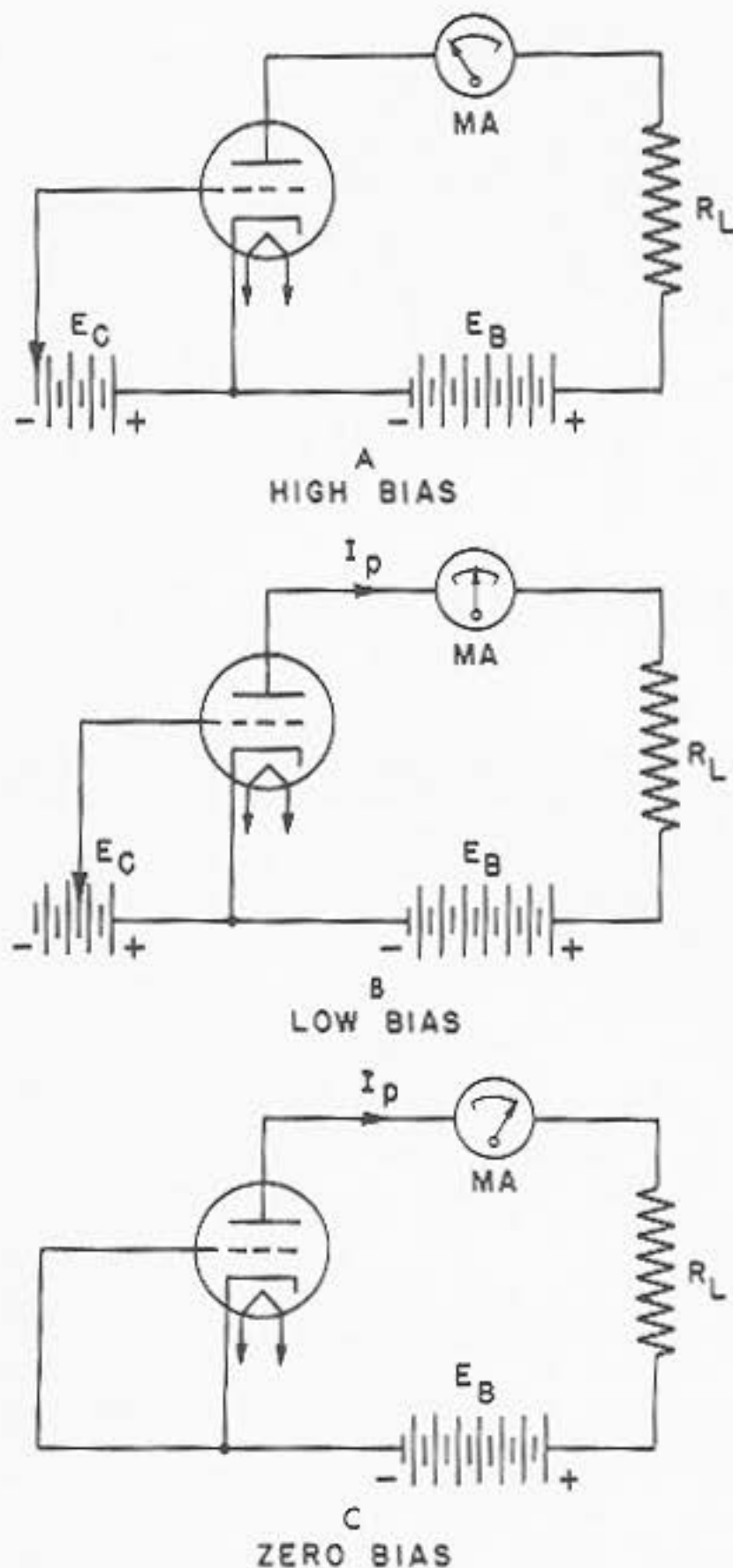


Figure 3-59.—Effect of control-grid voltage on plate current.

the signal applied to the grid. If the applied grid signal voltage and bias voltage are negative enough to prevent plate current flow, the output voltage will not vary in the same manner as the input voltage. The same will be true if a combina-

tion of the voltages causes maximum current flow (saturation) in the plate circuit.

At high frequencies the triode is limited as an amplifier, because of certain undesirable characteristics appearing at high frequencies. This characteristic causes the a-c resistance (reactance) between the elements of the tube to decrease as the frequency increases. After the frequency has increased sufficiently to make the interelectrode reactance small or near zero, the tube is no longer useful as an amplifier. This effect is similar to connecting the elements together with wire. To overcome this undesirable effect, special multi-element electron tubes were developed for use at frequencies of 100 megahertz (MHz) and above.

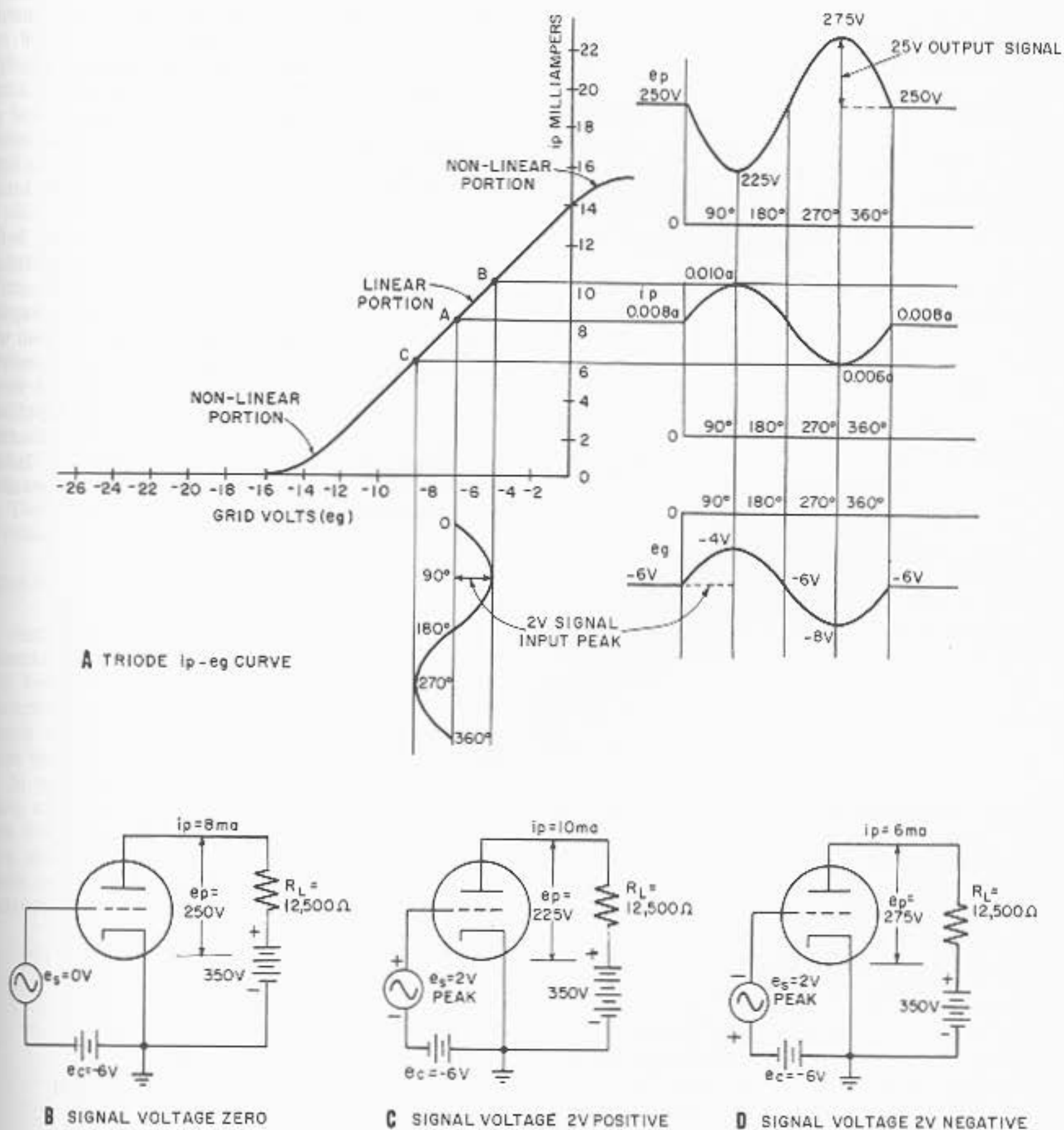
MULTI-ELEMENT TUBES.—Many desirable characteristics may be attained in electron tubes by using more than one grid. Some common types of multi-element tubes include tetrodes, which contain four electrodes, and pentodes, which contain five electrodes. Other tubes containing as many as eight electrodes are used for certain applications. Schematic representations of the tetrode and pentode are shown in figure 3-61.

Other tubes including diodes and triodes are constructed especially for high frequency operation. The tubes have very small electrodes placed close together, thus decreasing the interelectrode capacitance (which increases the reactance between the electrodes) without affecting the tube's amplifying ability. These tubes (referred to as acorn tubes) are very small physically and are not used extensively because of their limited power-handling capability.

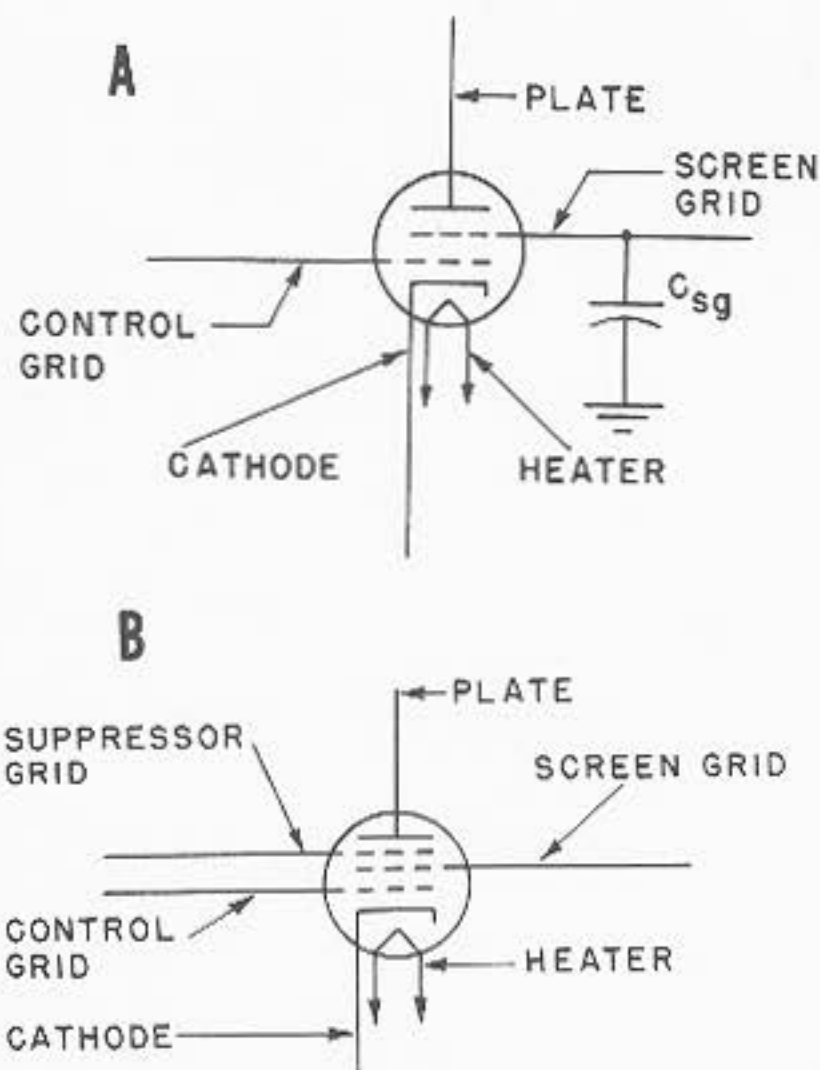
Gas-Filled Tubes

Gas-filled tubes (gas tubes) have many uses, such as, voltage regulators, rectifiers, electronic switches and triggers, and indicators. They may have either a heated (hot) cathode or an unheated (cold) cathode. Most gas tubes are diodes or triodes and capable of handling more current than vacuum tubes of the same physical dimensions.

Gas tubes conduct when ionization occurs. (Ionization is the process by which a particle—gas in this case—loses or gains an electron thereby having a positive or negative charge. It can be produced by collisions of particles, by radiation, and by other means.) The ionization point (firing point) varies with tube construction and type of gas used.



72.10
Figure 3-60.—Triode amplification.



20.9:11

Figure 3-61.—Schematic diagrams of a tetrode (A) and a pentode (B).

After ionization has started, the action maintains itself at a voltage lower than the firing-point voltage. To maintain ionization, however, voltage must be kept above a certain minimum. If the voltage across the tube falls below this minimum, the gas deionizes and current flow stops. (The voltage at which current ceases to flow is known as the deionizing potential.) The gas-filled tube may be used as an electronic switch that closes at a certain voltage and permits current to flow and opens at a lower voltage and thus blocks the flow of current. These tubes have a very high resistance before ionization and a very low resistance after ionization.

GAS DIODES.—The cold-cathode diode requires a higher firing potential than the hot-cathode diode. The neon glow lamp or neon

bulb is such a cold cathode diode. Its cathode may have the same shape as its plate so that the tube can conduct in either direction depending only on the applied potential; or the tube may be constructed to permit current flow in one direction only. The passage of current through the tube is indicated by a glow.

Glow tubes have several applications. They are used to indicate the presence of a voltage, as a source of light, as a rectifier, and as a voltage regulator. A schematic representation of a voltage-regulator glow tube is shown in figure 3-62A. The black dot denotes that the tube is gas-filled.

Hot-cathode, mercury-pool diodes (fig. 3-62B) are especially designed to serve as rectifiers. These tubes have a much higher current-handling capability than vacuum tubes. Mercury vapor is the gas used in these tubes; it is formed when the small amount of liquid mercury inclosed in the envelope is completely vaporized by the hot cathode. These tubes are not capable of supplying their rated output until the mercury is completely vaporized. To prevent damage to the tube, sufficient time must be allowed for



A
V-R TUBE



B
MERCURY-POOL POWER
RECTIFIER TUBE

Figure 3-62.—Schematic diagrams of two gas-filled tubes.

20.18

the mercury to vaporize before applying plate supply voltage to the tube.

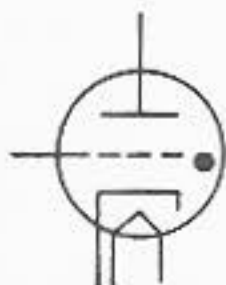
THYRATRONS.—A gas-filled triode (fig. 3-63), or tetrode, in which a grid is used to control the firing potential is called a thyatron. The firing potential depends upon both the plate potential and the grid potential. The grid-control characteristics of a typical thyatron are shown in figure 3-64. Thus it can be seen that the firing potential increases as the grid bias increases (becomes more negative). A grid bias of -4 volts requires approximately 350 volts on the plate to cause conduction. A grid bias of -7 volts requires 700 volts on the plate to cause tube conduction—thus plate current flow. When conduction starts the grid loses control and no longer is effective as a control element. To stop plate current flow the plate voltage must be reduced to the deionizing voltage. When conduction starts, the grid loses control and a positive ion sheath is formed around the negative grid. This sheath neutralizes the negative grid, thus destroying its effectiveness as a control element.

Thyratrons have many practical applications in relay and trigger circuits.

SEMICONDUCTOR DEVICES

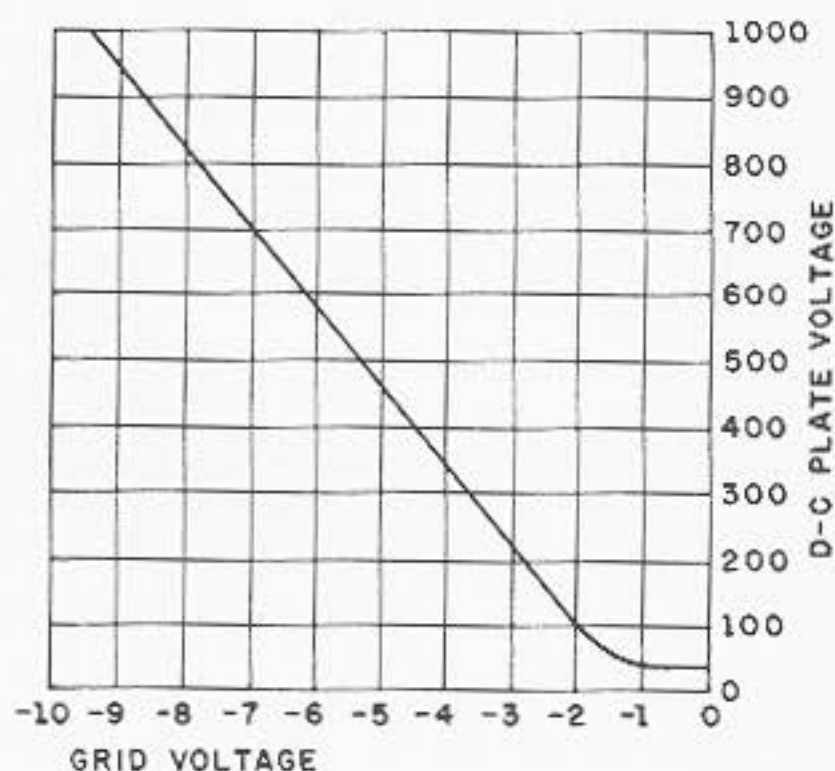
Semiconductor devices or semiconductors (sometimes referred to as solid state devices) are being used in almost all types of military electronic equipment. Virtually all new equipments incorporate them. Many equipments use them exclusively.

In addition to replacing the electron tube in many circuits, the semiconductor has no electron-tube counterpart for many of its uses. Transistors and most other semiconductor devices are more complex than electron tubes and require a substantial amount of background knowledge to



20.18

Figure 3-63.—Thyatron.



20.19

Figure 3-64.—Grid control characteristic of a representative thyatron.

understand completely their theory and operation. Some publications (such as *Basic Electronics*, NavPers 10087 series, *G. E. Transistor Manual*, and *Electronics* by Chirlian and Zemanian) explain semiconductors in detail and can be obtained from BuPers or the public library.

Semiconductors Diodes

When P- and N-types of semiconductor materials are combined in manufacture, the result is a semiconductor diode. (P-type semiconductors are materials treated—doped—with an impurity to give them an overall positive charge, and N-type semiconductors are those treated to give them an overall negative charge.) If the proper bias voltage is applied, the diode will conduct heavily in one direction and very little in the other direction.

Like electron-tube diodes, semiconductor diodes serve as rectifiers, voltage regulators, and in other uses. Semiconductor diodes have additional useful application. Semiconductors vary in size ranging from small ones with current ratings of less than one milliamper (0.001 amper) to large 500-ampere rectifiers.

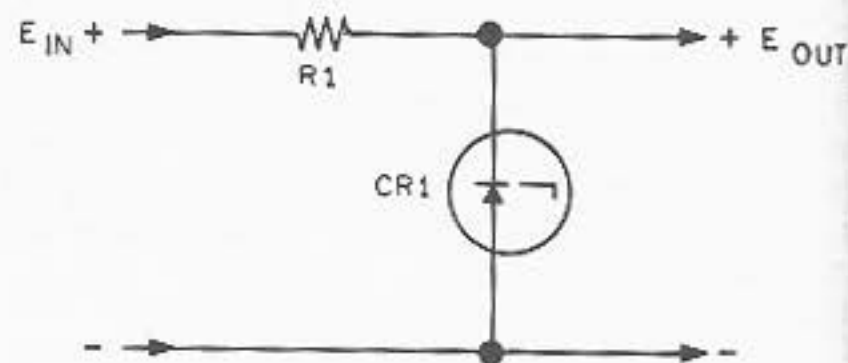
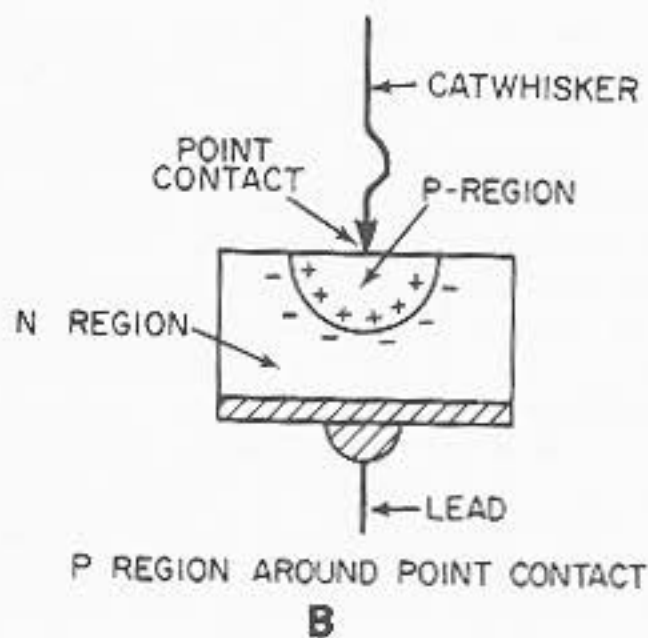
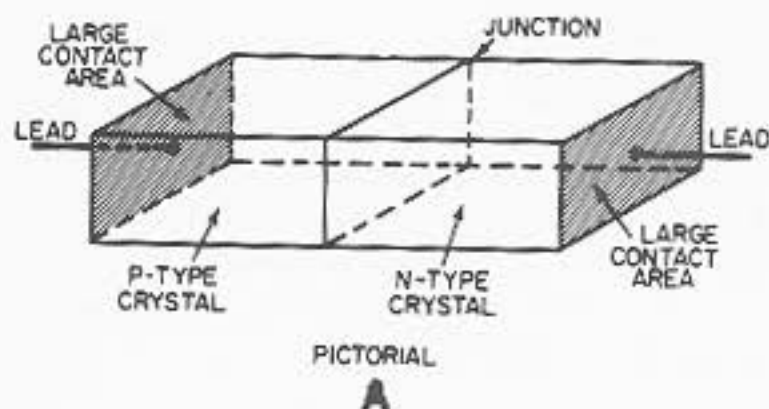
Semiconductor diodes are classified according to construction as the junction type or point

contact type. Both types are represented pictorially in figure 3-65. Modifications of these diodes are used for various purposes, some of which are represented in figure 3-66. Figure 3-66A is a diode (called zener) voltage-regulating circuit, figure 3-66B is a zener diode temperature compensation circuit, and figure 3-66C is a basic photodiode circuit which utilizes variations in the light impinging on the junction to produce output current variations.

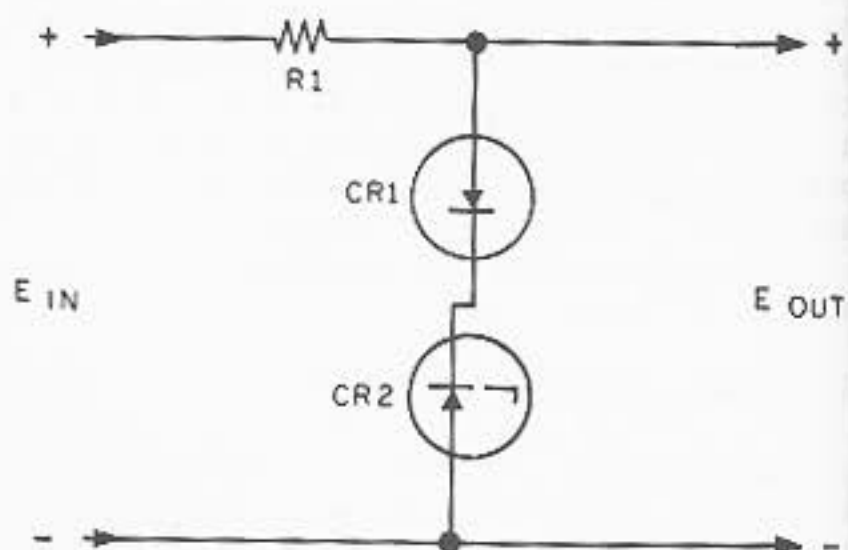
Transistors

A simple transistor can be constructed by placing two semiconductor diodes back to back with the center element common to both junctions.

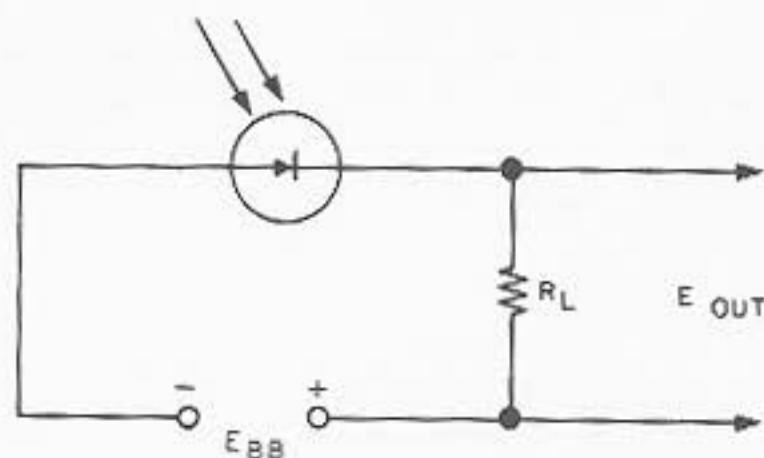
Transistors are made of PNP and NPN materials. The PNP transistor and the NPN transistor operates basically the same except that current flow in one is in a direction opposite to that in the other type, and bias-voltage polarities are reversed (refer to figure 3-67).



A ZENER DIODE TEMPERATURE COMPENSATION.



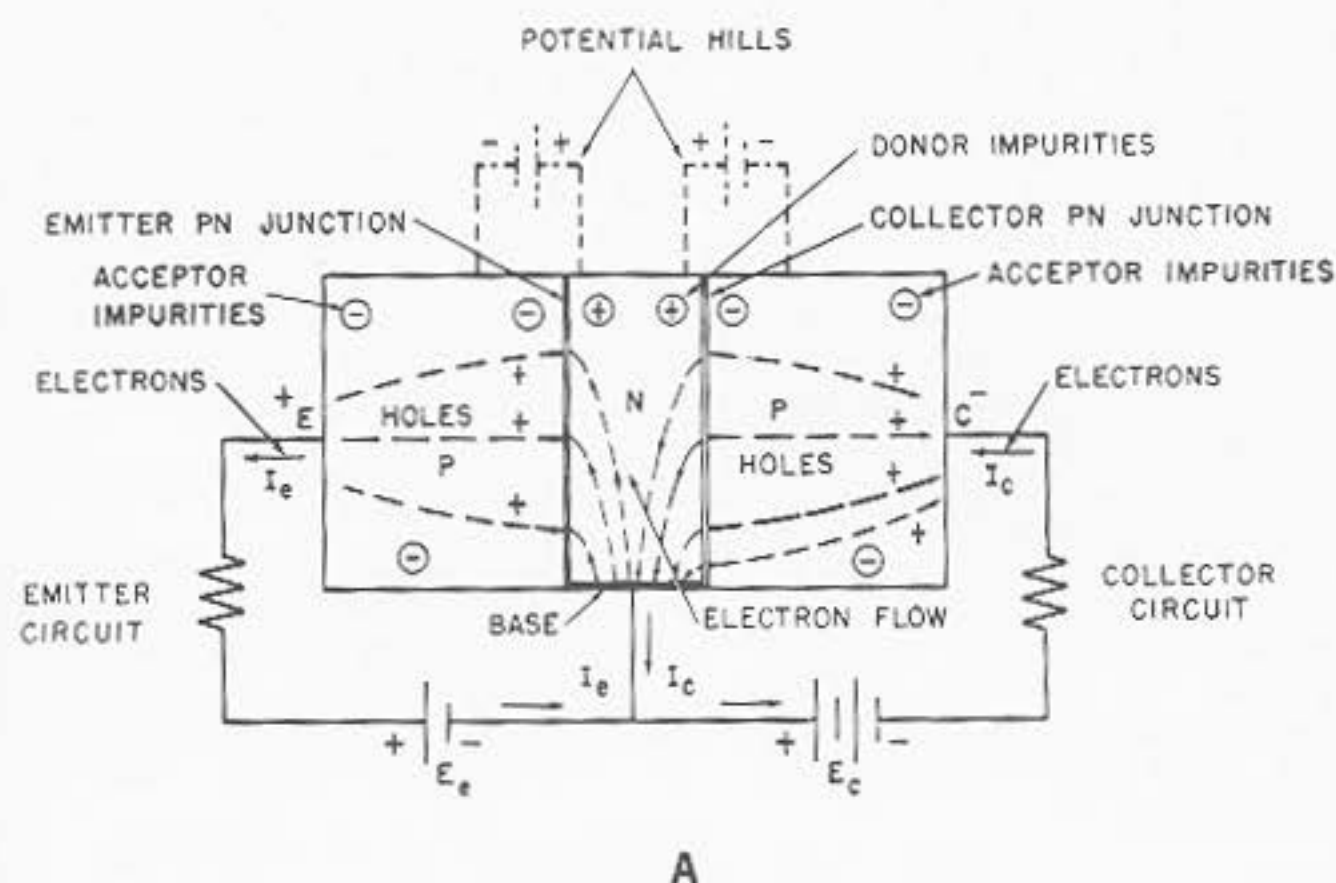
B ZENER DIODE VOLTAGE REGULATING CIRCUIT.



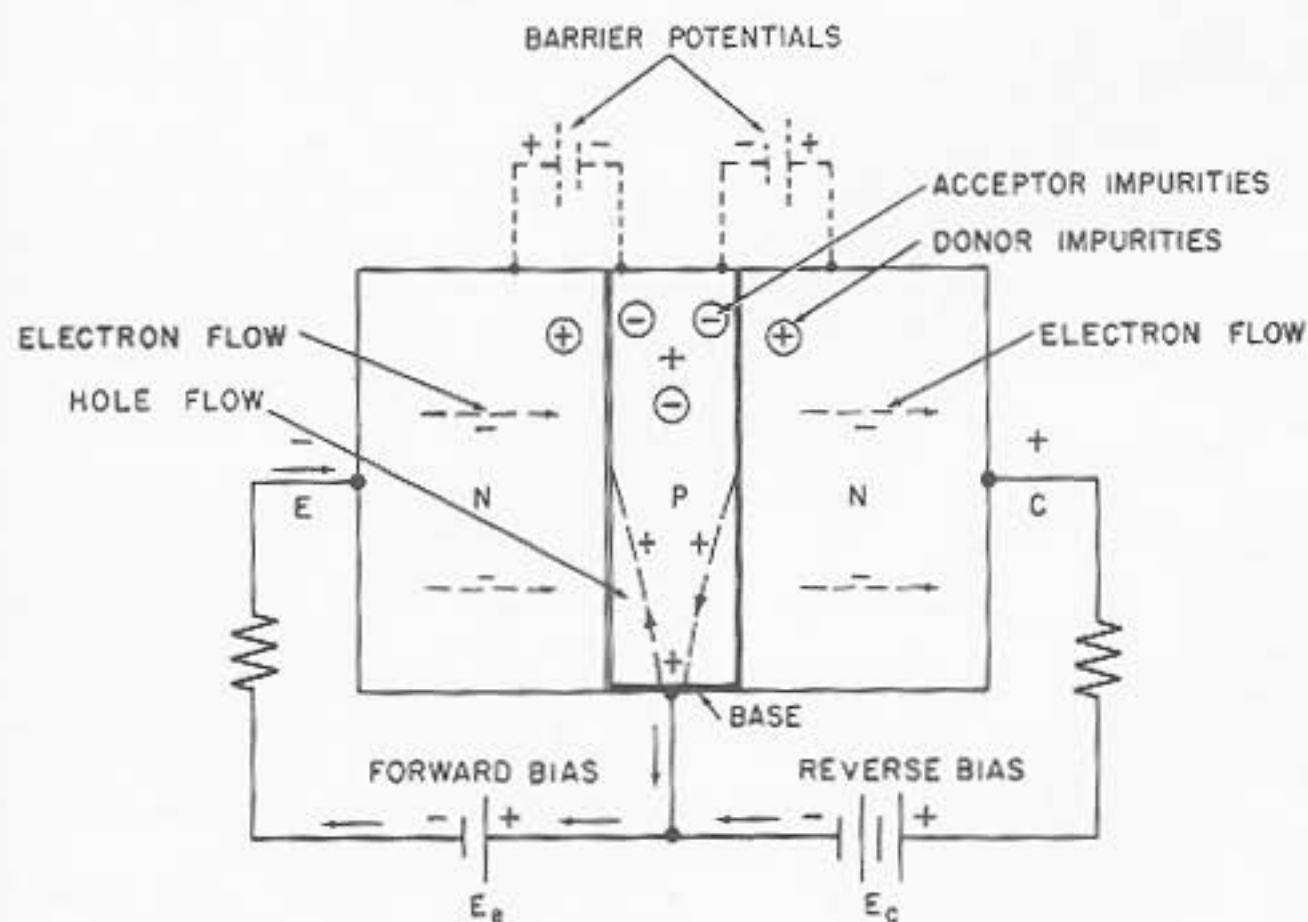
C BASIC PHOTODIODE CIRCUIT.

Figure 3-65.—Junction (A) and point contact (B) transistors.

Figure 3-66.—Diode uses.



A



B

1.278;.279

Figure 3-67.—PNP (A) and NPN (B) junction transistors.

Transistors are small, yet rugged. They can withstand very high centrifugal forces. Being solid devices, they require no special envelope and no filament power. Eliminating filament power greatly increases the efficiency (compared to electron tubes). They are capable of operating at frequencies far above the operating limits of any conventional electron tube.

Transistors also operate well with low-voltage power supplies (some at a fraction of a volt), and they are capable of operating with power outputs greater than 100 watts. Finally, transistors have a very long lifetime—sometimes over a hundred thousand hours.

TETRODES.—A tetrode transistor is produced by adding a fourth element to a 3-element transistor. In the junction tetrode, the fourth electrode is essentially another base, whereas in the point-contact type, it is essentially another emitter. The tetrode transistor permits a higher frequency response and a higher power output than the 3-element transistor.

Comparing Tubes and Semiconductors

Semiconductor diodes have an emitter and a collector, corresponding respectively, to the

cathode and plate of an electron tube diode. The transistor has a collector terminal that corresponds to the triode plate, a base terminal that corresponds to the grid, and an emitter terminal that corresponds to the triode cathode.

Figure 3-68 shows the similarities between basic circuits using the triode tube and the 3-element transistor, both NPN and PNP types. The direction of electron flow is from the cathode to the plate in the tube and from the collector to the emitter (against the arrow in the emitter terminal) in the PNP and from the emitter to the collector in the NPN.

BASIC ELECTRONIC CIRCUITS

Some basic electronic circuits are used in this section to show the principle of operation of the more complex circuits such as those found in radars, computers, and weapon power drive amplifiers. The circuits used here are simplified for instructional purposes.

Rectifier and Voltage-Regulating Circuits

Basic rectifier circuits and voltage-regulating circuits using electron tubes were discussed earlier in this section and are not discussed further.

Basic semiconductor rectifier circuits are shown in figure 3-69. Their operation is the same as that of the electron-tube rectifier circuits. There may be a small difference in circuit construction however. The semiconductor rectifier circuit may have a small surge resistor (R_s) connected in series with the diode to limit its peak current.

The bridge rectifier circuit in figure 3-69C (or F) is a full-wave rectifier that with a similar input has twice the output of the full-wave, center-tapped circuit shown in figure 3-69B (if both circuits use the same input transformers).

Each rectifier has advantages and disadvantages. The half-wave rectifier is the least expensive but the hardest to regulate. The full-wave bridge rectifier is the most expensive but the most efficient rectifier.

The bridge rectifier uses the entire secondary winding of its input transformer on each half-cycle of operation. On one half-cycle current flows from point 2 to 1, then in numerical sequence from 3 to 8, and then on the next half-cycle it flows in sequence from points 1 to 2, 8, 4, 5, 6, 7, 3, and back to point 1 completing the circuit.

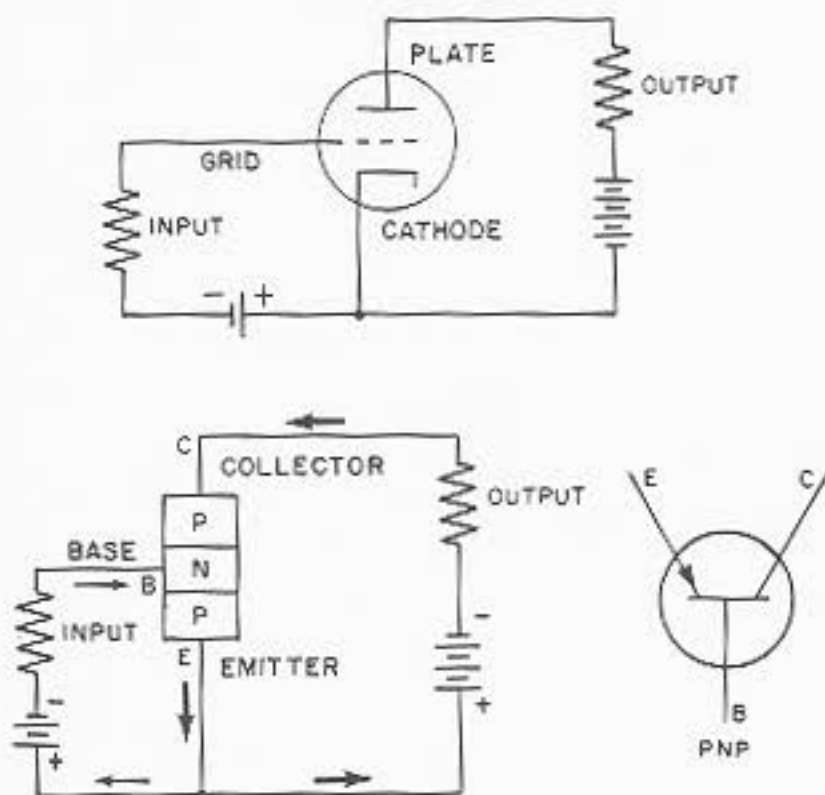
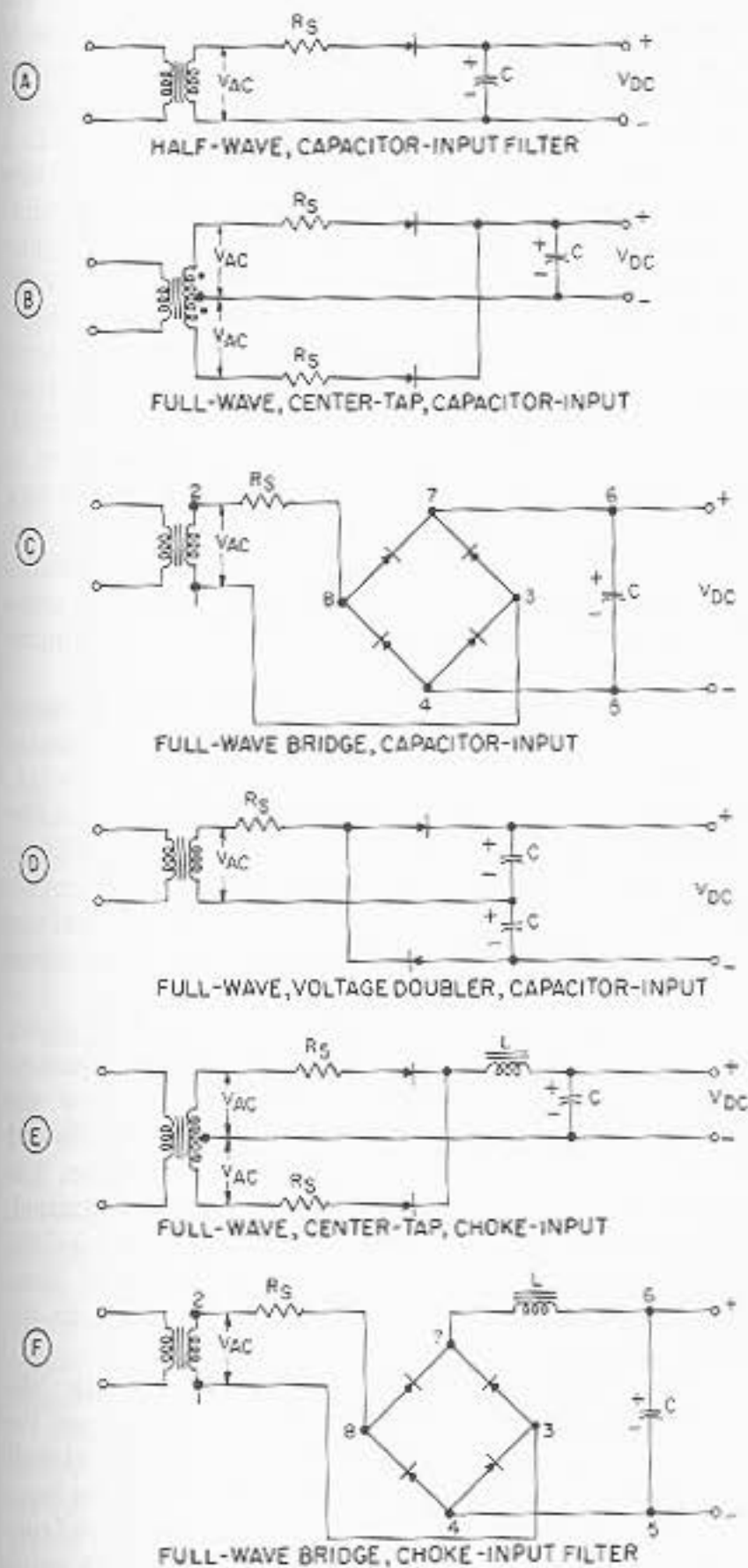


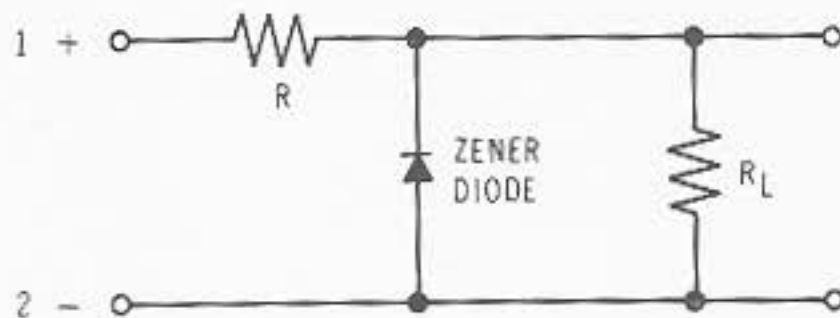
Figure 3-68.—Corresponding elements in triode and transistor.



20.406

Figure 3-69.—Basic semiconductor rectifier circuits.

A simple voltage regulator circuit employing a Zener diode is shown in figure 3-70. The Zener diode has properties that make it an excellent voltage regulator when the proper bias voltage is applied. If the voltage between points 1 and 2 increases, the current flow through the



110.130

Figure 3-70.—Simple shunt voltage-regulator.

Zener diode increases, but its resistance decreases. The voltage across the Zener and the parallel load (R_L) remains constant. The additional voltage would drop across the series resistor R .

Other voltage regulators such as those in figure 3-71A use both Zener diodes and transistors. Still others, such as that in figure 3-71B, use a regulating amplifier for improving voltage stability.

Amplifiers

Amplifiers are classified according to use, bias, frequency, response and circuit configuration. Generally, amplifiers are a combination of these classifications. An example of this would be a class A (bias), grounded-cathode (circuit configuration), audio frequency (frequency response), voltage (use) amplifier.

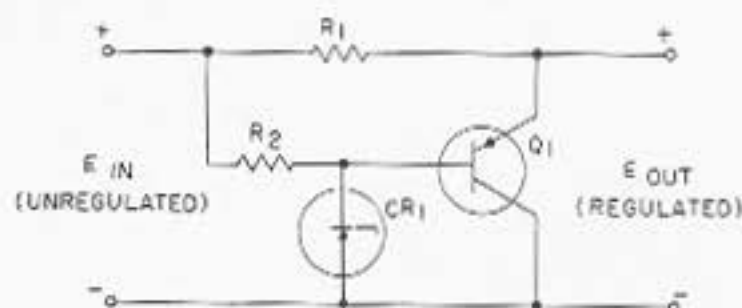
When classified according to use, amplifiers fall into two general groups—voltage amplifiers and power amplifiers. Voltage amplifiers are designed to produce a large change in output voltage, across the plate load by applying a small input voltage (signal) between the grid and cathode. The gain of a voltage amplifier is the ratio of the a-c output voltage to the a-c input voltage (voltage-out/voltage-in). Voltage amplifiers are commonly used in radars and computers.

Power amplifiers are designed to deliver a large amount of power to the load in the plate circuit of the tube or the collector (or emitter) circuit of a transistor.

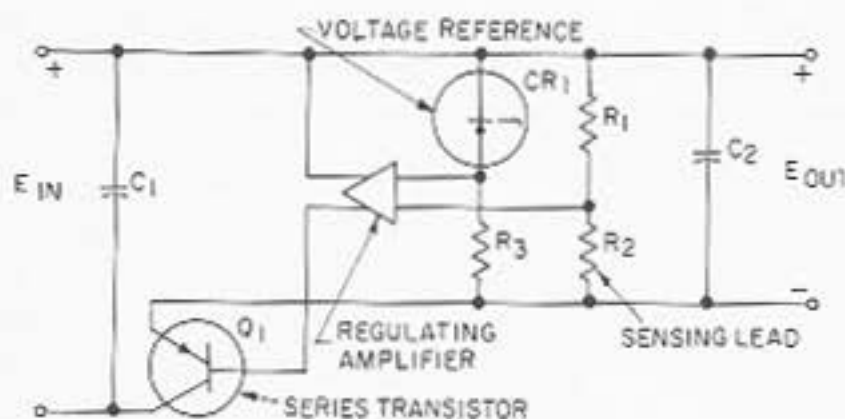
They are used: (1) to drive servo motors in computers, (2) in output stages of radars, and (3) output stages of power-drive amplifiers on gun mounts and other ordnance units.

Amplifiers that are classified according to bias fall into three main classes of operation, A, B, and C.

Class A amplifiers are biased (grid-to-cathode or base-to-emitter) so that with a normal signal



A BASIC SEMICONDUCTOR SHUNT VOLTAGE REGULATOR



B EMITTER-FOLLOWER SERIES REGULATOR

20.407:.408

Figure 3-71.—Basic semiconductor voltage regulators.

input the tube or transistor will conduct during the entire grid signal cycle. As long as the amplifier operates within its limits the output will be a replica of the input. Class A amplifiers are used in audio circuits where a reproduction of the input is desired.

Unlike the class A amplifier a class B amplifier is biased so that no plate current flows in the absence of a signal to the grid or base. Plate current flows for approximately one half of each cycle (positive alternation) of grid signal voltage. Plate current is cut off for the duration of the negative alternation.

Class C amplifiers are biased beyond cutoff—about 2 to 3 times the cutoff value. This amplifier requires a large input signal to cause conduction. It conducts only for a small portion of the positive alternation of the input signal. Class C operation is used principally in radio-frequency amplifiers and is never used for audio amplification.

Amplification may be classified according to the frequency range over which they are designed to operate. These are known, as direct-current (d-c); audio-frequency (AF); intermediate-frequency (IF); radiofrequency (RF); and video-frequency amplifiers. Direct-current amplifiers

are used when the signal current is in but one direction. Audiofrequency amplifiers operate in the audiofrequency range—from approximately 20 hertz to 20,000 hertz. Intermediate-frequency amplifiers and RF amplifiers operate within a particular frequency range. These amplifiers usually are tuned to a certain frequency (called midfrequency) which varies according to application. An AM radio uses 456 kHz as its IF, whereas an FM radio uses 9.1 MHz. Video amplifiers (used in radars, target designation displays and TV) operate within a range extending from the lower audiofrequencies to about 5 MHz.

Another method of classifying amplifiers is according to circuit configuration—how the tube elements are connected in the circuit. There are three circuit configurations: grounded-cathode (or common-emitter), grounded-grid (or common-base), and grounded-plate (or common-collector).

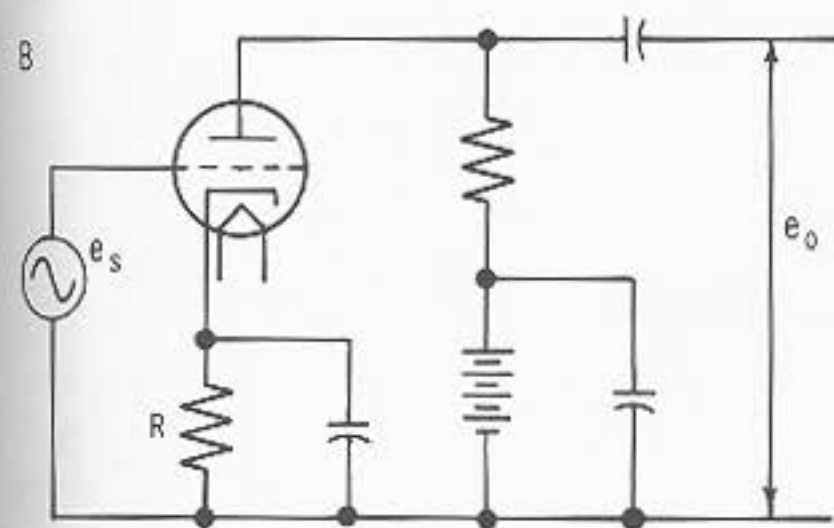
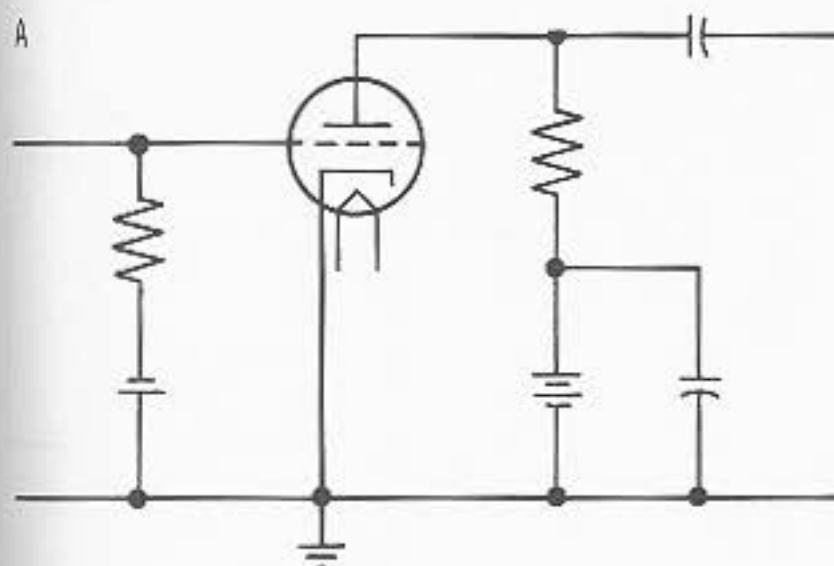
A grounded-cathode amplifier circuit is shown in figure 3-72A. The cathode may be connected to ground directly, as shown in figure 3-72B, or through a resistor (R) with a bypass capacitor as shown in figure 3-72B. (The bypass capacitor holds the cathode at ground potential in respect to the input signal.) Common-emitter transistor amplifiers for PNP and NPN circuits are shown in figure 3-73A and 3-73B.

Grounded-grid amplifiers like the one shown in figure 3-74A are used as radiofrequency amplifiers in the lower radar frequencies and in television circuits. The signal is applied to the cathode in series with the bias voltage. The output is taken between the plate and ground. A common-base circuit is shown in figure 3-74B. Resistors R_1 and R_2 develop forward bias, making the emitter positive in respect to the base.

The other circuit configuration is the grounded-plate amplifier (fig. 3-75A) or the common-collector amplifier. This type circuit is used in high-frequency applications. The input signal is to the grid, and the output is taken from the cathode. Common-collector amplifiers using PNP and NPN transistors are shown in figures 3-75B and 3-75C, respectively.

Direct-current amplifiers are used extensively in some analog computers. A typical d-c amplifier circuit is shown in figure 3-76. In this circuit a fixed portion of the output (feedback) is taken from across R_2 and fed back to the base of Q_2 . This provides stable gains over a wide range of frequencies.

A high-gain d-c amplifier called an operational amplifier is used in some applications.

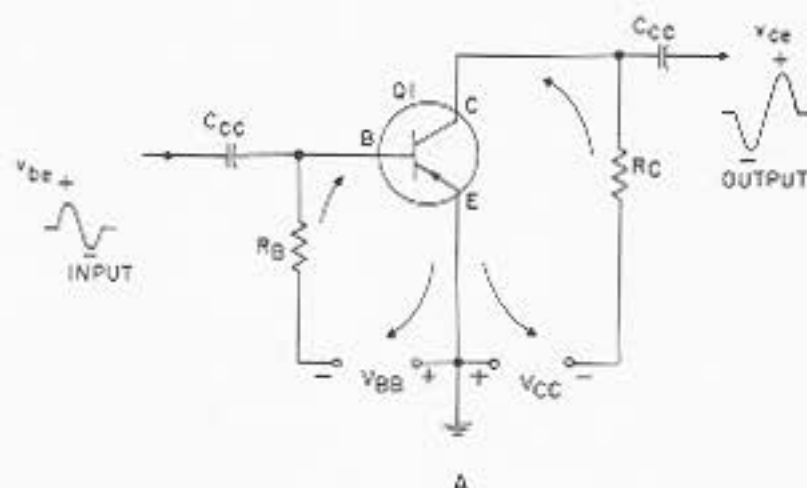


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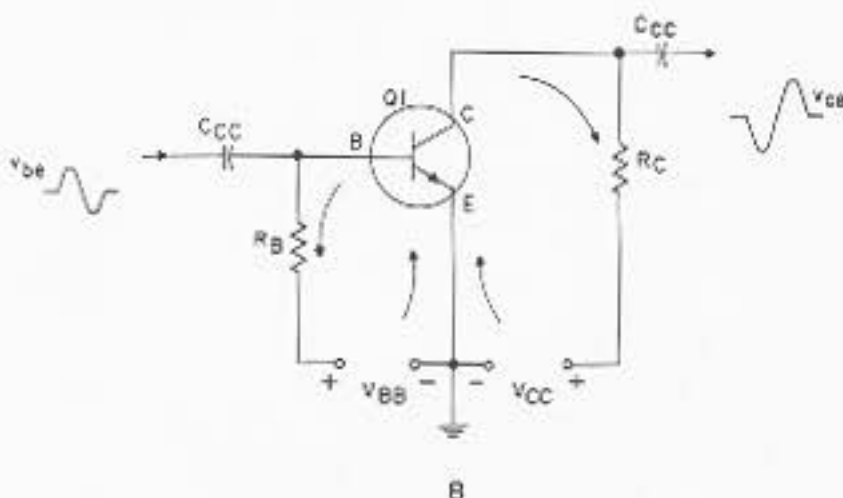
Figure 3-72.—Grounded cathode amplifier circuits.

It usually consists of three d-c amplifier stages in series (cascade), and it has a gain of up to 50,000 to 1 or higher. A typical operational amplifier circuit is illustrated in figure 3-77. Resistor R_2 is the feedback resistor.

Some uses of d-c amplifiers in analog computers are: (1) to solve equations; (2) as algebraic adders in summing amplifiers; and (3) as multipliers and dividers. A schematic diagram and the equivalent circuits of the summing amplifier are shown in figure 3-78. The summing amplifier works on a similar principle as the mechanical differential, which was explained earlier in this chapter. If there are two or more voltage inputs of the same polarity, as shown in figure 3-78B, the output is the algebraic sum of the input voltages with the polarity of the output reversed (+5 and +3 = -8). By reversing the polarity, +8 becomes -8. If the polarities of the input voltages are not the same, as in figure 3-78C, the output is still the algebraic sum of the input voltages with the



A



B

20.413

Figure 3-73.—Common-emitter circuits; A. PNP; B. NPN.

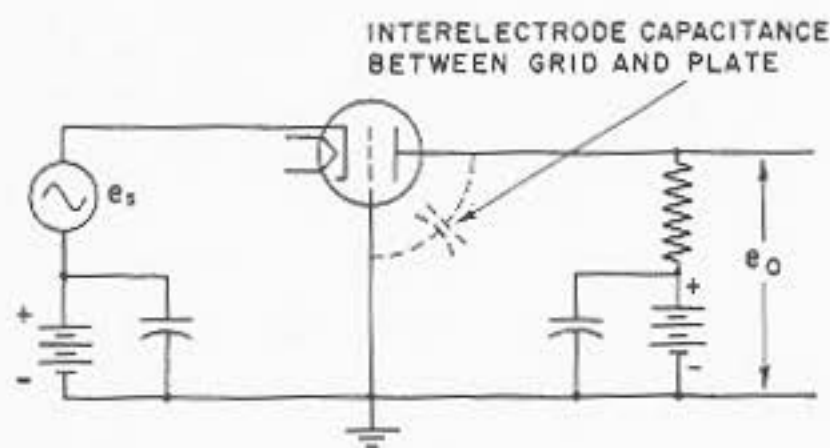
polarity of the output reversed (-5 and +3 = 2). (The output of a summing amplifier is opposite in polarity from the input, which means that if the input to a unity gain amplifier is +2 volts, the output will be -2 volts.)

DIGITAL DEVICES

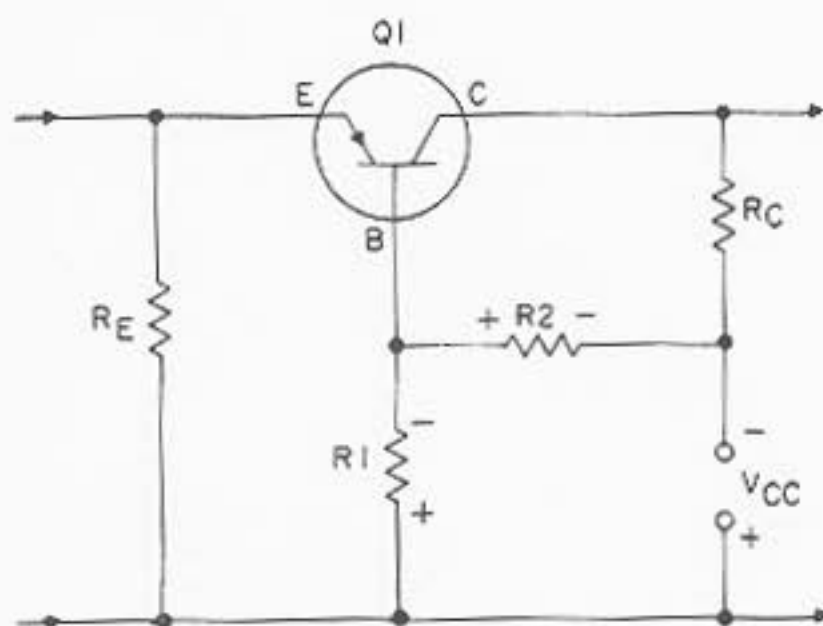
Digital computers function in the binary-numbering system using the digits 0 and 1. Their components represent data that can only be in one of two stable states—ON or OFF, conducting or not conducting, energized or deenergized. The action of a digital device or digital-computer component can best be illustrated by the action of a common light switch; it is either ON or OFF.

Binary Numbering System

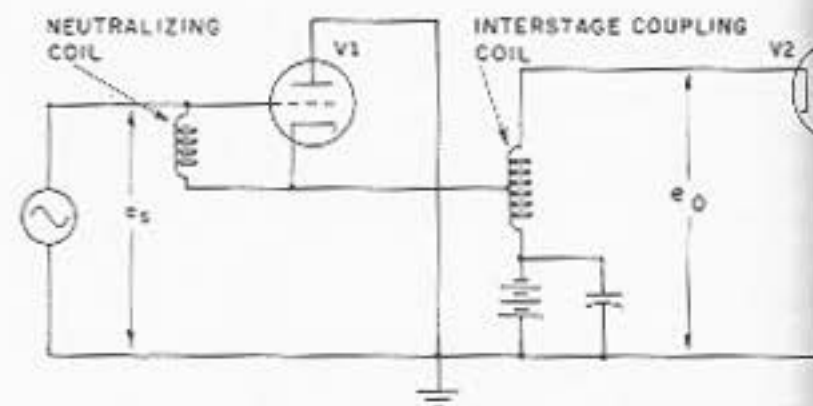
A brief review of the binary numbering system may help you to better understand the digital devices that will be discussed later.



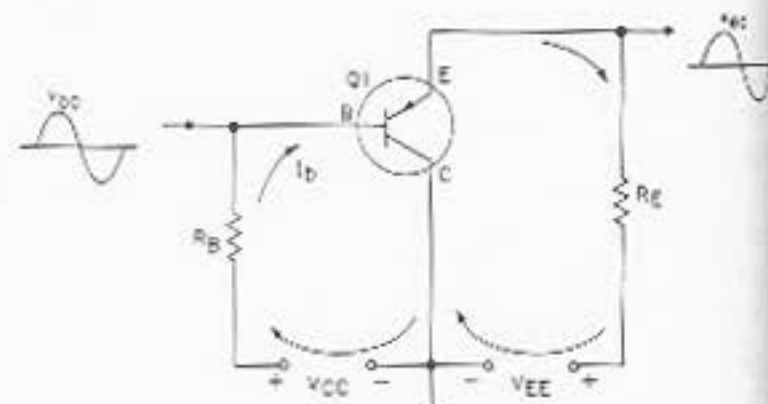
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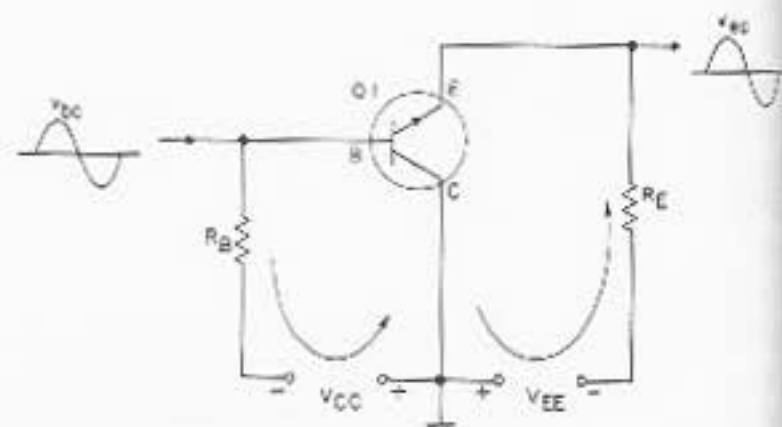
B



A



B



C

20.83;.412
Figure 3-74.—Grounded grid amplifier circuit and single supply, common-base fixed-bias circuit.

The binary numbering system uses the base 2 and not the base 10; that is, it uses only two digits, 0 and 1. Thus, the sequence followed in counting up to 1000 (base 2) uses:

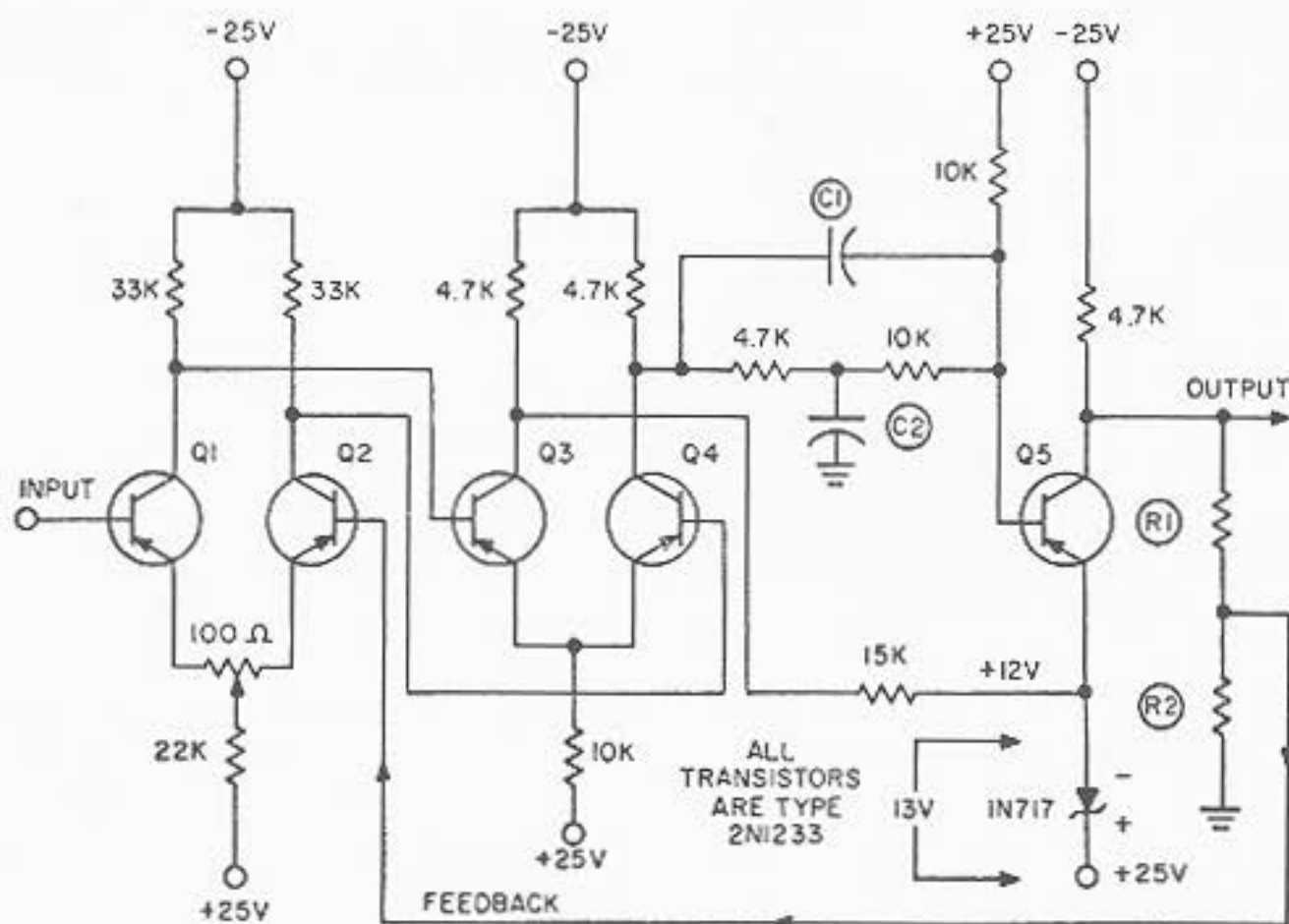
base 2	base 10	base 2	base 10
0000	= 0	0101	= 5
0001	= 1	0110	= 6
0010	= 2	0111	= 7
0011	= 3	1000	= 8
0100	= 4		

Of course you can easily see that 1000 to the base 2 (1000_2) is not equal to 1000 to the base

20.84;.416
Figure 3-75.—Grounded plate (A) and common-collector circuits; (B) PNP; (C) NPN.

10 (1000_{10}). It is equal to 8 to the base 10. A quick look at the number sequence shows that the terms are powers of the number 2. Thus

decimal		binary
1	= 2^0	= 0001
2	= 2^1	= 0010
4	= 2^2	= 0100
8	= 2^3	= 1000
16	= 2^4	= 10000
32	= 2^5	= 100000



110.131
Figure 3-76.—A typical d-c amplifier.

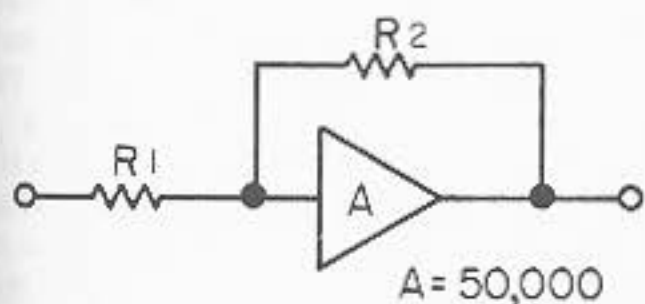


Figure 3-77.—The typical operational amplifier circuit.

Binary addition, subtraction, division, and multiplication is accomplished in the same manner as the decimal operations. An example of addition follows:

binary

$\begin{array}{r} \textcircled{1} \textcircled{1} \\ 1101 \\ 1001 \\ \hline 10110 \end{array} = \begin{array}{r} \textcircled{1} \\ 13 \\ 9 \\ \hline 22 \end{array} \quad \textcircled{1} = \text{carry}$

Boolean Algebra

Boolean algebra is used in the study of digital devices to determine the "truth value" of the combination of two or more statements. Because Boolean algebra is based upon elements having two possible stable states, it becomes very useful in representing switching circuits. This is because a switching circuit can be in only one of two possible stable states at a given time—open or closed. These two states may be represented as 0 and 1, respectively. As the binary numbering system consists of only the symbols 0 and 1, we can use these symbols with the Boolean algebra.

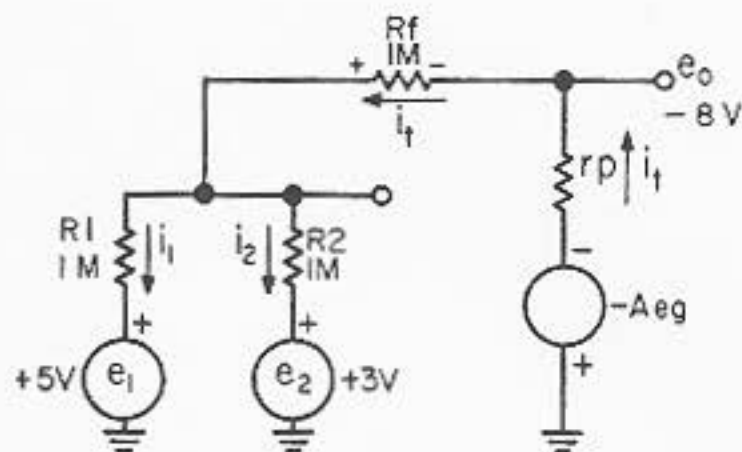
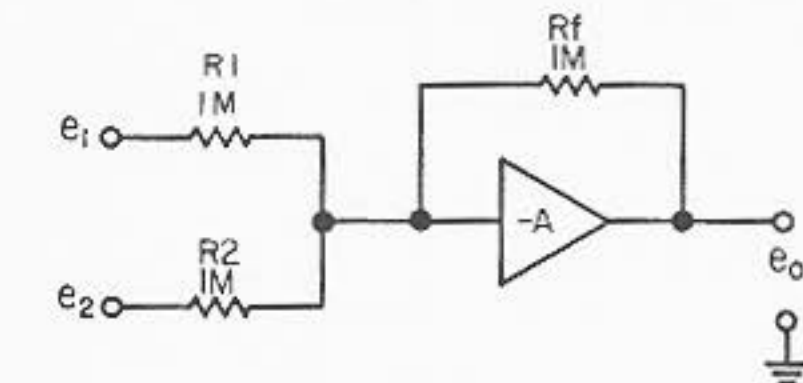
In Boolean algebra there are three basic operations—AND, OR, and NOT. The basic operations are represented in logical equations by the symbols shown in table 3-1. The OR operation is indicated by the addition symbol, whereas the AND operation is indicated by a multiplication symbol (the dot, parentheses, or other multiplication signs). The NOT function is indicated by a solid line over the letter or letters—example: $\overline{A}$ and $\overline{AB}$.

Table 3-1.—Logic symbols.

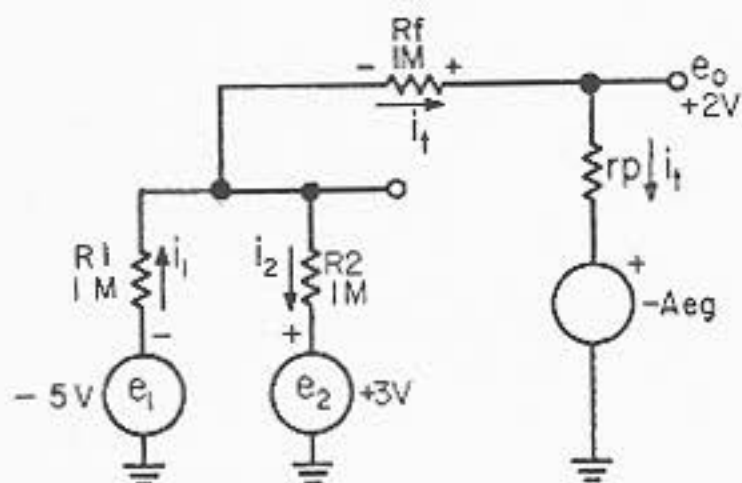
OPERATION	MEANING
$A \cdot B$	A and B
$A + B$	A or B
$\overline{A}$	A NOT

110.134

A SCHEMATIC OF THE SUMMING AMPLIFIER AND ITS EQUIVALENT CIRCUIT.



B AN EQUIVALENT CIRCUIT OF THE SUMMING AMPLIFIER.



C EQUIVALENT CIRCUIT USING A SECOND INPUT CONDITION.

110.133

Figure 3-78.—A. Schematic of the summing amplifier and its equivalent circuit; B. An equivalent circuit of the summing amplifier; C. Equivalent circuit using a second input condition.

Logic Operations

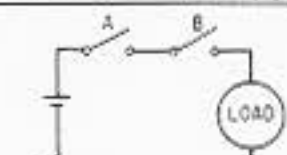
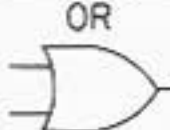
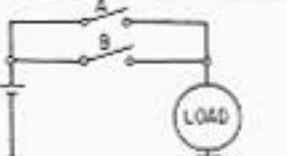
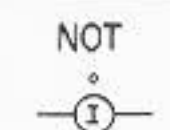
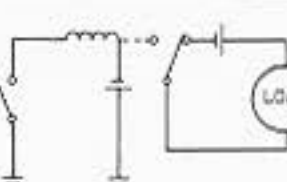
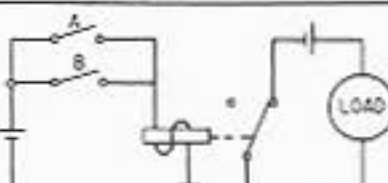
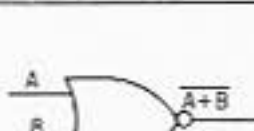
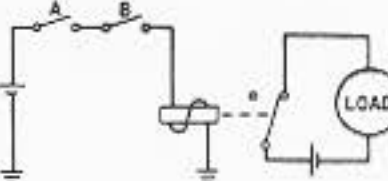
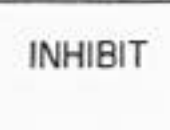
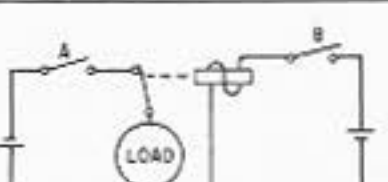
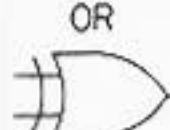
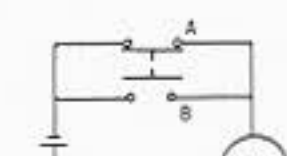
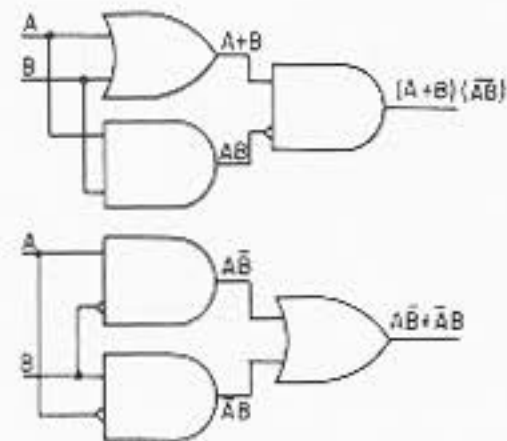
The three basic logic operations and four of the simpler combinations of the three (NOR, NAND, INHIBIT, and EXCLUSIVE OR) are shown in figure 3-79. For each operation a representative switching circuit, a truth table, and a block diagram are given. A 1 at the input indicates the presence of a signal (corresponding to the switch closed), and a 0 indicates the absence of a signal (switch open). In the outputs, a 1 indicates a signal across the load, and a 0 indicates no output.

For the AND operation every input line (two in this case) must have a signal present in order to produce an output (or all switches must be closed to produce an output). The OR circuit produces an output whenever a signal is present at any input. The NOT operation is simply an inversion, an input signal produces no output, while no signal input produces an output.

The NOR circuit operates just the opposite from the OR circuit, and the NAND operates just the opposite from the AND circuit. The EXCLUSIVE OR circuit has an output only when there are a combination of a 0 and a 1 input and not when all inputs are the same (either 0's or 1's). An EXCLUSIVE OR logic diagram is shown in figure 3-79.

Positive and Negative Logic

Logic circuits may be utilized to provide "yes" or "no" or "true" or "false" answers to specific questions. A "yes" or "true" answer is usually represented by a binary 1, and a "no" or "false" answer is usually a binary 0. As far as the circuitry is concerned, however, it is possible to use either a positive voltage or

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20.471

Figure 3-79.—Logic operations, comparison chart.

negative voltage to represent either binary digit. Therefore some distinction must be made regarding the system of logic for a particular application. The term POSITIVE LOGIC is used to denote a circuit in which the voltage level representing a binary 1 is positive in respect to that used to represent a binary 0. NEGATIVE LOGIC is the term used to denote circuitry in which the voltage level representing binary 1 is negative in respect to that representing binary 0.

Basic Logic Circuits

Many of the basic circuits used in digital devices are conventional electronic circuits generally applicable to electronic equipment. Circuits which perform the logic operations previously discussed, provide an output only if certain input conditions exist. They can be classified generally as gate circuits and may employ electron tubes, transistors, semiconductors, and/or magnetic cores.

The basic circuits of the inverter, OR, AND, NOR, and NAND gates are discussed briefly.

The inverter or NOT circuit is nothing more than a gate amplifier that produces an inversion of the input signal and has unity gain. The inverter circuit shown in figure 3-80 uses a PNP transistor biased at cutoff by the divider R_2 and R_3 . The input signal is divided by R_1 and R_2 to make circuit gain unity. This circuit represents a negative logic circuit because the input must be negative to cause conduction. An inverter using an electron tube is shown in figure 3-81.

An OR circuit or gate with four inputs is shown in figure 3-82. Many OR circuits have only two inputs or any other practical number of inputs. The OR circuit shown has 16 possible input signal combinations ($2^4 = 16$) as illustrated in the truth table. When any one or more of the inputs receive a positive signal, the diode (or diodes) receiving that input conduct(s). This results in a positive-going output at F, measured across R_L . (This circuit uses positive logic.)

A transistorized AND gate is illustrated in figure 3-83. This version uses two inputs and positive logic. The transistors are biased so that they conduct down across R_L with no input. With either transistor conducting, there is an output across R_L . The application of positive signals at A and B at the same time, however, will cause both transistors to cease conduction and the output at F to rise to ground or zero potential representing a logic 1.

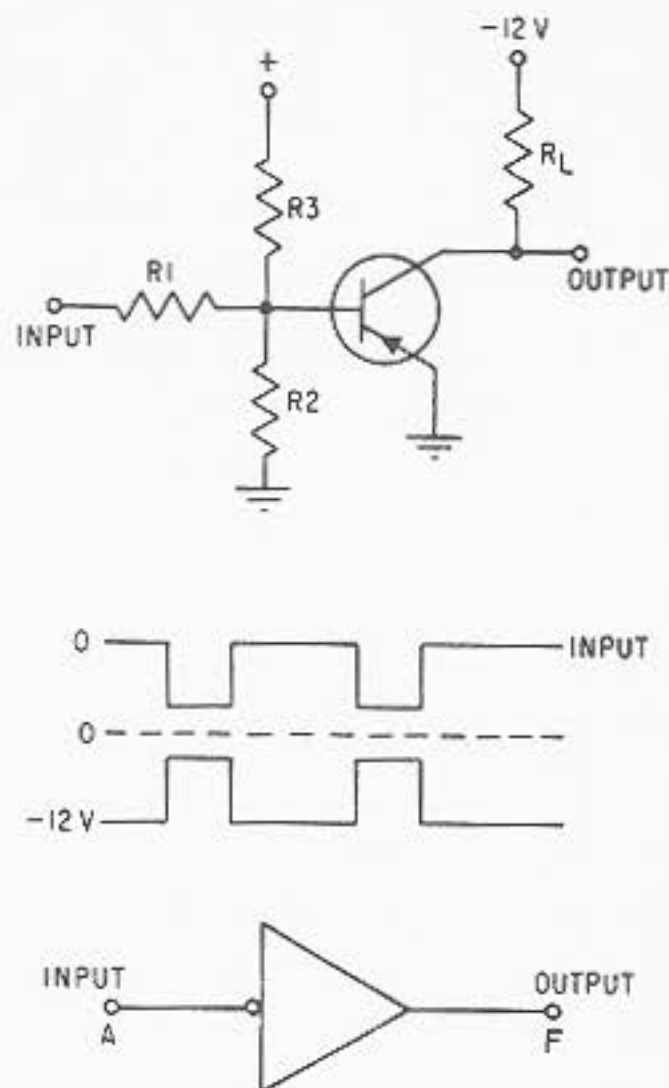


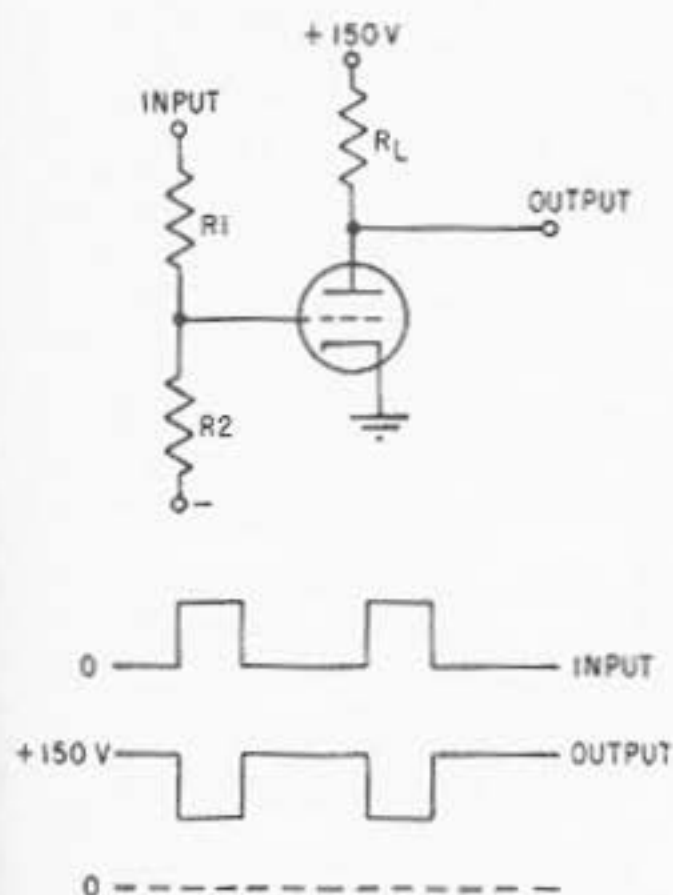
Figure 3-80.—Transistorized NOT circuits.

A NOR gate is a combination of an OR type circuit and of an inverter. The NOR circuit in figure 3-84 uses positive logic. With no signal input (0) the NPN transistor is biased to cutoff, and the output at F is positive (1). A positive signal (1) to any of the input terminals (A, B, C, or D) will cause the transistor to conduct and the output to go negative.

The NAND circuit combines the AND function and the NOT (inverter) function. In figure 3-85 the PNP transistors are biased for maximum conduction in the absence of signals. When positive signals are applied simultaneously to both transistor bases, both will be cut off, and the output voltage at the collectors goes relatively negative. (Note that both transistors must be cut off at the same time in order to change the output.) This is a positive-logic NAND circuit.

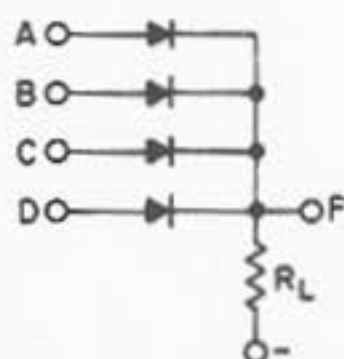
Flip-Flop Circuits

Flip-flop circuits (bistable multivibrators) are used in digital devices to supply an output



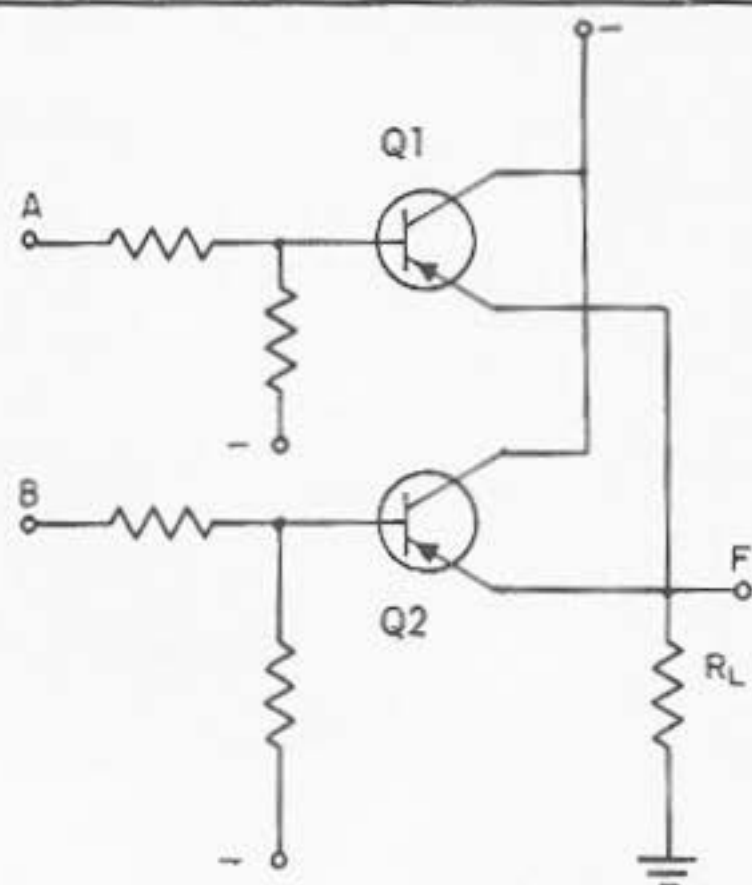
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Figure 3-81.—Electron tube NOT circuit.



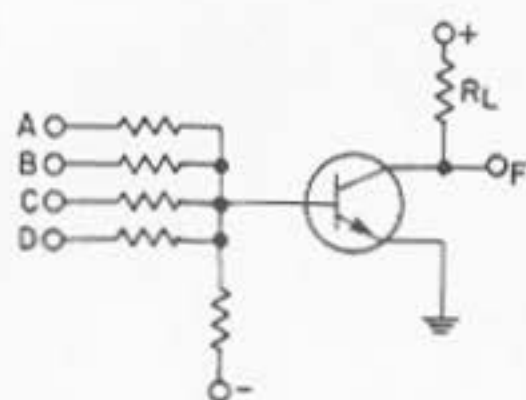
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Figure 3-82.—OR circuits.



12.133.1(20B)

Figure 3-83.—AND circuit.

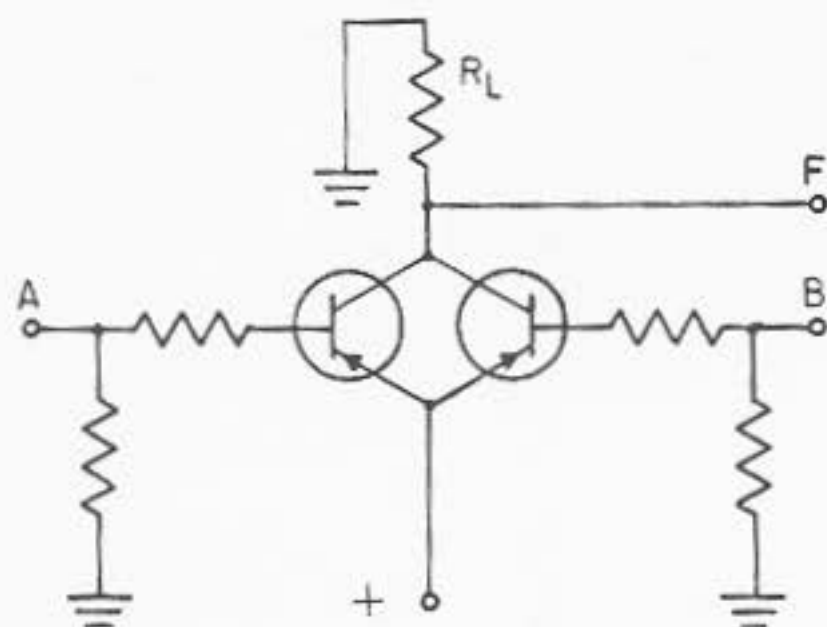


67.89

Figure 3-84.—NOR circuit.

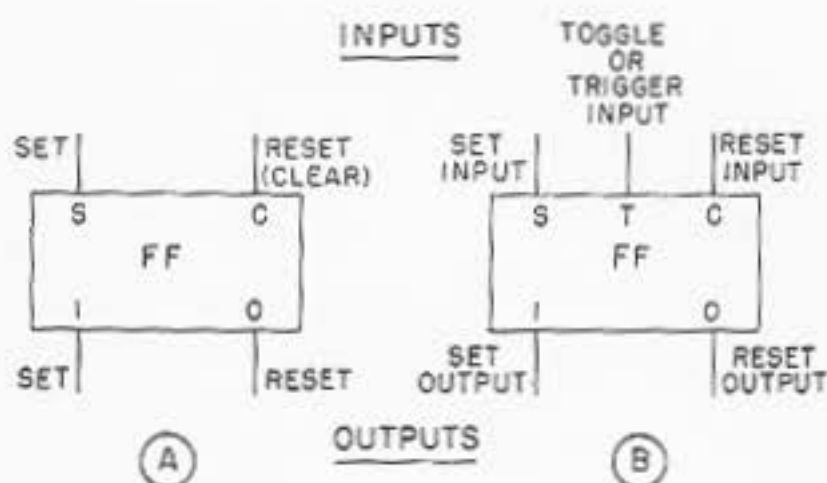
are the same—set (1) and reset (0). The set input is used to get a "1" from the set output; the reset input is used to reset the flip-flop for a "1" out of the reset output. The trigger input is used to change the flip-flop from one stable state to the other. This is accomplished by applying the same signal to both transistor bases at the same time.

The schematic of a simple transistor flip-flop is shown in figure 3-87. Outputs are taken from points X and Y. Inputs are represented by switches A and B which temporarily ground these points when the trigger input is to be applied. The trigger input may be applied in



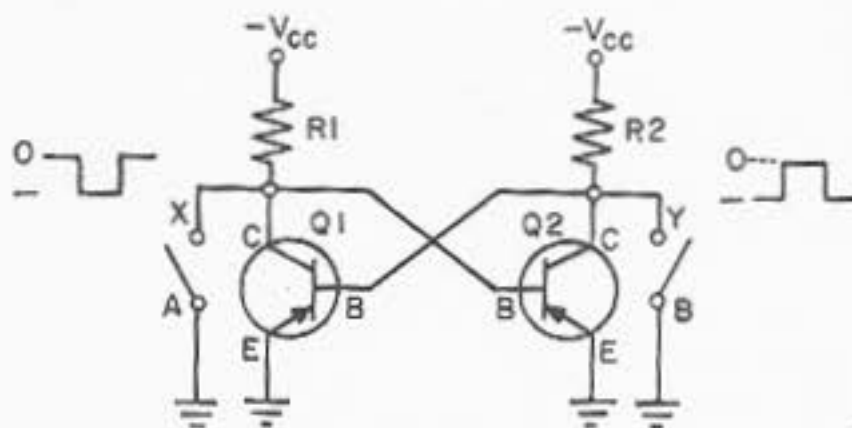
67.90

Figure 3-85.—NAND circuit.



124.26

Figure 3-86.—Flip-flop symbol.



20.473

Figure 3-87.—Transistor flip-flop circuit.

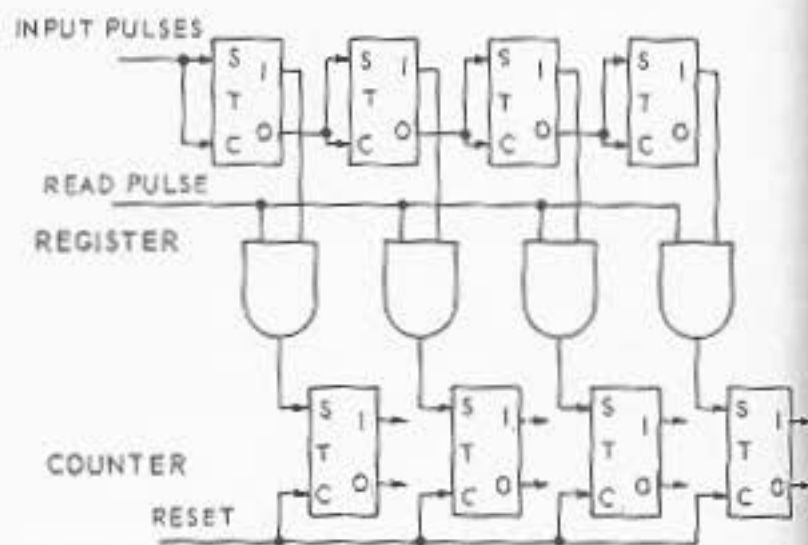
several different ways, such as by diode, transistors, switches, relays, or otherwise.

In one of the two stable states of the flip-flop, transistor Q_2 conducts heavily and transistor Q_1 is cutoff. With this arrangement, point Y will be at ground or zero potential, whereas point X will be at the V_{cc} potential. As you can see, the negative potential at point X is directly connected to the base of Q_2 , keeping it forward biased and conducting heavily. If switch A is now closed momentarily (simulating a SET input), the base of Q_2 is grounded and the forward bias is removed. This causes Q_2 to cut off and causes its collector to go negative, applying forward bias to Q_1 . Then transistor Q_1 conducts heavily, maintaining the base of Q_2 at ground potential. If switch B is closed momentarily, the circuit will change back to its other stable state— Q_2 conducting and Q_1 cut off. Thus when Q_2 conducts, the X output is negative or a binary 1, and Y is a binary 0; when Q_1 conducts, the Y output is 1 and X output is 0. (This circuit uses negative logic; the voltage level that represents a binary 1 is negative in respect to the level that represents a binary 0.)

Flip-flops, along with other devices, are used extensively in digital computers.

Storage Register

A storage register consists of a group of flip-flops (fig. 3-88), each capable of handling one bit (a 1 or a 0) of information. It is used to



20.473

Figure 3-88.—A four-bit register and associated counter.

store a word (two or more bits of information) temporarily.

The register in figure 3-88 represents a storage register that is capable of storing a four-bit (or less) word such as 1011. The lower group of flip-flops comprises the register, and the upper group forms an associated counter. Other storage registers are designed to handle longer words, and therefore they have more flip-flops. The number of flip-flops depends on the maximum word length expected.

Storage registers together with other devices are used in digital computers to perform mathematical logic computations such as addition and subtraction.

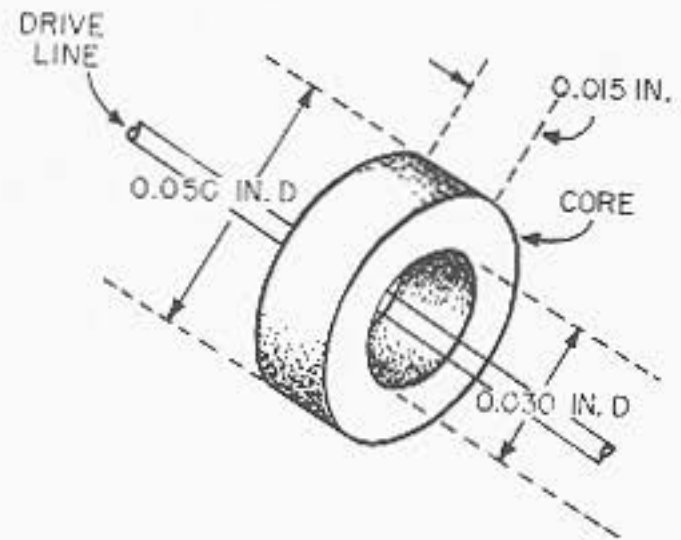
Storage Devices

Digital equipment utilizes various storage devices. This brief discussion is limited to some common magnetic devices used for storing information over a period of time.

The on-off principle using magnetic devices is easily understood if we let the magnetized condition represent binary 1 and the nonmagnetized condition represent binary 0. In the case of magnetic cores, each core is small, and the entire core is magnetized in one direction to represent 1 and in the opposite direction to represent 0. Magnetic drums and tapes represent data as small magnetized or nonmagnetized areas on their surfaces.

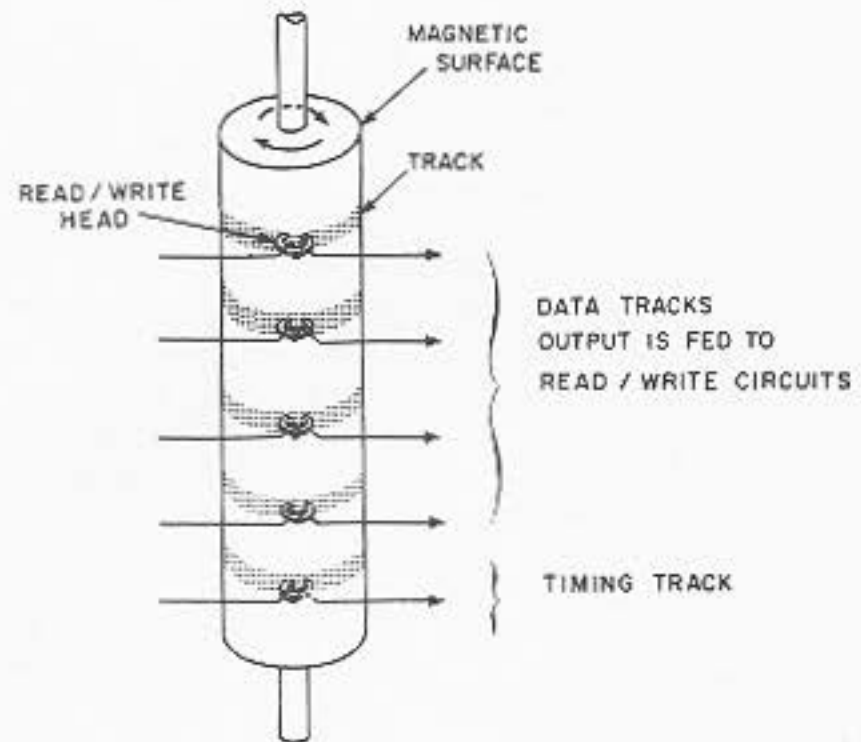
A representative magnetic core is shown in figure 3-89. Its outside diameter is .050 inch; its inside diameter is 0.030 inch; its thickness is 0.015 inch. The core is magnetized by current flowing through wires that are threaded through the core. Several cores are arranged in a flat panel inside a frame to make up a matrix. A computer that uses magnetic cores for its computations contains many of these matrices.

A magnetic drum (compared to a core) provides an inexpensive method of storing large amounts of data. The amount of data the drum is able to store, however, depends on the size of the drum. A representative drum, which may have a diameter from 5 to 24 inches, is shown in figure 3-90. The surface of the drum is divided into tracks or channels which encircle it. A number of read/write heads (at least one for each track) are used for recording and reading out information. The heads are placed a specified distance from the drum. For proper operation, this distance must be constant; therefore, the drum must be perfectly balanced. Each read/write head is connected in a separate circuit



124.54

Figure 3-89.—A magnetic core.



124.60

Figure 3-90.—Magnetic drum.

so that read or write operations can take place on any or all tracks simultaneously.

A third type of storage device is magnetic tape. It is similar to tape used with commercial tape recorders, except that a very high quality tape is required for greater accuracy. Seven-channel tape (commonly used in computers) is usually 1/2 inch wide and has a recording density of 100 to 500 binary bits per inch. This enables a 2,400 foot roll to store 3 to 16 million characters (bits of information). The main advantage of magnetic tape is its ability to store millions

of data bits inexpensively. Under ordinary operating conditions, magnetic tape is reusable many times; data on a used tape may be transferred to a new one.

Another storage device, commonly used in digital computers, is the magnetic disk. Several of these disks are used in each computer. They resemble phonograph records and are arranged in much the same way as a record stack in a modern "juke box." The main advantage of magnetic disk storage is the high storage capacity obtainable from a bank arrangement of several disks. Some magnetic disk systems can store over 5,000,000 coded digits.

PRINCIPLES OF OPTICS AND ORDNANCE OPTICAL INSTRUMENTS

The optical instruments used in naval fire control present a magnified image of the target to the observer's eye. At the same time, the observer sees an image of a reticle, or reference mark, located inside the instrument itself. By accurately superimposing the reticle image on the target image, the observer can establish an accurate line of sight to the target. The range-finder, by establishing two separate lines of sight, makes it possible to find the target range by a form of triangulation.

To form the reticle and target images, an optical instrument must control the path of the light that passes through it. It does so by the use of lenses, prisms, or mirrors, or some combination of these elements. This section briefly reviews the behavior of light as it passes through optical elements. Familiarity with these basic principles will make possible a general understanding of most optical instruments.

NATURE OF LIGHT

Light is a form of energy. It travels from one point to another in the form of waves. Except for their wavelengths and frequency, light waves are identical with other types of electromagnetic radiation, such as radio waves and gamma rays. The wavelength of visible light ranges from approximately 0.35 micron to 0.70 micron. (A micron is one thousandth of a millimeter.) The color of light depends on its wavelength. In order of increasing wavelength, the colors are violet, indigo, blue, green, yellow, orange, and red. Radiation of longer wavelength than visible red is called infrared, or heat radiation. Beyond infrared are the radio waves.

Radiations shorter than visible violet are (in the order of decreasing wavelength): ultraviolet, X-rays, gamma rays, and cosmic rays.

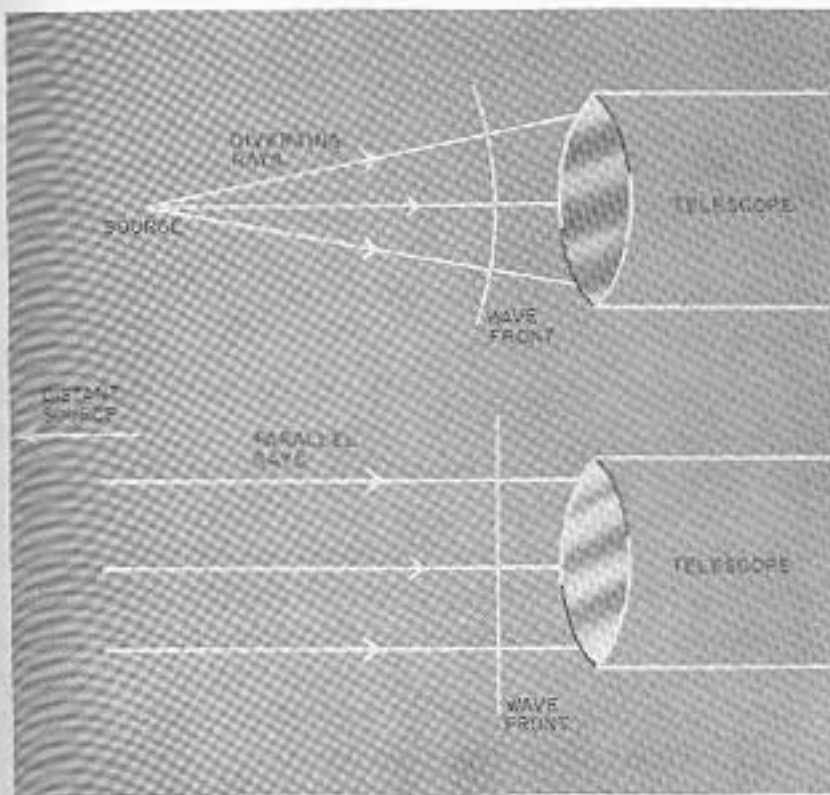
If a small object is dropped into water, a series of concentric circular waves will spread out from the point of impact. This provides a familiar analogy for the behavior of light waves. Waves in water, however, move on a two-dimensional surface; light waves move in three dimensions. The waves that move outward from a small source of light may be thought of as a series of concentric, rapidly expanding spheres.

In the study of optics it is convenient to trace the path of light rays, rather than waves. At any given point, a light ray is an imaginary line used to show the direction in which the light wave is moving. Since the wave is an expanding sphere, its direction of movement at any point is along a radius of that sphere. A ray, then, is a radius of the sphere formed by the wave front, and is at right angles to the wave front.

A telescope or similar instrument will receive only a small part of the light emitted by the source. Each wave that enters the instrument, therefore, is only a small part of a sphere. If a wave comes from a nearby source, the part of it that enters the instrument will be strongly curved. And the rays (radii of the spherical wave) that enter the instrument will be diverging. But if the source is at a great distance, the part of the wave that enters the instrument will be nearly flat; for all practical purposes it can be considered a plane. Since the rays are perpendicular to the wave front, the rays that enter an optical instrument from a distant point can be considered parallel. Figure 3-91 should make this clear.

In the drawings in this section only a few rays are used to represent the light that enters the instrument. But remember that light rays enter an optical instrument at every point on its first lens. In diagrams of optical instruments, only a few of these rays will be shown. Three rays are usually enough to show the path of light and formation of images within the instrument.

Light travels at about 186,000 miles per second in air. In a denser medium, it moves more slowly. For example, the velocity of light in water is about 140,000 miles per second; in glass it ranges from 95,000 to 127,000 miles per second, depending on the optical density of the glass. This difference in velocity makes it possible for an optical instrument to control the path of light, to form images, and to magnify them.



12.230

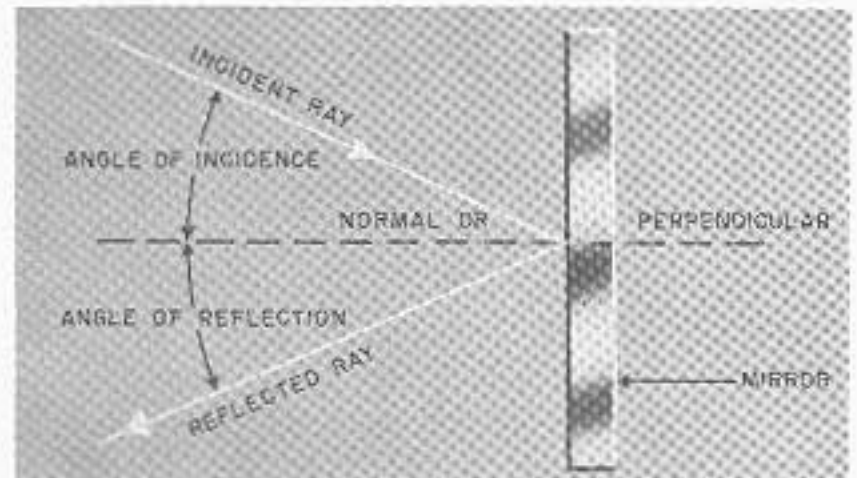
Figure 3-91.—Light rays from nearby and distant sources.

REFLECTION

When light traveling in air strikes the surface of a mirror, most of it is reflected back into the air (fig. 3-92). The incoming ray is the incident ray. The normal is an imaginary straight line, at right angles to the mirror surface, passing through the point of incidence. The angle of incidence is the angle between the incident ray and the normal, and the angle of reflection is the angle between the normal and the reflected ray. The law of reflection states, first, that the angle of incidence is equal to the angle of reflection; and, second, that the incident ray, the reflected ray, and the normal all lie in the same plane.

When light traveling in air strikes the surface of clear glass, a part of the light will be reflected; the rest will enter the glass. If the incident ray lies on the normal (zero angle of incidence), about 5% of the light will be reflected. As the angle of incidence is increased, the amount of reflection increases. As the angle of incidence approaches 90° , the reflection approaches 100%.

When light traveling in glass strikes an air surface, part of the light will be reflected back into the glass; the rest will enter the air. At zero angle of incidence, about 5% of the light



110.30

Figure 3-92.—Reflection at a mirror surface.

will be reflected back into the glass. As the angle of incidence is increased, the amount of reflection increases rapidly. When the angle of incidence becomes greater than the critical angle, all of the light will be reflected back into the glass; none of it will enter the air. (The critical angle for various types of glass, at an air surface, varies from 37° to 43° .) This property of a glass-air surface, called total internal reflection, is used in many optical instruments. Figure 3-93 shows how the line of sight may be deviated through an angle of 90° by internal reflection at the diagonal face of a right-angle prism.

If the prism in figure 3-93 is rotated (in the plane of the page) through any angle, the angle of incidence will be changed by the same angle. The angle between the incident ray and the reflected ray will therefore be changed by twice that amount.

REFRACTION

When light passes from air into glass, its speed will decrease. It will resume its original speed when it leaves the glass and enters the air. If a ray of light strikes an air-glass or a glass-air surface at an oblique angle, its change of speed will result in a change of direction. Figure 3-94 shows why this is so.

The diagonal lines in the figure represent the approaching light waves. Since they are coming from a distant source, they are parallel. As each wave enters the glass, various points along the wave front will slow up successively, and as a result the entire wave front will change its angle. Since the direction of movement, shown by the

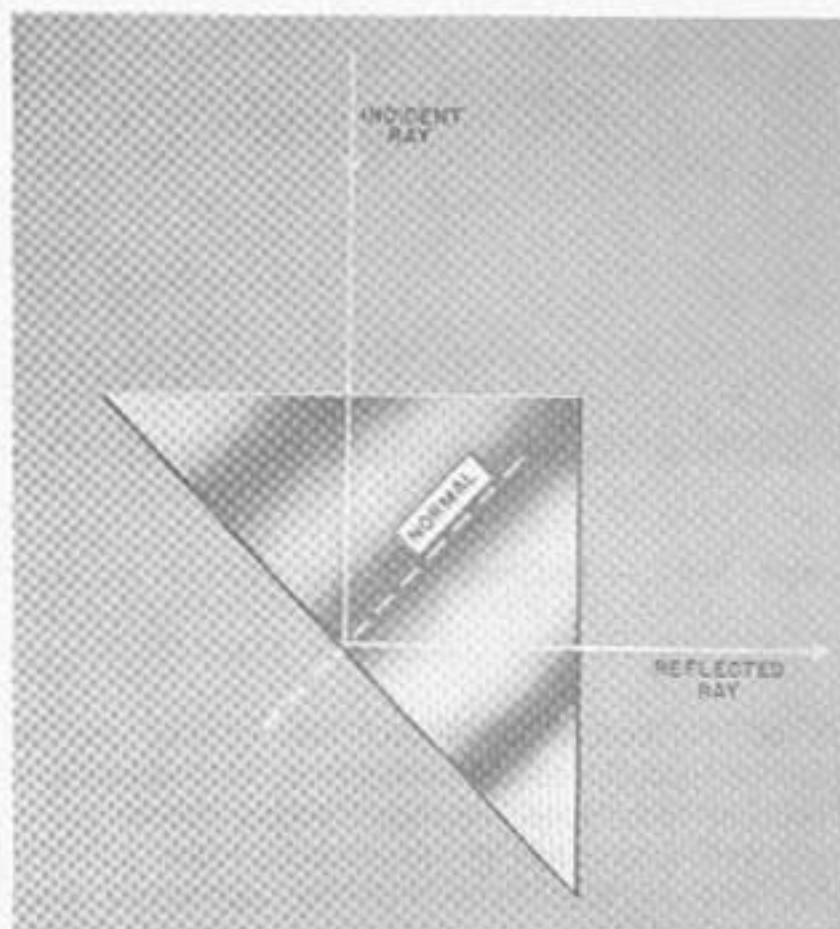


Figure 3-93.—Total internal reflection in a prism, 110.31

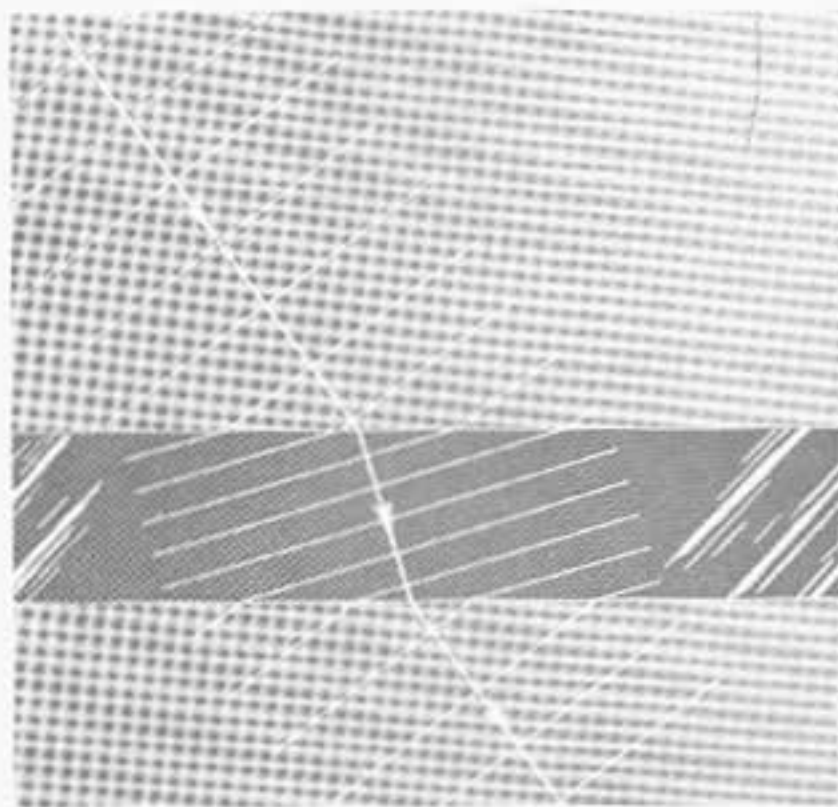


Figure 3-94.—Path of wave fronts through a sheet of glass, 12.232

ray, is at right angle to the wave fronts, the light bends as it enters the glass. The opposite effect occurs when the waves leave the glass. Now the various points along the wave successively increase their speed. As a result, the emergent waves are parallel to those that entered the glass. And the emergent ray is parallel to the incident ray, although it has been displaced on one side.

Figure 3-95 illustrates some of the terms used to describe the refraction, or bending, of light. The LAW of refraction states that light bends toward the normal when it passes into a denser medium; it bends away from the normal when it passes into a less dense medium. The exact angle of bending may be easily calculated. It depends on the angle of incidence, and on the optical density of the two media. Optical density is expressed as index of refraction. (The index of refraction of a vacuum is 1; the index of refraction of air is approximately 1. The various types of optical glass range from approximately 1.5 to 1.96.)

When the two glass surfaces are parallel, as in figure 3-94, the emergent ray is parallel to the incident ray. When such elements occur in optical instruments (as, for example, in the end windows of rangefinders), they do not deviate the line of sight. However, if the two glass surfaces are not parallel, the line of sight will be deviated, as in figure 3-96. Thin prisms are used

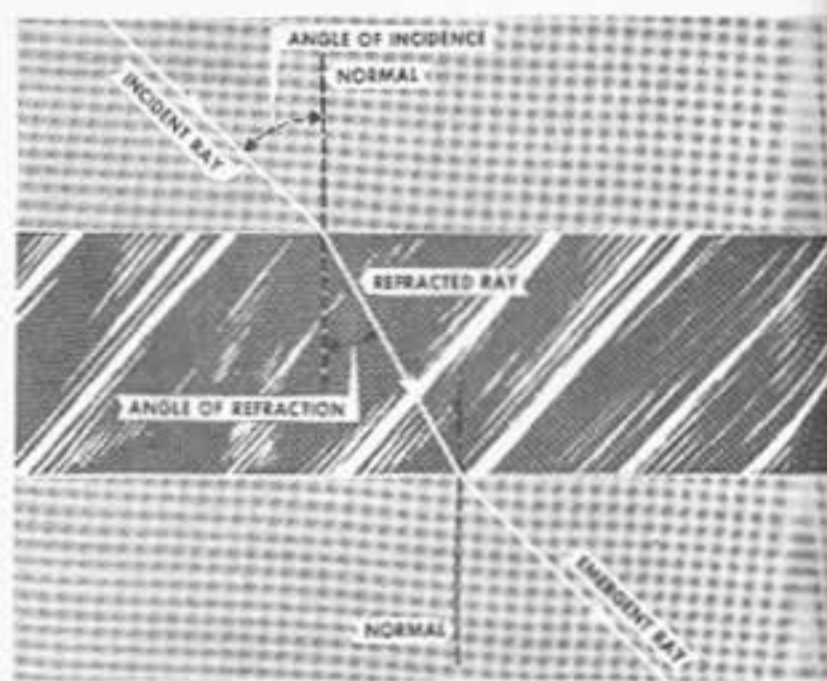
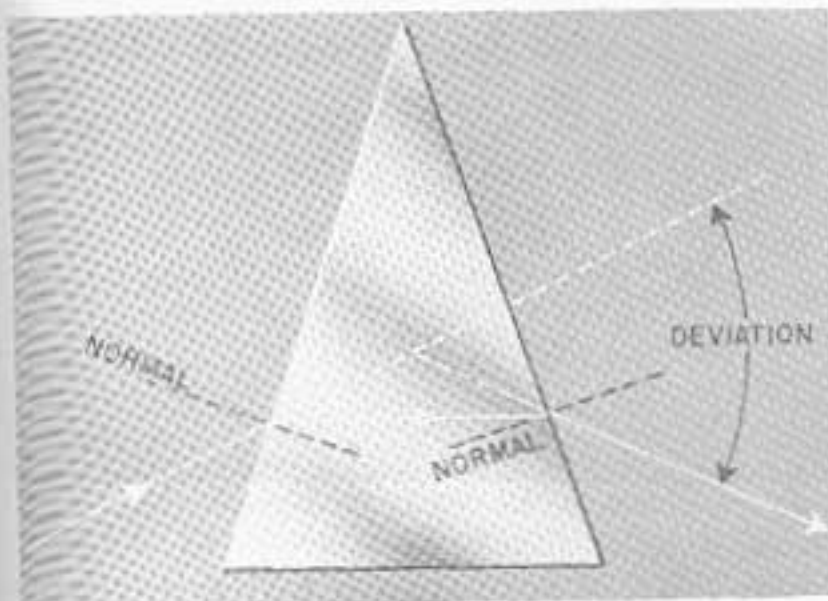


Figure 3-95.—Terms used to describe the refraction of light, 12.233



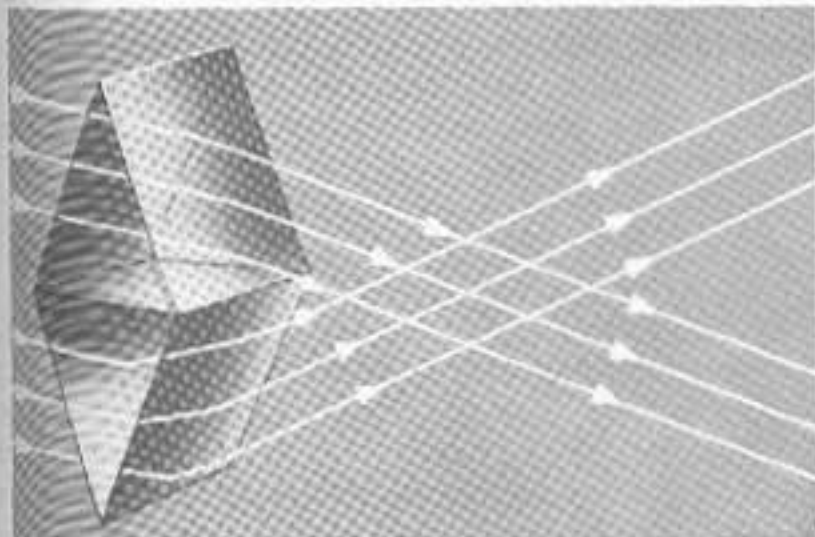
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Figure 3-96.—Refraction in a prism.

in rangefinders to deviate the line of sight through a small angle.

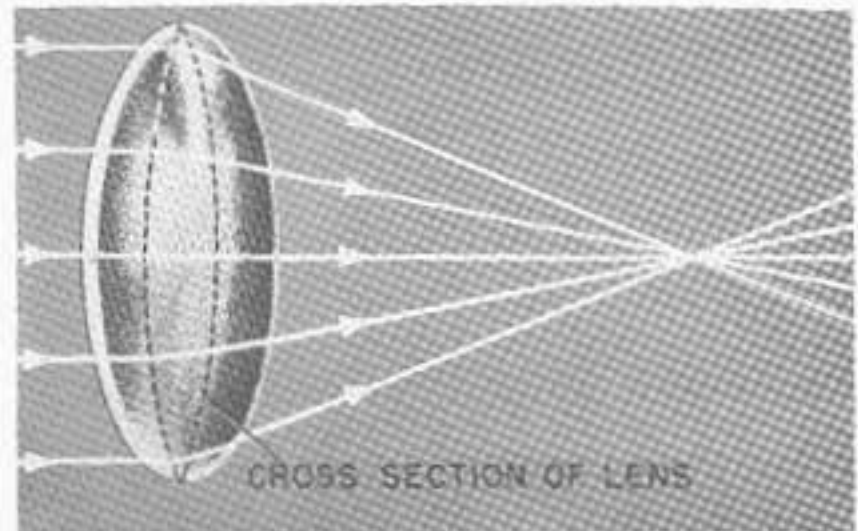
IMAGE FORMATION

Figure 3-97 shows the path of parallel rays of light on passing through two prisms mounted base to base. Each ray will be deviated toward the base of the prism it passes through. The upper rays deviate downward, and the lower rays upward. All the rays emerging from the upper prism are parallel, and all the rays emerging from the lower prism are parallel. But if the surfaces of the two prisms in figure 3-97 are rounded off to form a convergent lens, as in figure 3-98, each ray will have a different angle



110.33

Figure 3-97.—Deviation of rays in two prisms.



12.234

Figure 3-98.—Deviation of rays passing through a convergent lens.

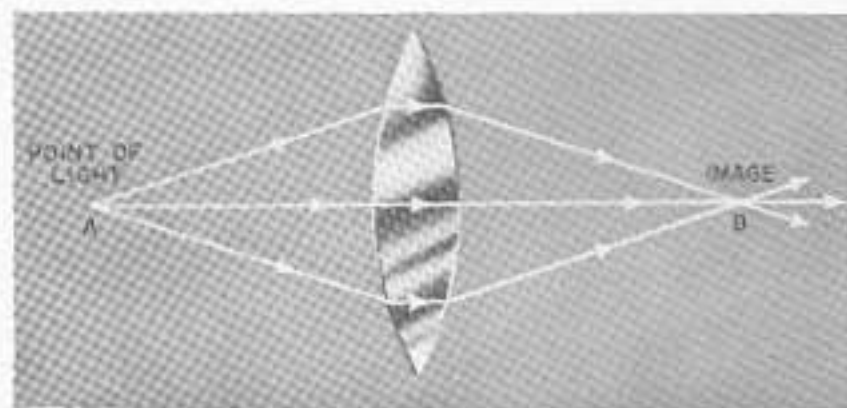
of incidence, and will therefore bend to a different degree. The ray that passes through the center of the lens is normal to both surfaces, and does not bend. Such a ray is said to lie on the optical axis of the lens. The greater the distance from the axis, the greater the angle of incidence at each surface, and the greater the deviation toward the axis. If the lens is perfect, all rays parallel to the axis will meet at a single point, called the focal point of the lens.

Every lens has two focal points, one on each side. The two focal points are equally distant from the lens. The distance from either focal point to the center of the lens is the focal distance or focal length of the lens.

Figure 3-99 shows three rays of light diverging from a point source and passing through a convergent lens. (An infinite number of rays strikes the lens, but three suffice to show what happens.) All the rays from A that pass through the lens converge and meet at point B. Point B is therefore the image of A. Note that B is itself a source of light, since rays diverge from it just as they do from A. If a sheet of paper is held at B, the image may be seen as a bright point on the paper. If B lies between the lens and the observer's eye, the image may be inspected directly.

In figure 3-99 the distance from point A to the lens is greater than the focal length. If the source were at or closer than the focal point, the rays emerging from the lens would not converge.

A target or other object is visible when it reflects light toward the observer. For each point on the target, a convergent lens will form



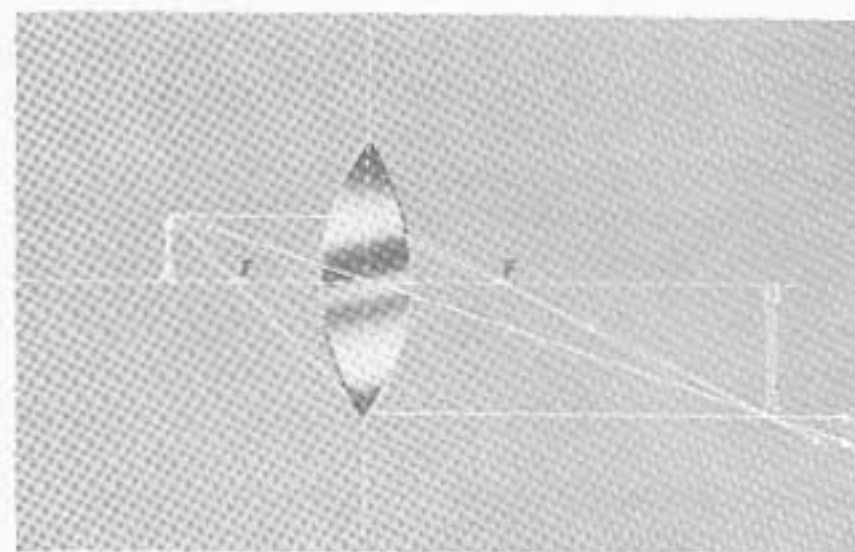
110.34

Figure 3-99.—Image of a point.

a corresponding image point behind the lens. These image points together form a real image of the whole target which would appear inverted on a flat sheet of paper held at this location (see figure 3-100).

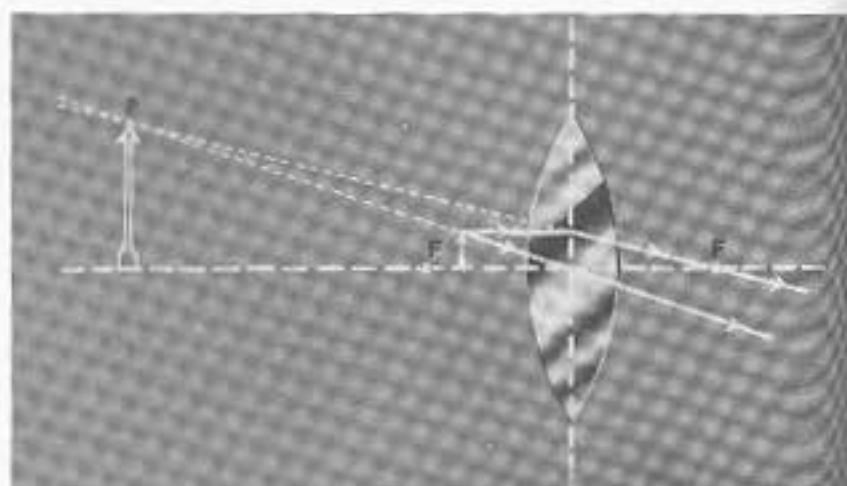
VIRTUAL IMAGES

Figure 3-101 shows the path of several rays diverging from the point of an arrow when the arrow lies between the lens and its first focal point. The lens makes the rays less divergent, but does not bring them to a focus. However, an observer on the right side of the lens may see the point (and the rest of the arrow) by looking through the lens. Since the observer is accustomed to assuming that light travels in straight lines, it will appear to him that the rays from the arrow are actually coming from P, and he



110.35

Figure 3-100.—Formation of a real image by convergent lens.



110.36

Figure 3-101.—Formation of a virtual image by a convergent lens.

sees an image of the arrow apparently located at P. However, if a sheet of paper is held at P, no image will be formed on the paper. The arrow image at P is therefore not a real image. No rays actually diverge from the arrow at P, as they do from a real image; they merely appear to. The arrow at point P is said to be a virtual image.

Note the following characteristics of the virtual image formed by a convergent lens:

1. It is erect. (The real image formed by such a lens is inverted.)
2. It appears to be farther behind the lens than the light source.
3. It is enlarged.

A single convergent lens may be used as a simple magnifying glass by holding it close to the eye. The object distance is adjusted until the image appears in sharp focus when the muscles of the eye are completely relaxed. The object distance will then be equal to the focal length of the lens, and the virtual image will lie at infinity.

ELEMENTARY TELESCOPES

A telescope provides, to an observer's eye, an enlarged image of a distant object. A single lens cannot be used to provide an enlarged image of a distant object. However, a telescope can be made by using a combination of two or more lenses. The first lens, called the objective, forms a real image of the distant object. The observer may examine the real image through a second lens, called the ocular or eyepiece lens.

The ocular serves as a simple magnifying glass. It forms an enlarged virtual image of the real image formed by the objective.

Figure 3-102 shows the path of rays from a distant target through a simple telescope. The drawing shows two rays from the head of the arrow converged by the objective to meet at point B. A real, inverted image of the target lies in a vertical plane through B. After crossing at B, the two rays diverge and strike the ocular lens, which makes these rays less divergent. To the observer's eye, the two rays appear to diverge from point C. The virtual image of the target therefore lies in a vertical plane through C. (The ocular is usually adjusted so that this image is at infinity; the drawing shows the image at C only for convenience.) To the observer, the virtual image appears to be considerably larger than the object itself. The telescope therefore forms an enlarged image of the distant object.

In some instruments, the ocular is so mounted that the observer may adjust its distance from the objective to focus on the real image of a close target. In the sight telescope, this focusing adjustment is unnecessary, since the target is always at a considerable distance.

The real image formed by the objective lens and the enlarged virtual image seen by the observer are inverted. To function as a useful fire control instrument, the telescope must present an erect image. One way to do this is to add an erector lens, used as a second objective with the first real image as its target. The erector forms a real image of the first real image and inverts it a second time. The ocular then forms an enlarged, erect, virtual image of the second real image.

A few telescopes, and most binoculars, use prisms to erect the image, by internal reflection

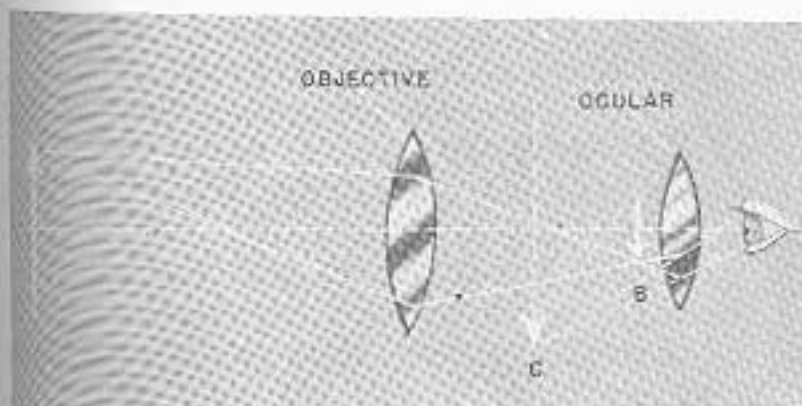
at the various prism faces. Figure 3-103 shows typical ways in which prisms may be used to erect an image.

To provide a fixed line of sight through a telescope, a reticle may be added. The reticle is a flat piece of glass on one surface of which suitable reference marks, often two lines (called crosshairs or crosswires), intersecting at a right angle, have been engraved.

In practice, it takes more than four optical elements (objective lens, erector lens, ocular lens, reticle) to make a sight telescope. Additional lenses are necessary to correct the aberrations or distortions of the optical system. Or an individual lens may be constructed of several carefully cemented pieces of glass. In a "simple" telescope, the objective may consist of two or three separate lenses, cemented together. The erector and ocular are each made up of from two to four separate lenses. The spacing of the various elements must be maintained precisely; moisture must be excluded, and the interior parts and cementing compounds must be protected against tampering, and corrosion and other causes of deterioration. All Navy optical equipment is therefore hermetically sealed. Fixed equipment such as gun and director sight telescopes, rangefinders, etc., is in addition charged with dry helium or nitrogen gas.

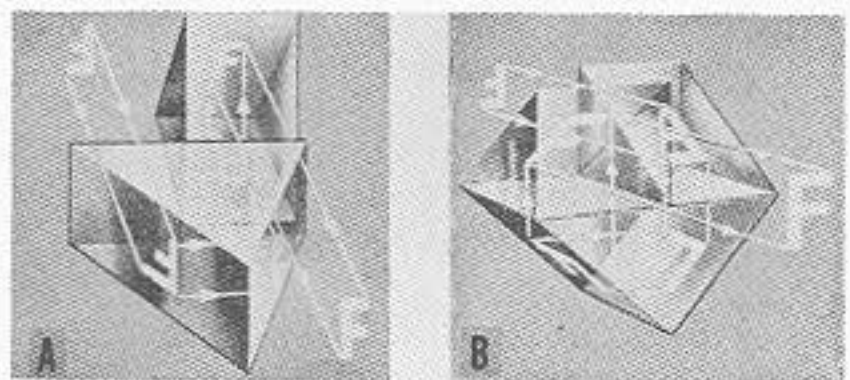
SIGHTS

The primary purpose of any sight on a gun or director is to establish a line of sight from the observer to the target. When the target is distant, the sight may in addition provide an enlarged image of the target to improve the accuracy of the line of sight. In the type of telescope described above, this can be done by using the reticle crosshairs to establish the line



110.37

Figure 3-102.—Simple telescope.



110.38

Figure 3-103.—Prism erecting systems.

of sight, while the remainder of the optical system enlarges the target image.

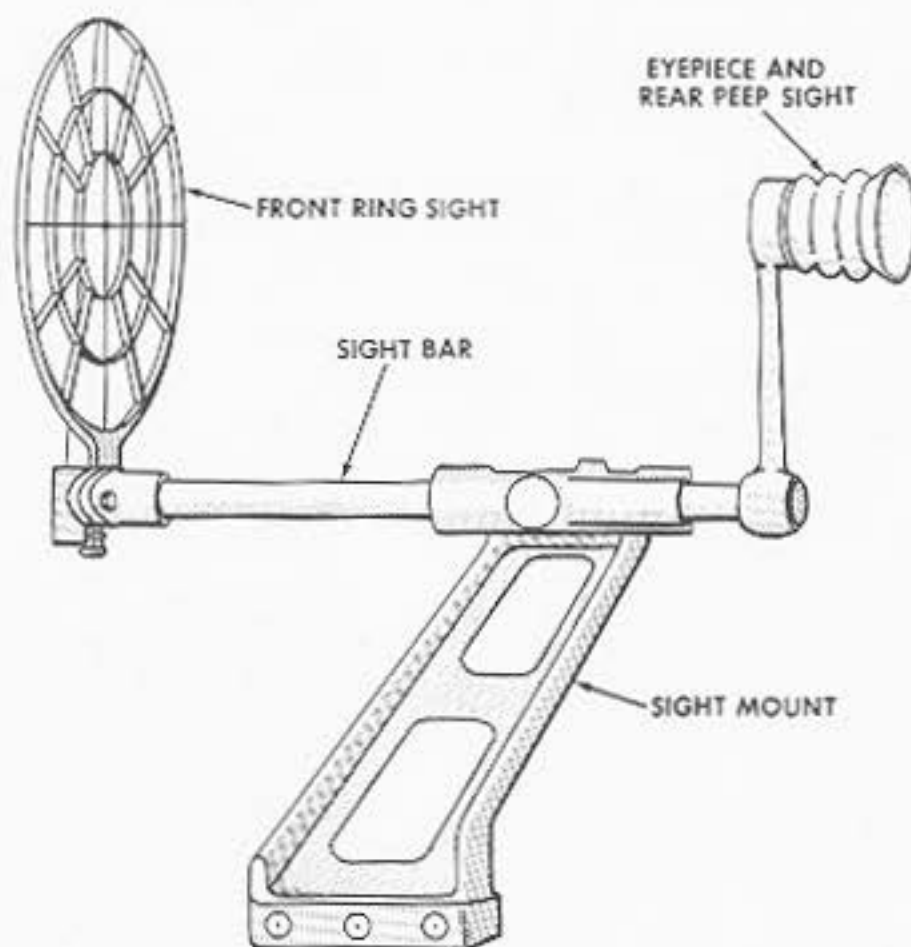
Chapter 6 will explain the geometry of the fire control problem and the function of the optical sight and the line of sight in it. Here let us concentrate on the optical systems used in sights. No specific marks and mods of sight are described here, but we can identify three general types of sight:

1. Simple sights without optical systems.
2. Telescopic sights with fixed optical components.
3. Sights with movable optical components.

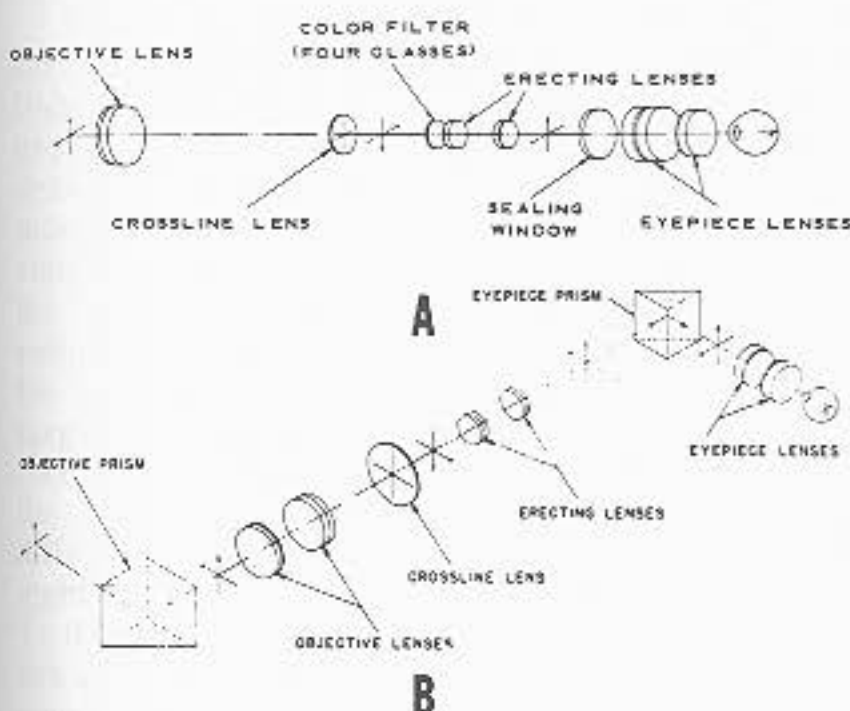
SIMPLE SIGHTS WITHOUT OPTICAL SYSTEMS. An example of this is the peep sight used on infantry small-arms weapons, or the ring sight (figure 3-104) installed for emergency use on some antiaircraft gun mounts. The observer looks through the eyepiece. When he has the target in line with the center of the front sight, the line of sight to target is parallel with the gun bore. To provide for ballistic and other fire control corrections, the observer must offset the line of sight so that it diverges from the gun bore by a certain angle. He can judge the amount of offset in this simple sight

by using the concentric rings and spokes of the sight instead of the sight's center to align the line of sight to target. Use of this type of sight is restricted to targets at short ranges in emergencies when other methods are not available. Effective use of the sight to direct gunfire requires considerable training, and at best it is not as accurate as other systems.

TELESCOPIC SIGHTS WITH FIXED OPTICAL COMPONENTS. Sights of this type are used in antiaircraft rapid-fire gun mounts, in fire control directors, and in heavy turret mounts. Two typical systems are diagrammed in figure 3-105. The main difference between them is that one has all the elements in a straight line, while the other uses prisms. In the direct system (part A in the figure), the objective lens forms an inverted real image of the target. This image falls on the engraved surface of the cross-line lens, or reticle. Between the reticle and the erecting lenses are three color filters and a plain glass filter, so mounted that the operator can bring any one of them into the line of sight. A filter will, under some conditions, increase the contrast of the target image, and decrease glare from sky and water. The erecting lenses erect the target image, and form a real image



84.206
Figure 3-104.—Open ring sight.



110.39

Figure 3-105.—Optical systems of telescopic sights with fixed optical components. A. Direct (no prisms); B. Indirect (prismatic).

near the eyepiece of the crosslines superimposed on the target. The sealing window, of plain glass, helps to keep out dirt and moisture. The eyepiece may be moved to focus the image without affecting the seal of the rest of the instrument.

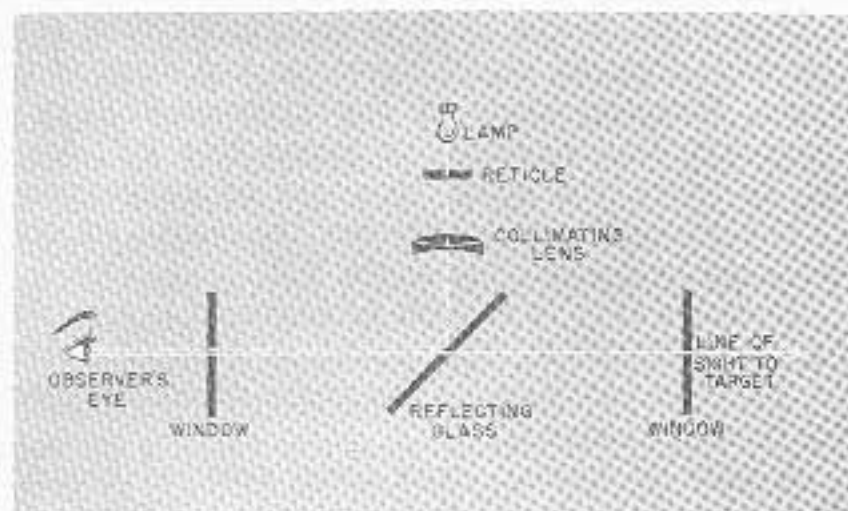
The indirect optical system, shown in part B of figure 3-105, is basically similar. The principal difference is that the line of sight is twice reflected by prisms, so that most of the telescope lies at right angles to the line of sight from gun to target. Two separate objective lenses, or two lenses cemented together, form the first real image. Other varieties of this kind of optical system may use a single prism. To adjust the offset to the gun bore, the telescope is moved as a whole.

SIGHTS WITH MOVABLE OPTICAL COMPONENTS. There are two main varieties of sight with movable optical components.

In one, which is used in heavy antiaircraft gun mounts, the optical system in principle resembles that illustrated in part B of figure 3-104, except that an additional prism as well as the objective or head prism are linked mechanically to a sight setting system on the gun mount. Thus the line of sight can be offset without moving the entire telescope. (Such a system may additionally contain erecting and other prisms.)

In the other variety of sight with movable optical components, shown in figure 3-106, the optical system includes a reflecting glass, a collimating lens, and a lamp. This kind of optical system is used with gyroscopic lead-computing sights (explained in a later chapter). The two windows seal the instrument to keep out dust and moisture. The system illustrated here does not magnify the target image. The operator observes the target directly, through the two windows and the clear reflecting glass. The lamp illuminates the reticle, which is located at the focal point of the collimating lens. Rays of light from the reticle are therefore parallel after they pass through the lens and are reflected toward the operator by the reflecting glass. Because these rays are parallel, the reticle image appears to lie at infinity, and the reticle will not change its apparent direction when the operator moves his head from side to side. The sight's gyroscopic mechanism rotates the reflecting glass so that it will deflect the reticle image as seen by the operator. The operator then trains and elevates the gun mount to keep the reticle on target; this automatically offsets the gun bore as required by the computed solution to the fire control problem.

In another variant of this principle, the reticle image is transmitted through the reflecting glass, while the target image is reflected. The principle remains the same, except that it is the target image rather than the reticle image that is apparently shifted. It is also possible to use two mirrors, one for elevation and one for train, combined with a true



110.40

Figure 3-106.—Optical system for a lead-computing sight. Simplified.

telescopic optical system, filters, and an additional device called a "pellicle" (actually a kind of half-mirror) which can reflect a radar scope image to the operator. This arrangement makes it possible to use the sight even when (as in fog or darkness) no optical target image is available.

RANGEFINDERS

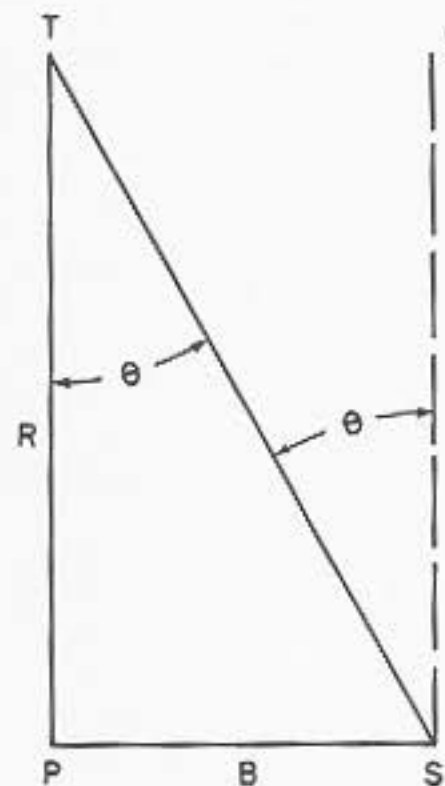
As you will find in chapter 6, one important item of information needed for solving the fire control problem is the range to the target. One way of getting this information is to use an optical rangefinder. Let's briefly discuss the principle of operation of the most used type—the stereoscopic rangefinder. (Another type, not taken up here, is the coincidence rangefinder, which is similar in external appearance, somewhat different in optical principle, and not as versatile.)

The rangefinder consists essentially of a system of optical units assembled in a long, cylindrical tube, mounted in a turret or director, so that only the protruding ends are exposed. On its forward surface, the tube has a window at each end. Through these windows, the operator establishes two separate lines of sight to the target. The distance between the windows is the base length.

The rangefinder determines range by solving a right triangle in which one side (the base length) and two angles are known. Range is one of the unknown sides. In figure 3-107, TPS is the range triangle. PS is the known base length (B) of the rangefinder. The target lies at T; PT is the target range (R). TPS is always a right angle; the line of sight from the left end window is at a right angle to the rangefinder tube axis. The two lines of sight converge and meet at the target, forming angle of convergence θ . SI is an imaginary line parallel to range line PT. Angle TSI is therefore equal to angle of convergence θ . The rangefinder measures the angle of convergence by measuring angle TSI.

Because this is a right triangle, it is apparent that $R = B \cot \theta$. The equation may be solved for R, then, as soon as the angle of convergence has been measured.

A pair of human eyes uses several clues in its perception of relative distance. Of these, the one on which the functioning of the stereoscopic rangefinder depends is convergence, i.e., the sensing of angle θ (fig. 3-108) by the muscular effort required for both eyes to see a single

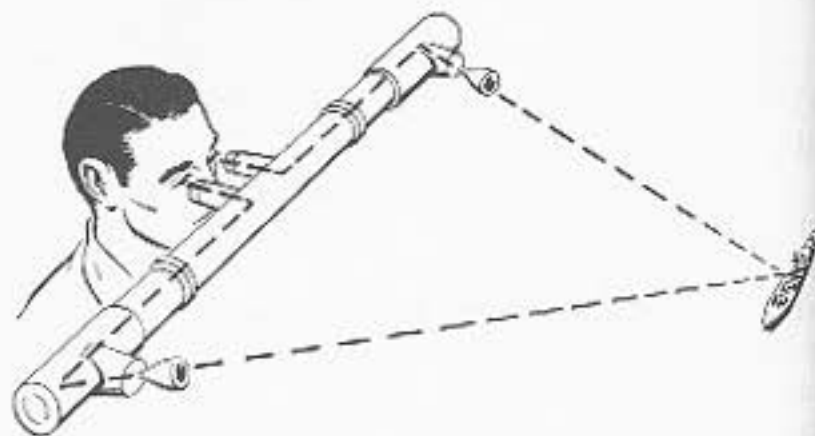


110.41

Figure 3-107.—The range triangle.

fused image. You can demonstrate this to yourself in exaggerated fashion by first holding your finger a foot in front of your nose, and focusing on it; then, without shifting your line of vision, focusing on an object ten feet or more distant.

The "base length" (or pupil-to-pupil distance) of a pair of human eyes is about 2.75 inches. Beyond a range of about 450 yards or so the lines of sight of the two eyes converge so little that changes in angle θ are too small to sense. If the base length could be increased, θ could be reliably measured for much longer ranges. In one sense, as shown in figure 3-108, that is what the rangefinder is designed to do.



55.289

Figure 3-108.—Function of the rangefinder.

Figure 3-109, shows in simplified schematic form the optical system of a stereoscopic range-finder. (Each of the two telescopes contains an erector system, which has been omitted from the drawing for the sake of simplicity.) The diamonds represent the reticle pattern; the arrows represent the two images of the target. Because the apparent angle of convergence of the two reticles is fixed, the reticle pattern appears to lie at a certain fixed distance in space. If the target happens to be at this distance, target and reticle will appear to be equally distant from the observer. If the target's convergence angle differs from the reticle's, the right-hand line of sight to target must be adjusted till they match. To do this, the knob on the right is used to rotate two compensator wedges—thin prisms with sides nearly parallel—through which the light from the target passes. But since they are not parallel, rotating the prisms will deflect the line of sight. This corresponds to changing angle θ (fig. 3-106).

Figure 3-110 shows the image as seen in the stereoscopic rangefinder eyepieces. This represents two images (one for each eyepiece) blended stereoscopically to form a single impression. If the rangefinder operator turns his range knob until the target appears to be at the same range as the large central diamond, the range scale will read the actual range to the target. The other reticle markings (wander marks or ranging marks) are used in estimating how far from the target projectiles are bursting or falling, and in correcting fire accordingly.

ELEMENTS OF SOUND

Sound is the physical cause of your sensation of hearing. Anything that you hear is a sound. But there are also sounds that you cannot hear.

Sound travels in the form of waves. These waves vary in length. A long wave length is heard as a low-pitched sound, a short wave length is heard as a high-pitched sound. A complete wave length is called a hertz. If the sound is below about 20 hertz (abbreviated Hz) or above 15,000 hertz, most people cannot hear it. The range between, which can be heard, is called the audible range and the sounds you hear are known as sonics. Sounds below this range—below 20 hertz—are subsonics. Sounds above this range—above 15,000 hertz—are ultrasonics.

In order to have sound, it is necessary to have a sound source which can vibrate, and a medium to transmit the vibrations. And, for our purposes, it is necessary also to have a detector.

Anything which moves rapidly to and fro, or vibrates and thus disturbs the medium around it, may become a sound source. Bells, radio loud-speaker diaphragms, the human voice, and musical instruments are familiar sound sources.

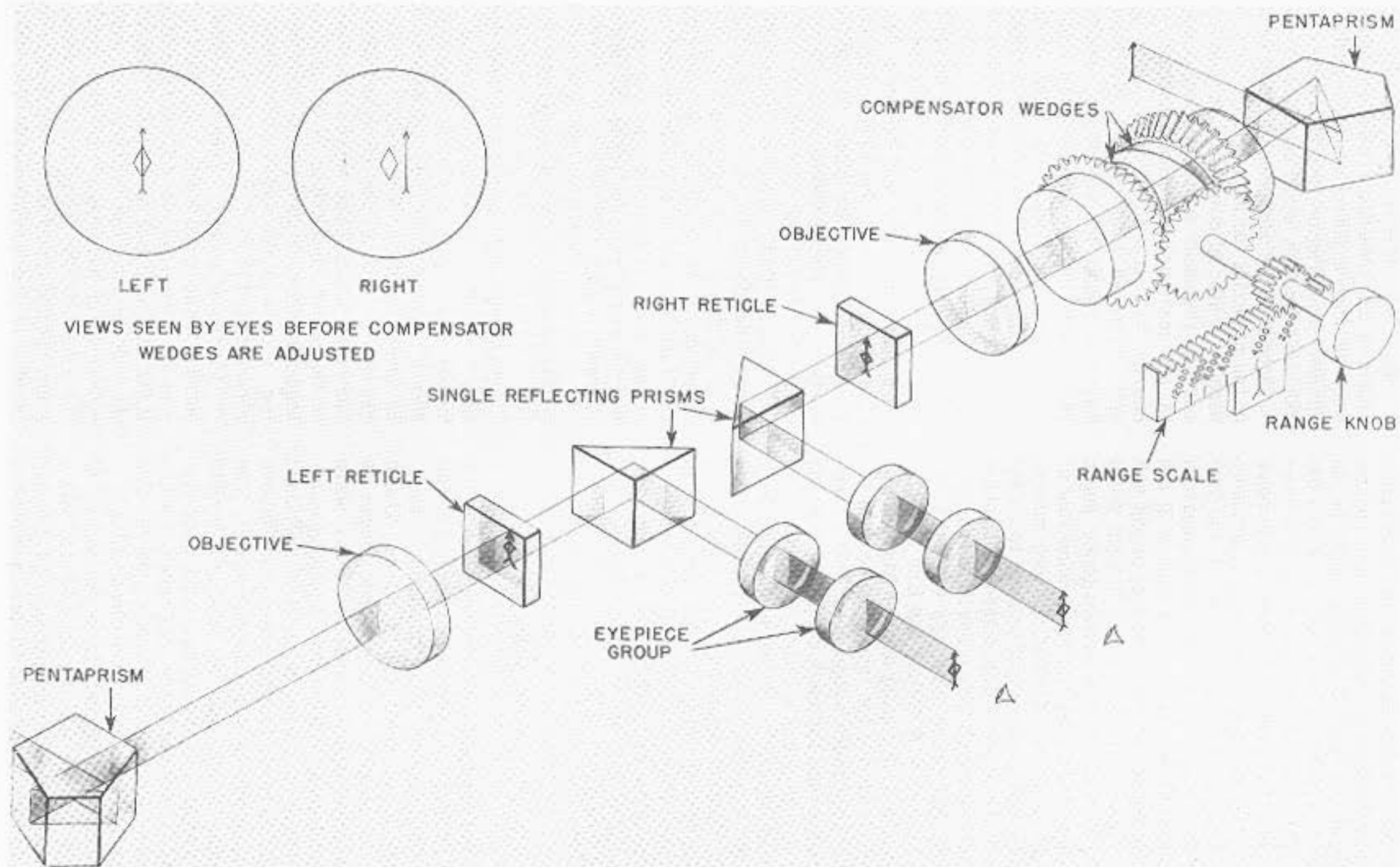
Sound waves are passed along by the particles of the material through which they travel. Therefore, a material substance, a medium, is necessary to transmit sound waves. A sound medium is any material substance through which sound energy will travel. It may be a gas (such as air), a liquid (water), or a solid (steel). The medium must be something material, or the sound will not be transmitted. Sound will not travel through a vacuum. Most of the time you are mainly concerned with sounds transmitted through air, but in sonar, you are interested in the liquid medium—water.

Commonly, the detector of sound is the human ear. It receives part of the sound wave energy from the medium, and converts it into an impulse that goes to the brain. Electrical devices like microphones or other transducers can also respond to sound waves and convert them into electrical impulses. (In general, a transducer is any device that converts electrical signals to some other form, or vice versa.) These impulses may be reproduced again as sounds or in some other way—for example, as spots on a cathode-ray tube. Although the human ear can detect as sound only vibrations in the audible range, microphones can be made to detect sounds of any wavelength.

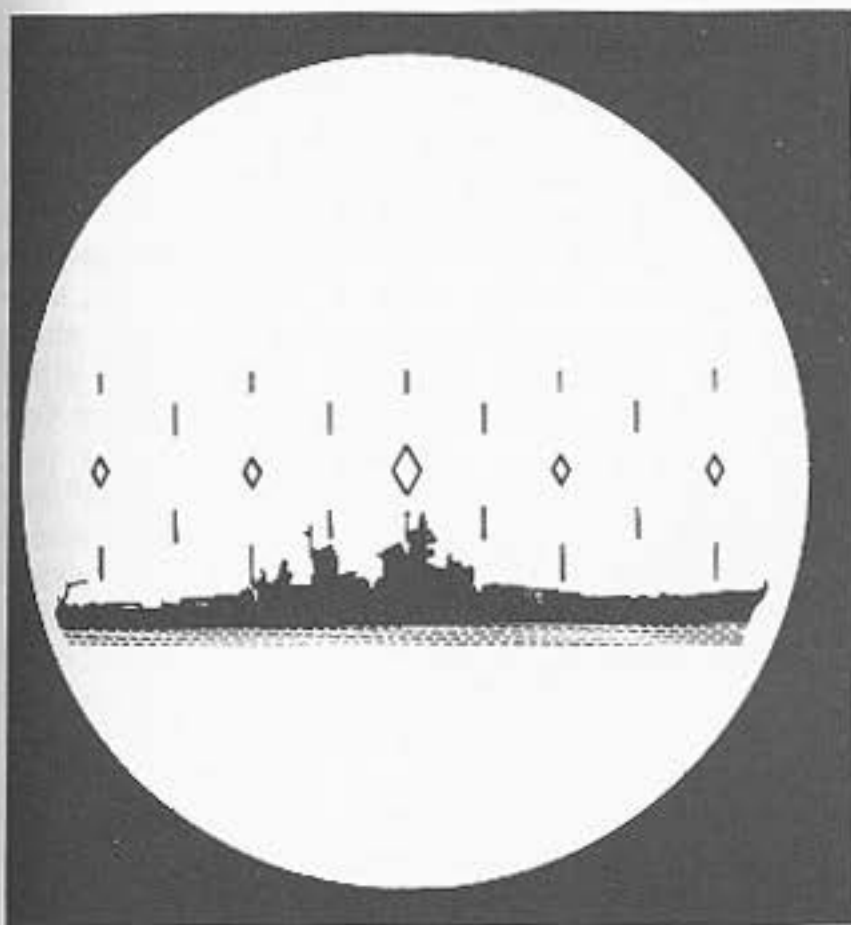
CHARACTERISTICS OF WAVES

TRANSVERSE WAVES. If you throw a stone into a quiet pool, series of circular waves will travel away from the disturbance. Figure 3-111 shows such waves diagrammed as though seen in cross section. The water waves are a succession of crests and troughs. Water waves are known as transverse waves because the motion of the water molecules is up and down, at right angle to the direction in which waves are traveling. A cork on the water bobs up and down as the waves pass by.

Although sound waves are not transverse waves, transverse waves (fig. 3-111) like the ripples on a water surface illustrate clearly the notions of amplitude and cycle. Before you threw the stone into the water, the water level (if perfectly undisturbed) was just halfway between the crest and the trough of each wave. The maximum displacement of the surface from this "zero level" is the amplitude of the wave motion. A

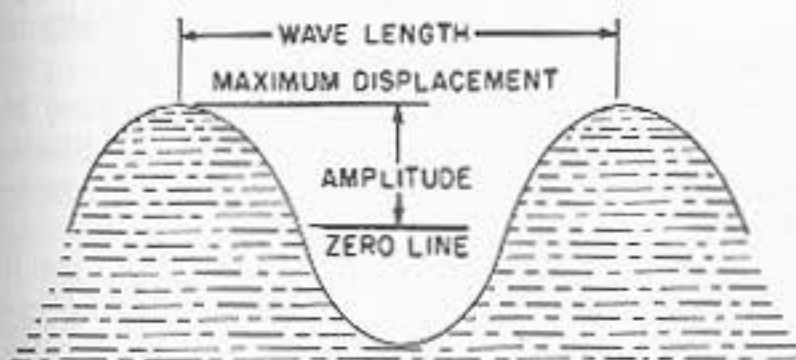


110.42
Figure 3-109. — Elementary stereoscopic rangefinder.



55.294

Figure 3-110.—Reticles and target as seen in stereoscopic rangefinder eyepiece.



71.19

Figure 3-111.—Transverse water wave.

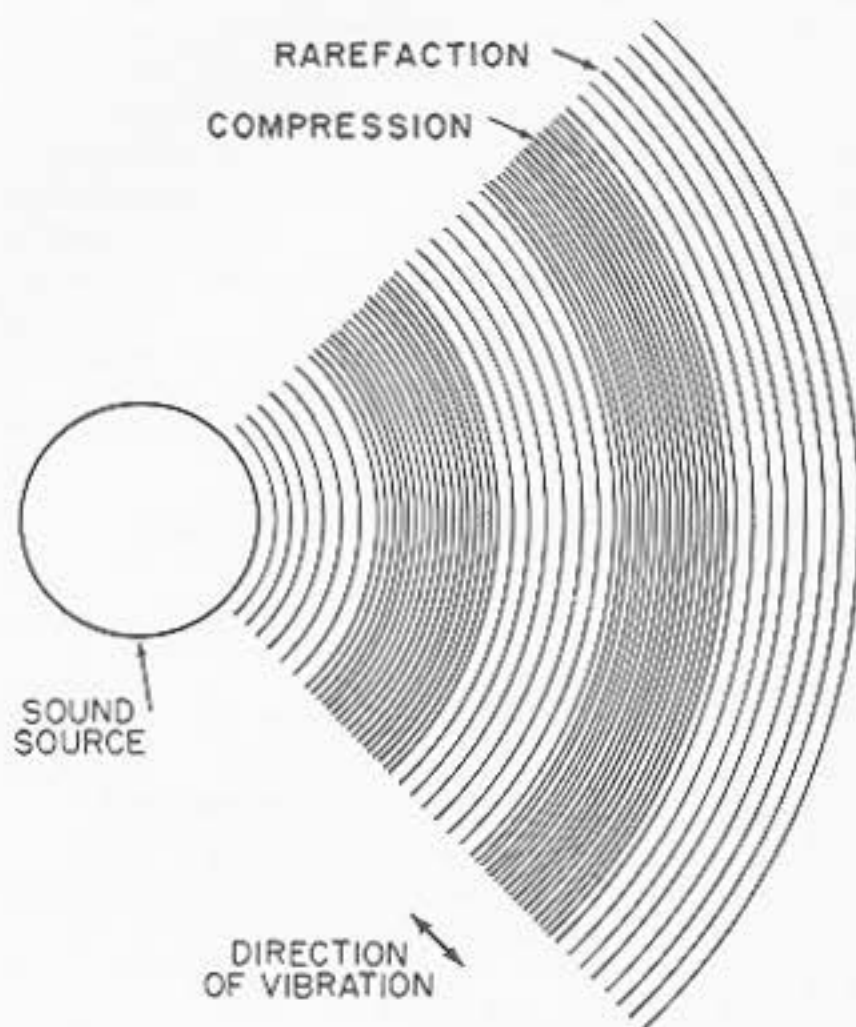
cycle is one complete double vibration—in this case measured from one crest through zero, the trough, zero again, and the next crest. If you take zero as your reference or starting point, you must include one trough and one crest. If you measure the number of cycles that pass a fixed point in one second, you have the frequency in hertz.

LONGITUDINAL WAVES. Sound waves are longitudinal or compression waves, set up by

some vibrating object such as a sonar transducer. In its forward movement, the vibrating transducer pushes the water particles lying against it, and thus produces an area of compression or high pressure. The backward movement of the transducer produces an area of low pressure, or a rarefaction. This action goes on and on, and sets up a spreading series of compressions and rarefactions. In figure 3-112 the compressions are represented by dark rings. As the sound waves spread out, their energy at the same time is spread through an increasingly large area, and the wave motion at a distance is weaker (i.e., amplitude decreases).

The wavelength is the distance from one point along the wave to the next point of similar compression. The particles of the medium vibrate longitudinally—that is, parallel to the direction in which the sound is propagated.

You already know that the frequency of the wave is the number of cycles per second. In the motion of the sound wave through the medium, the particles of the medium move back and



4.221

Figure 3-112.—Longitudinal sound waves.

forth in a limited space, passing the wave along, as it were.

Sound waves can go through all gases, liquids, and solids, but not through a vacuum, because there are no particles in a vacuum to be subjected to alternate compression and rarefaction. In different substances and at different temperatures and pressures sound travels at different speeds. In air, the velocity (speed) of sound is about 1,090 feet per second at 32°F. at sea level. For each 1° rise in Fahrenheit temperature, the velocity is increased by 1.1 feet per second. For instance, in air of 72°F., sound travels at the rate of $1,090 + (72 - 32) \times 1.1$, or $1,090 + 44 = 1,134$ feet per second.

In pure water, the velocity of sound is approximately 4,708 feet per second. In sea water, the velocity depends on salt content (salinity), pressure, and temperature. Sound travels at a speed of about 4,800 feet per second in sea water at 39°F.

WAVELENGTH

If a sonar transducer vibrates at the rate of 25,000 vibrations per second, and if the temperature is 39°F., the first wave will be 4,800 feet away at the end of the first second. Between the transducer and this wave there will be 25,000 other compressions. Thus the wavelength, that is the distance between points of similar compression, must be $4,800 \div 25,000$, or 0.149 foot, because there are 25,000 compressions extending through a distance of 4,800 feet. The wavelength always can be found if the frequency and the velocity are known, according to the following relationship: $W = \frac{v}{f}$, where W is wavelength, f is frequency, v is velocity.

Example: Suppose that the wavelength is 0.4 foot and the frequency is 12,000 hertz.

What is the velocity?

$$0.4 = \frac{v}{12,000} ; \text{ or,}$$

$$v = 0.4 \times 12,000 = 4,800 \text{ feet per second.}$$

Similarly, if the wavelength and the velocity are known, the frequency can be found.

$$0.4 = \frac{4,800}{f} ; \text{ or,}$$

$$f = 4,800 \div 0.4 = 12,000 \text{ hertz.}$$

CHARACTERISTICS OF SOUND

As already indicated, the human ear detects vibrations in the audible range as sounds. Concentrate for a moment on what you hear as you read this. No matter how quiet a place you are in, you will hear something. Many of the sounds will have some kind of pattern or organization—for example, speech, music, Morse code, automobile horns, police or fire sirens, ship's whistles, humming motors, etc. These either have patterns that can be interpreted by your mind into specific feelings or thoughts (e.g. speech or Morse code or music), or at least have identifiable pitches or rhythms. Other sounds may be quite without pattern, though not necessarily meaningless—for example, rushing water, radio static, applause, rustling leaves. Such disorganized or patternless sound is, in contrast to "organized" sounds, called "noise." (However, the term "noise" in connection with the problems of communications and signal detection is used in quite a different sense, as will be explained later.)

A musical note has a pattern of regular vibrations. Such a sound has three characteristics—pitch, intensity, and quality.

An object that vibrates at high frequency produces a sound with a high pitch, as, for instance, a police whistle. The slower vibration of a ship's whistle causes a low-pitched sound. When the frequency is low, the sound waves are long; when it is high, the waves are short. Velocity is not affected by pitch.

Intensity (roughly equivalent to loudness) at any selected frequency varies with amplitude. Wavelength and amplitude are independent variables.

Now consider sound quality. As we defined it above, a noise has no identifiable dominating frequency or pitch. It is composed of a large number of frequencies sounding simultaneously. But all sounds of identifiable pitch that you normally hear can be analyzed into more than one frequency. In a note sounded by a musical instrument, the lowest (and principal) frequency is the fundamental, and other, higher, frequencies (called harmonics or partials) present in the sound give the sound much of its characteristic color or quality. Quality depends in large degree on just what frequencies are present, and in what proportion. Hence the difference between the sounds produced by a trumpet and a violin both playing the same sustained note. Other factors also affect quality, such as how the sound begins, how it ends, and how it fluctuates in pitch.

and intensity while sounding. Such considerations make sounds recognizable even when the pitch cannot be identified. Niagara would sound different from a leaky bathroom faucet even with its sound intensity reduced to comparable level. Ability to recognize differences in sound quality is an extremely important characteristic in sonar and hydrophone work.

SOUND TRANSMISSION IN WATER

As you may have inferred by this time, one of the main reasons for including this section on sound is its importance in the sonar method of submarine detection and location. This is done either by detecting sounds made by submarines in the water, or by radiating sound pulses into the water and analyzing the echoes that return to identify those from submarines. Details concerning sonar gear appear in chapter 13. In this article we discuss briefly the characteristics of sound transmission through water.

When sonar's sound pulse travels through the water, and when the echo returns, they encounter hazards which reduce their strength. Signal strength lost in this manner is known as transmission loss.

ABSORPTION. Some of the sound is absorbed in passing through the water. The amount lost this way depends on the state of the sea. Absorption is high when the winds are great enough to produce white caps and cause a concentration of bubbles in the surface layer of the water. Absorption is also great in wakes and strong currents, such as rip tides. Absorption is greater at high frequencies than at low.

SCATTERING. Sound waves are weakened when they traverse sea water that contains seaweed, silt, animal life, air bubbles, etc., which scatter the sound beam. Scattering reduces echo strength, especially at long range.

REFLECTION AND REVERBERATION. Sonar sound pulses behave somewhat like light in that they can be reflected and refracted. The target can reflect a sound pulse, but so can other underwater objects, and so can the sea bottom and the sea surface ("total reflection" much like that of light in glass, as described in an earlier section of this chapter). The combined echoes from such disturbances are called reverberations. Since they are reflected from various ranges, they seem to be a continuous sound which is stronger at first and gradually fades

away. Reverberations from nearby points may be so loud that they interfere with the returning echo from a target.

REFRACTION. Refraction can distort the path of the sound pulse in the water. Sound speed varies with medium density, and this can cause bending of a "ray" of sound much as it bends a ray of light. This effect is described in further detail in chapter 13.

SOUND PERCEPTION

It is no news that when some one is talking to you in a noisy room it is more difficult to hear him than when the room is quiet. To make himself understood, the speaker may turn his face directly toward you, or move closer to you, or talk louder, or eliminate or tone down the source of noise. So far as your own sensing of his voice is concerned, all of these boil down to one thing: He is increasing the strength of his signal relative to that of the disturbing noise, or increasing the signal-to-noise ratio.

In communication work and in sound detection you will find that this ratio is extremely important. The ratio is expressed in decibels (abbreviated db). Ten decibels make a bel, a large unit named after the inventor of the telephone, Alexander Graham Bell. A decibel is a logarithmic expression of the difference in level or intensity between a "reference" signal and another signal, or between a signal and noise or interference. The intensity level of signal A is n decibels higher than that of reference signal B if

$$n = 10 \log A/B$$

Under laboratory conditions (i.e., completely quiet room, with no sound-reflecting surfaces, use of "pure" tones—fundamentals with no harmonics—of constant pitch in the most sensitive range of the human ear, etc.) 1 decibel is the minimum difference in sound level that the average observer can detect. As a practical matter, under fairly quiet (not laboratory) conditions, an attentive, acute observer cannot detect differences in level of such sounds as speech and music much less than 3 db—and a signal 3 db higher in intensity than a second signal has twice the sound energy of the second sound.

When an audible signal is equal in level to the noise or interference accompanying it, and is of similar characteristics to the interference or noise as regards frequency, pulse rate (if any),

etc., the human ear cannot distinguish it from the noise. (In this sense, "noise" can include not only unorganized sounds that we previously, defined as noise, but also other unwanted signals such as speech, even though such signals are not noise in the sense of an earlier definition. From this point of view, noise is any sound that interferes with reception of the desired signal.) Sometimes, if the noise is in a different frequency range from the desired signal, comes from a different direction, or is different in some other fundamental characteristic, it may be possible to filter it out to some degree mechanically, electrically, or by "selective listening." Thus, you may be able to communicate on the phone through a loud high-pitched squeal or low-pitched hum, but it's much harder to do this if there's another lively conversation on the wire at the same time.

In general, however, there must be a sizable difference in level between signal and noise for effective reception. In this connection, "sizable difference in level" doesn't mean a 50% difference, or even a 100% difference. You simply cannot perceive satisfactorily a signal that is only twice as loud as the accompanying noise (i.e., a signal at 3 db level). Bear in mind that in a quiet room ordinary speech is about 60 db higher in level than barely audible background noise, and this represents a signal-to-noise ratio of about one million to one. Under excellent radio conditions, the signal may be 30 db

above the interference ("static") level; this signal-to-noise ratio is about 1,000 to one. When the signal-to-noise ratio in sonar reception is 10:1 (i.e., 10 db), only a well-trained Sonarman with excellent hearing can reliably get the signal above the interference. A Sonarman with less training won't get the signal unless it's at a level of 15 db. The lowest level signal that any Sonarman has ever been able to perceive is on the order of 5 db (three times as loud as the interference).

These ratios apply also to radio communication. The signal-to-noise ratio concept (and even measurement in db) has been applied even to video (visual) signal presentation and in general to other areas in which power levels must be compared, or intelligible signal reception through "noise" (audible, visible, or electrical) must be measured.

The human ear's sensitivity differs throughout its frequency range, and this characteristic is utilized in sonar to provide for optimum performance. Although sonar pulses and echoes are often in the ultrasonic part of the sound frequency spectrum, sonar equipment converts the received signal to a selected frequency, usually in the range of 600 to 1,000 Hz, where the human ear is at its best with respect to sensitivity, pitch discrimination, and ability to recognize an echo by its characteristic quality.

CHAPTER 4

EXPLOSIVES AND AMMUNITION

This chapter is designed to introduce to the student the principles of those naval weapons that depend for their functioning on the use of chemical explosives and propellants. These include gun projectiles, torpedo and rocket warheads, and explosive trains in mines, and bombs.

The next section of this chapter discusses the characteristics and nomenclature of chemical explosives in general. (Since much of the second volume of this text is devoted to nuclear weapons, such weapons and the principles of nuclear reactions are not discussed here.) The section following that discusses gun projectiles and weapons other than guns.

As the preceding chapter brought out, many words that have precise technical meanings when used in specific fields of science and technology have much broader, and sometimes quite different, meanings when they appear in more general contexts. This is worth repeating here because in this chapter and throughout the remainder of this text you will continually encounter words of this kind, such as range, booster, explosive, and detonate.

Note also that there have been some relatively recent changes in nomenclature and definitions in the subject matter of this chapter. Since these changes have probably not yet been incorporated into all the older technical materials you will encounter on the subject, the older usages are indicated where appropriate, for your convenience. However, make it a habit to avoid using older terminology and colloquialisms; restrict yourself to the up-to-date vocabulary of the naval officer's profession when discussing technical matters of this kind.

EXPLOSIVES AND RELATED MATERIALS

Broadly, if used without further qualification, the term explosive includes all those substances

that, when initiated (by spark, friction, shock, or other means), undergo a rapid chemical reaction that results in the formation of gases and the release of a great amount of stored energy. The reaction is accompanied by high pressure and usually by high heat. In this sense the term explosive is broad enough to include all the substances described in this section.

Note that this usage of the term, though broad, excludes as explosive substances such things as high-pressure steam which may burst (or colloquially, "explode") a boiler, or high-pressure gas that under certain circumstances may rupture its container.

In strictly technical usage, however, the term explosive includes only those substances that detonate. This means that when their reaction is initiated they produce a sharp shock wave that releases all the stored energy almost instantaneously. As it appears hereafter in this text, the term explosive will be used in this strict sense only (when applied to chemical explosives).

High explosives are classified by use into three broad groups: (1) primary (initiating) explosives, (2) Auxiliary (booster) explosives, and (3) bursting charges. Primary explosives are the most sensitive of high explosives and are used to detonate other charges. They are particularly sensitive to shock, heat, or other physical disturbances and are therefore used in initiating devices (such as fuzes, described later in this chapter) to set off chemical reactions in less highly sensitive substances. Boosters are used to detonate explosive charges when the initiating explosion is not sufficient to cause a thorough (high-order) detonation of the main charge. Bursting charges are comparatively insensitive to heat, they are the explosive payload of the projectile (or warhead), detonated by the initiators or boosters. Bursting charges damage the target by blast, heat, or fragments from the container (such as, projectile body, bomb case, etc.).

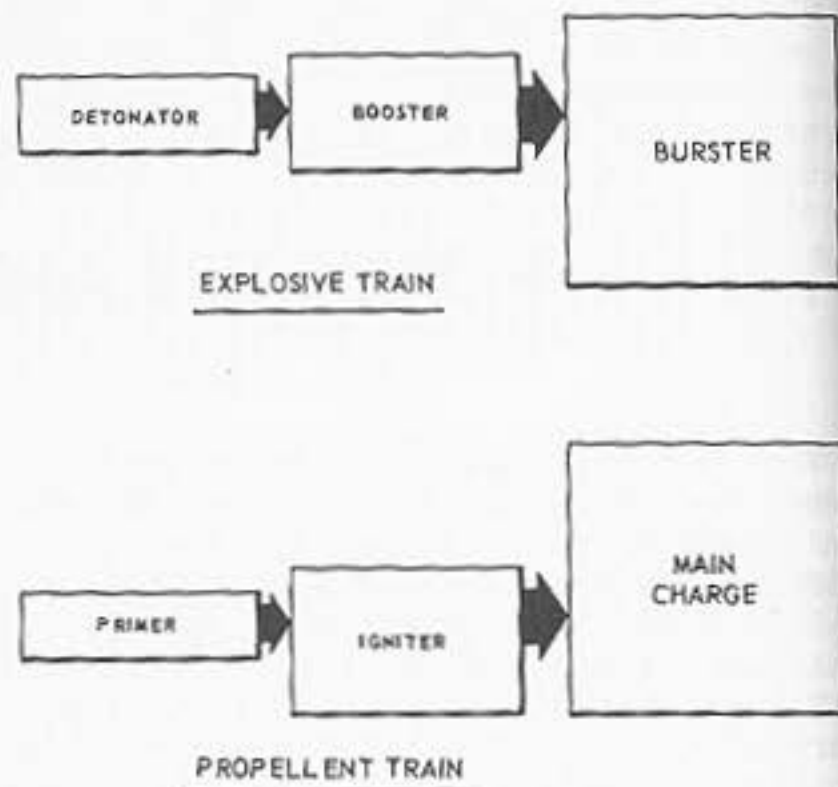
Propelling charges or propellants are explosive-like substances that burn rather than detonate. The rate of burning, though rapid compared with the burning of common combustible materials, is much slower than detonation. (For example, a high explosive like TNT detonates at the rate of several thousand yards per second; a typical gun propellant burns at a rate measured in inches per second.) An important characteristic of any propellant's burning rate is that under a given set of conditions it will always be the same. Propellant burning rate is controllable, and, in contrast to explosives which detonate rather than burn, can be predetermined within close limits by adjusting the propellant's composition, the conditions of burning, and related factors.

Note that the distinction between explosives and propellants rests as much on the conditions under which they react as upon differences in composition. Explosives that normally detonate can be made to burn, under certain conditions not characteristic of their usual application; conversely, under abnormal conditions, propellants can be made to detonate. To underline this point, consider gasoline vapor mixed with air. Under optimum conditions in an internal combustion engine cylinder, this mixture burns like a propellant to produce useful thrust. Under less favorable conditions it detonates with damaging impact, evidenced by a characteristic "knock" or "ping."

Propellants may be liquids or solids (but such fuels as gasoline are not propellants in the sense defined in this article). When a propellant burns, it produces hot high-pressure gas. In such applications as rockets and JATO units the thrust produced by the gas as it escapes through a suitably shaped nozzle is used to drive a load (i.e., the rocket head or aircraft). In such applications as mortars, guns, and depth-charge projectors the thrust produced by the gas directly propels the projectile.

With specific reference to propellants used in guns, the term cool propellant is used to describe one that burns at a relatively low temperature. This is an advantageous characteristic.

For reasons which will become evident later in this text when explosive ordnance is described, practically all explosive and propellant units contain two or more explosives and explosive devices, arranged so that they function in sequence when the unit explodes. This series of stages is called an explosive or propellant train (fig. 4-1).



56.36(110)
Figure 4-1.—Explosive and propellant trains.
Simplified schematic.

In explosive devices like bombs and gun projectiles, the explosive train typically consists of an initiating device called a detonator, containing a relatively small quantity of primary explosive; a booster which contains a larger quantity of less sensitive explosive and is set off by the functioning of the detonator; the booster detonates the burster, which is the main charge of the device and in general is much less sensitive than the preceding stages. In specific devices there are variations on this basic sequence of stages; in small gun projectiles the explosive train is simpler, with the booster omitted or combined with the initiating device, while large aircraft bombs and mines have additional auxiliary stages.

Propelling charges use similar trains. The initiating stage is called a primer, and produces a hot flame which sets off the next stage, called the igniter. The igniter in turn sets off the main charge.

PYROTECHNICS are chemical devices that produce light for illumination or signaling, or smoke for signaling, and may utilize explosive or propellant substances in performing their functions. Specific pyrotechnic devices used by the Navy are described later in this chapter.

CHEMICAL AGENTS include a variety of gaseous, liquid, or solid substances used for

signaling, for screening, for harassing or attacking the enemy by asphyxiation or other chemical damage to personnel, or for burning enemy targets. The three main groups of chemical agents are war gases, smokes, and incendiaries. Further detail on specific chemical warfare devices and substances appears later in this chapter.

DEMOLITION AGENTS are explosives issued and used in specialized demolition equipment other than ammunition. Certain military explosives like TNT are used both in ammunition and in demolition equipment, but in general the requirements of an explosive for demolition and for use in ammunition are not the same, and many explosives, such as Explosive D and nitro-starch respectively, are used either in ammunition, or in demolition equipment, but not in both. The Navy uses demolition explosives in such work as destruction of obstacles or hazards to navigation (such as the sinking of floating hulks), blasting preparatory to construction, destruction of classified equipment if capture by the enemy is imminent, or destruction of designated enemy targets by specially trained personnel such as frogmen.

OUTMODED TERMS. Older textbooks on ordnance, and even current texts directed to supply personnel and activities, use the expression low explosive to include the various explosive-like substances whose reaction is a burning process rather than a detonation. The term is no longer correct in military context. It is retained in shipping instructions and similar documents because the law still recognizes it as a valid blanket term covering propellants and pyrotechnics.

BASIC CHEMISTRY OF EXPLOSIVES AND PROPELLANTS

Explosive substances include a large number of chemical compounds and mixtures. Relatively few of these have the characteristics that make them practical for military use, and the discussion in this chapter applies only to those actually used in the Navy.

Most explosives and propellants used by the Navy are organic compounds or mixtures of explosive organic compounds, most of them based on nitrogen. (Hence the presence of "nitro" in the chemical names of most Navy explosives.) A few are inorganic compounds (the chief example is lead azide, used as the sensitive initiator in detonators). One explosive used in the Navy is a simple mechanical mixture (not a

chemical compound) of chemicals which individually are not explosives—this is black powder.

It is important to note the distinction between mixtures and chemical compounds. A mixture consists of two or more distinct substances, either chemical elements or chemical compounds, which may be mixed in various proportions as described. The components in a mixture (of solids) can always be identified individually, even though a microscope may be necessary to do it; no matter how fine the components may be ground and how thoroughly they may be conglomerated, the mixture cannot be truly homogeneous. In a chemical compound, on the other hand, (1) the substance (if pure) is always homogeneous down to the point where it is broken up into its constituent chemical elements; (2) the components, when isolated, are invariably chemical elements; and (3) the constituents are always present in exactly the same proportions.

Broadly, two kinds of chemical reactions account for the functioning of both propellants and explosives. One is combustion—the combination of oxygen with other atoms or atomic groups with the accompanying release of energy. The other is a molecular breakdown or disintegration (followed by some recombination) of the relatively unstable nitrogen compounds that, as mentioned above, make up most Navy explosives and propellants.

In propellants, much of the energy developed by the reaction characteristically comes from oxidation. No significant proportion of the oxygen comes from the atmosphere. In black powder, the oxygen comes from potassium or sodium nitrate, which yields oxygen when heated; the oxygen combines with the other two components of the mixture (charcoal and sulfur). In other propellants, the oxygen is part of the original composition, and recombines with other elements when the composition breaks up.

In high explosives, oxidation is not so important a feature of the reaction, though it is usually present. The important energy source is in the breakup of the chemical bonds of the original composition and the recombination of the elements into simpler compounds.

The products of detonation and burning (in explosives and propellants respectively) include the usual products of complete combustion (e.g., carbon dioxide, water vapor), products of incomplete combustion (e.g., carbon monoxide, free hydrogen), products of molecular breakdown and partial recombination (e.g., free nitrogen, oxides of nitrogen, methane, hydrogen cyanide),

and unburned residues of the original composition. Some of these products are harmless, some are suffocating, some are combustible or even explosive, and some are dangerous poisons even in fairly low concentrations. These are dangerous substances, particularly in enclosed spaces (where, for example, a high-explosive-loaded projectile may have burst). They are also dangerous in enclosed gun mounts, which are therefore fitted with gas-expelling devices to eliminate them. When such gases are not promptly expelled they may ignite while the gun is being reloaded, causing a burst of flame inside the mount called a flareback.

CHARACTERISTICS OF EXPLOSIVE AND PROPELLANT REACTIONS

- **VELOCITY.** An explosive reaction differs from propellant reaction in its velocity. The velocity of combustion of explosives and propellants may vary within rather wide limits, depending upon the type of substance and upon its physical state. The burning rate of colloidal cellulose nitrate powders used as propellants in modern guns is in the order of 24 centimeters per second and up at average gun pressures. The velocity of reaction of high explosives ranges from about 2,000 to 8,500 meters per second.

- **HEAT.** An explosive reaction is always accompanied by the rapid liberation of heat. The amount of heat represents the energy of the explosive and hence its potentiality for doing work. The quantity of heat given off by an explosive or propellant reaction is not as large as is popularly supposed. A pound of coal, for example, yields five times as much heat as a pound of nitroglycerine. However, coal cannot be used as an explosive, because it fails to liberate heat with sufficient rapidity, and because it does not incorporate an oxidizing agent.

- **GASES.** The main material products (as distinct from energy products) of explosive or propellant reactions are hot gases and a small amount of solid residue. The pressure characteristics of the gases evolved are discussed below; their composition was discussed in the preceding article. In gun barrels, propellant gases have an additional erosive effect, which contributes significantly to the wear of the gun bore. The effects of such wear on gun performance are taken up in further detail later, in chapter 5.

- **PRESSURE AND SHOCK WAVE.** The high pressure accompanying a propellant or explosive reaction is due to the formation of gases which are expanded by the heat liberated in the reaction. The work which the reaction is capable of performing depends upon the volume of the gases and the amount of heat liberated. The maximum pressure developed and the way in which the energy of the explosion is applied depend further upon the velocity of the reaction. When the reaction proceeds at a low velocity, the gases receive heat while being evolved, and the maximum pressure is attained comparatively late in the reaction. If, in the explosion of another substance, the same volume of gas is produced and the same amount of heat is liberated, but at a greater velocity, the maximum pressure will be reached sooner and will be quantitatively greater. However, disregarding heat losses, the work done will be equal.

The rapidity with which an explosive develops its maximum pressure determines its brisance. A brisant explosive is one in which the maximum pressure is attained so rapidly that its shock wave shatters material surrounding it.

INITIATION OF EXPLOSIVE AND PROPELLANT REACTIONS

Explosive and propellant reactions are initiated by the application of some stimulus which provides energy required to get the reaction started. In general, propellant substances are commonly initiated by heat. The resulting reaction is a burning process, which occurs on the exposed surfaces of the substance and progresses through the mass as each layer is consumed. However, some high explosives will react when sufficient heat is applied, especially if heat is applied suddenly throughout the mass. Initiation by percussion (direct blow), or by friction, is a form of initiation by heat derived from the energy of the blow or friction.

High explosives, such as the main charges of mines or torpedoes, in general require the sudden application of a strong shock or detonation to initiate the explosive reaction. This detonation is usually obtained by exploding a smaller charge of a more sensitive high explosive in contact with or close to the main charge.

Detonation of an explosive mass can also be transmitted to other high explosives in the vicinity, without actual contact. The explosion resulting is said to be initiated by influence,

and is called a sympathetic explosion. When this happens with mines or depth charges that are located too close together in the water, the phenomenon is called countermining.

The amount of energy necessary to initiate the reaction is the measure of the sensitivity of the explosive or propellant. Sensitivity is important in selecting an explosive for a particular purpose. For example, the explosive in an armor-piercing projectile must be relatively insensitive or the shock of impact will detonate it before penetration. Too much sensitivity is also undesirable because minor shocks or temperature variations incident to normal handling would initiate the reaction.

Sensitivity has little relation to the power developed by a given weight of explosive. TNT, for example, is quite insensitive, but is pound for pound a much more powerful explosive than mercury fulminate, an initiating compound of great sensitivity.

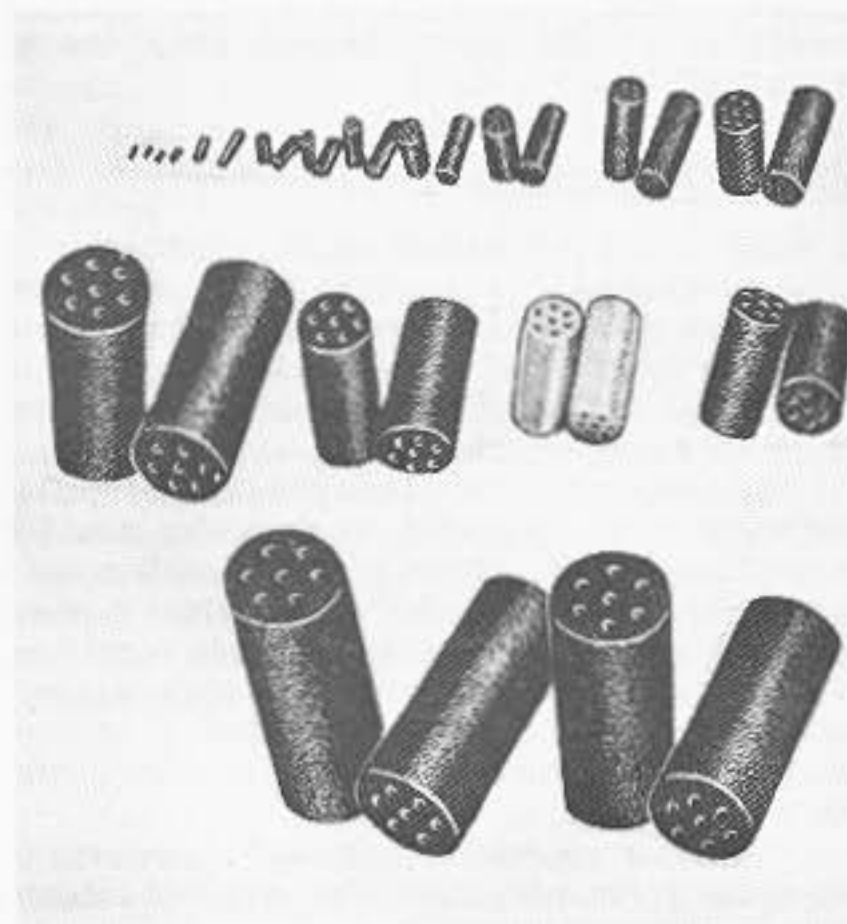
CLASSIFICATION OF NAVY EXPLOSIVE AND PROPELLANTS BY USE

In the remainder of this section, the characteristics of individual chemical explosives and propellants now in use in the Navy will be described. These are arranged in the following classification based in each case on their principal use:

1. PROPELLANTS. Propellants are used to propel projectiles from guns, to propel rockets, launch torpedoes, and catapult aircraft. Examples are smokeless powder, ballistite, Cordite, and black powder. Figure 4-2 shows smokeless powder grains of various sizes.

2. PRIMARY (INITIATING) EXPLOSIVES. The initiation of an explosive reaction requires the application of energy in some form. Propellants are commonly ignited by the application of flame, while explosives are set off by a severe shock. Many primary explosives can be used for initiating either propellants or explosives because they produce both a flame and a shock when exploded.

A **PRIMER** is used to initiate the burning of a propellant explosive. A simple primer consists of a small amount of lead azide and a small charge of black powder. When fired, the primer produces the flame required to ignite the next component in the train.



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Figure 4-2.—Smokeless powder grains (caliber .30 to 16"/50); the two white grains are SPCG powder.

A **DETONATOR** is used to initiate the reaction of a high (disrupting) explosive. It may consist of a charge of lead azide or lead styphnate, either alone or with granular TNT or tetryl in a container. When fired, the detonator produces the shock necessary to initiate the explosive reaction.

3. AUXILIARY EXPLOSIVES. Large propellant charges and relatively insensitive high explosives require an intermediate charge, so that the increased flame or shock will ensure reaction of the main explosive charge. This auxiliary, when used with propellants, is called an ignition charge. It consists of a quantity of flame-producing black powder. The auxiliary explosive used with high explosives is called a booster. It consists of a quantity of more sensitive high explosive, such as tetryl or granular TNT.

4. BURSTERS. Explosives of this classification are all employed to create damage to the target under attack. They are used alone or as part of the explosive charge in mines, bombs, and torpedo warheads, and in projectiles as a

burster charge. There is a wide variety in this category, but the more common examples are RDX, TNT, and tetryl.

Propellants

The primary function of a propellant is to produce gases under pressure which can be used to develop a propulsive thrust. This gas pressure must be controlled to avoid exceeding the strength of the container in which it is produced (e.g., guns and torpedo tubes).

Any explosive would serve for propellant purposes if the velocity of explosion could be controlled. Investigations of this problem led to the development of today's smokeless powder. Nitrated cotton (pyrocotton), the main constituent of smokeless powder, is itself a high explosive entirely unsuitable as a propellant. It is combined with an ether-alcohol mixture to control its burning rate.

Smokeless powders are now used almost universally for propellant charges. For military purposes (especially for weapons larger than small arms) there are three main classes: (1) single-base, (2) double-base, and (3) multi- or triple-base powders.

In single-base powders, cellulose nitrates (nitro-cellulose) form the only explosive ingredient. Other materials in single-base powders are included for suitable form, desired burning characteristics, and stability.

Double- or multi-base powders include nitroglycerin to assist in dissolving the nitrocellulose during manufacture, as well as to add to the explosive qualities. Single-base nitrocellulose powders have lower burning temperatures and cause less wear in the gun bore than double-base powders. Present multi-base powders, with a large proportion of the "cool"-burning explosive nitroguanidine, produce maximum temperatures comparable to those of single-base powders.

Propellants for present-day U.S. Navy guns larger than small arms are composed either of single-base or multi-base powder. Double-base powders are used as rocket propellants.

Single-Base Smokeless Powder

This type of powder is used by the U.S. Navy as a propellant in guns 20-mm and larger. It is a uniform ether-alcohol colloid of purified nitrocellulose, plus a small amount of diphenylamine as a stabilizer to retard deterioration of the powder. The grains are cylinders about four to five times as long as their diameters. Larger

grains burn more slowly and are used for larger calibers. Figure 4-2 shows the range of sizes. Small grains have 1 longitudinal hole; larger grains have 7. The number and size of holes determines the burning area of the grain (in addition to its ends and convex surfaces) and therefore its burning rate; these have been carefully calculated for each caliber. The grains have a hard, smooth finish, and have much the same texture as horn. Newly manufactured grains are generally translucent and amber. As the powder ages it darkens to opaque dark brown, then black. These changes do not, however, indicate any loss of stability.

Smokeless powder deteriorates in two ways, and particularly in the presence of moisture. First, it decomposes slowly in storage because it is not entirely stable chemically, and eventually will burn spontaneously if decomposition is allowed to run its course. The decomposition products include nitrogen oxides which tend to form acids, thus facilitating further decomposition. Diphenylamine is slightly alkaline in effect, and neutralizes the acid products. This doesn't prevent further decomposition, but prevents the process from accelerating. Short of the extreme of spontaneous combustion, this chemical deterioration does not make the powder dangerous to use. Its principal effect is to weaken the powder slightly, since some of the decomposition that should have taken place in the gun has taken place slowly in the magazine, and the powder therefore cannot produce as much heat energy.

The second type of deterioration is loss of volatile components (ether and alcohol). These tend to evaporate if the powder is in the open. A loss of volatiles increases the burning speed of the powder; severe increase in burning speed will cause the powder to develop excessive pressures in the gun when it is fired. Thus loss of volatiles can make the powder ballistically dangerous.

Smokeless Powder Designations

Letter designations for some of the single-base smokeless powder (SP) used with Navy guns are as follows:

1. SPD—smokeless powder that consists of colloided nitrocellulose and diphenylamine (the stabilizer). This powder is commonly known as PYRO powder by the U.S. Navy and has been used in standard service ammunition.

2. SPDN—smokeless powder composed of nitrocellulose and dinitrotoluene, to which is

added other ingredients to control the potential of the powder and to aid in plasticization. This composition also contains diphenylamine, which acts as the stabilizer.

3. SPDF—a modification of the basic composition of either SPD or SPDN made by adding a coolant or flash inhibitor, generally potassium sulfate. This combination of materials results in a flashless charge for the gun in which the powder is designed for use.

4. SPDE—smokeless powder containing lead carbonate for de-coppering purposes; otherwise it is similar to SPD powder.

5. SPC—a recently perfected cool-burning powder of special nitrated nitrocellulose containing centralite as a stabilizer.

6. SPCF—a powder similar to SPC powder, but containing ingredients that render the powder flashless.

7. NACO—a unique cool-burning propellant of the SPC type. This powder was developed in the latter part of 1950, and it was proofed and accepted by the Navy a few years later. NACO (Navy cool) gun powder burns at a temperature 300 degrees cooler than standard gun powder. Consequently the barrel life of rapid-fire guns is more than doubled. Another important characteristic of NACO powder is the elimination of most of the muzzle blast and smoke usually associated with gunfire. The virtual absence of smoke provide the Navy, for the first time, with a universal propellant suitable for round-the-clock operations. To prevent detection, firing ships will no longer have to employ two kinds of powder—a smokeless type for daytime and a flashless type for nighttime use. NACO serves both purposes, eliminating many handling and storage problems.

NACO propellant is now being produced for 5"/38, 5"/54, and 8"/55 guns.

Multi-Base Powder

Multi-base powder is used in many calibers of guns. It is commonly called Cordite N or SPCG and is composed of four principal ingredients—nitrocellulose (19 percent), nitroglycerine (a little under 19 percent), nitroguanidine (55 percent), and a stabilizer called carbamate or ethyl centralite (a little over 7 percent). Of these 4, the first 3 are explosives. A small amount of potassium sulfate may be added as a flash inhibitor. In some calibers other minor ingredients may be added.

Multi-base powder grains resemble pyro powder grains in size and shape. They have smooth, chalk-white surfaces. After considerable time in storage, the surface color may tend to yellow, but this is not a sign of deterioration.

Multi-base powders are far more stable in storage than equivalent pyro powder, because of relatively low nitrocellulose content, small content of volatiles, and low hygroscopicity. They are more suitable as gun propellants than double-base powder (described below); gases produced by a multi-base powder with nitroguanidine are much less erosive than those of double-base powder. Multi-base powders also are cheap to produce, have little residue after burning, and are relatively insensitive to high temperatures in stowage.

Storing Gun Propellants

In storage, smokeless powder must be protected against high temperatures, and sealed to prevent entrance of moisture and loss of volatiles. To protect against high temperatures, all magazines in which ammunition containing smokeless powder is stored must be adequately insulated and ventilated, and if necessary refrigerated. Moreover, recording or maximum-minimum thermometers are installed and read daily to verify that the ammunition is uniformly maintained at the lowest practicable temperatures. To protect against entrance of moisture and to prevent excessive loss of volatiles, ammunition containing smokeless powder is kept in sealed tanks or equivalent sealed containers. The tanks are not expendable; they must be periodically inspected and repaired if necessary. They must not be opened when loaded except for inspection or if the ammunition is to be used.

Solid Rocket Propellants

The stream of hot gases that propels a rocket is produced by chemical reactions; the fuel may be either solid or liquid. In this chapter we are concerned only with propellants used in ballistic rockets (i.e., those that do not incorporate systems for guidance after launching). Propellants used only in guided or ballistic missile propulsion are described in Principles of Guided Missiles and Nuclear Weapons, NavPers 10784 series.

Solid rocket propellants are double-base compositions with added ingredients for plasticizing, control of burning rate, and reduction of flash.

Gas pressure during burning is about one-tenth of that in a gun barrel, and erosion effect is not important in this application.

A typical propellant grain is made up of a composition identified as Type N-2 (JPN). Its main ingredients are nitrocellulose (slightly over 51 percent) and nitroglycerine (a little less than 43 percent). It also contains two plasticizers for homogeneity of composition, stabilizer (ethyl centralite), potassium sulfate to reduce flash, are carbon black to control burning rate. Depending on the particular rocket motor in which it is to be used, a grain is an extrusion of either cruciform (cross-shaped) or hollow cylindrical cross section, machined in a special lathe to the dimensions required for mounting. Single extruded rocket propellant grains range up to 60 inches in length and 6 inches in diameter. Larger grains for other applications may be cast rather than extruded.

From 1 to 4 grains of ballistite propellant are used as the propelling charge in a rocket motor. The grains are designed to burn at a uniform rate to provide uniform thrust during burning. In cruciform grains with suitable plastic inhibitor strips, the burning area, and hence the rate of gas production and thrust, tend to remain constant throughout the burn time. In hollow cylindrical grains, plastic inhibitors bonded to the grain limit burning area during the first part of the burn period. Cylindrical grains have holes at regular intervals to equalize pressures inside and surrounding the cylinder.

Like gun propelling charges, rockets must be stowed under conditions favorable to storage. Normally, rocket motors are stowed in different magazines from the heads with which they are used. Like pyro powder, double-base propellants such as ballistite must be protected from excessive heat and from moisture. Rocket motor magazines are ventilated, cooled, and inspected daily just like smokeless powder magazines. Rocket propellants are not subjected to surveillance or oven tests aboard ship. A shelf-life date is stencilled on the motor, if required. If the motors have short-circuiting tabs on the leads to the firing squib, these must be left on the rocket until the rocket is to be fired.

On many rocket motor tubes is printed the critical temperature above which the rocket should not be fired. Nor should a rocket motor be used if parts are missing, if the propellant grain is fractured, or if it is loose in the motor tube.

High Explosives

A high explosive for use in bursters must ideally have the following qualities:

1. Low sensitivity to shock of handling, gunfire, and impact against armor.
2. Maximum power.
3. Good fragmentation characteristics (i.e., ability to break up its container into lethal fragments upon detonation).
4. Low cost for manufacture, handling, and loading.
5. Maximum stability for good durability and resistance to adverse conditions like moisture, heat, etc.

No single explosive meets all these requirements suitably for all applications, so the Navy uses a number of explosives. The important ones which will be studied here are TNT, RDX, HBX, tetryl, and Explosive D. Explosives used only for demolitions will not be discussed. Of the five explosives named, the first four often are used in varying forms or with other substances intermixed.

TNT (trinitrotoluene), the best known of military explosives, is made by treating the organic compound toluene with nitric acid. At temperatures below about 170°F, TNT is a crystalline substance (white when pure, but yellow to brown as found in munitions), chemically quite stable (it won't react with metals or become unstable even in temperatures approaching 150°F.), and quite insensitive to shock. However, excess moisture makes it hard to detonate; it should be kept dry. It is loaded by casting—pouring the molten substance into a cavity in the projectile or explosive device. Its detonation rate is about 7,000 meters per second. After prolonged storage, cast TNT may give off an oily exudate that is not itself oversensitive but combines with cellulose material such as wood or natural fabric to make an easily combustible and sometimes even explosive compound. This exudate on the exterior of a projectile or other explosive device is a real fire or explosive hazard. It must be wiped off promptly (but without using soap or other alkaline compounds, and without using steel scrapers).

Cast TNT can be used as a bursting charge in gun projectiles (other than armor-piercing), torpedo, rocket, and missile warheads, and mines. In granulated form it is more sensitive and can be used as an auxiliary explosive (booster). TNT is also the main component of two other

explosives—amatol and tritonal. Amatol, used mostly in very large aircraft bombs, is a mixture of TNT with ammonium nitrate—the mixture is cheaper than straight TNT. Tritonal is a mixture of TNT and aluminum powder. Though the aluminum does not significantly affect the powder of the explosive, it increases brisance.

RDX, also known as "Cyclonite" and "Hexogen," is made by nitration of a complex organic compound, and is substantially more powerful and more sensitive than TNT or Explosive D (which is described below). When pure, coating RDX crystals with wax makes it insensitive enough to handle, but its pure crystalline form is nonetheless too sensitive for use as a military explosive. To make it usable, other materials must be added. RDX is available in the following forms:

1. Composition A. A mixture of RDX and 9 percent wax. Since this composition is as insensitive as Explosive D but is more powerful, it is used as a projectile filler in place of Explosive D.

2. Composition B. A mixture of about 60 percent RDX, 40 percent TNT, and less than 1 percent wax. It is used as a projectile and bomb filler.

3. Composition C. A plastic mixture of about 90 percent RDX and 10 percent emulsifying oil, used as a demolition explosive.

HBX. There are in service use two varieties of HBX: HBX-1 and HBX-3. HBX-1 is a cast explosive, consisting of a mixture of RDX, TNT, aluminum powder, and a desensitizer (chiefly wax). Stable, relatively insensitive to impact, and more powerful than TNT, it is used as a rocket head burster. HBX-3 has a much larger proportion of aluminum powder to increase brisance, and produce much greater destructive effect underwater. It is used in some underwater explosive devices.

Tetryl is produced by nitration of an aniline-based organic compound, and is both more powerful and more shock-sensitive than TNT. It is used as a burster in small gun projectiles (40-mm and 3"), but is more generally employed as an auxiliary or, when mixed with a primary explosive, in detonators.

Explosive D. This noncommittal appellation continues to reflect the aura of secrecy that once surrounded this explosive, in the closing years of the last century. What made it the subject of cloak-and-dagger concealment was its then revolutionary combination of high power (nearly

that of TNT) with sensitivity so low that an armor-piercing projectile containing an Explosive D burster can be fired through armor plate without being detonated. It is a phenolic compound in crystalline powder form, chemically stable up to 150°F. when not exposed to unprotected metal. (Bursting cavities in armor-piercing projectiles are protected by varnish before Explosive D is loaded.)

Primary (Initiating) Explosives

The first chemical reaction in the train or series of stages which culminates in the detonation of an explosive burster or the burning of a propellant occurs in the primary explosive. The primary explosive is the most sensitive in the train, and is present in the smallest quantity. (Detonation of a "blockbuster" bomb with thousands of pounds of high explosive burster begins with the miniature explosion of a few grams of initiator.) The primary explosive may be set off by the impact of a small firing pin, by the heat produced by the passage of a firing current through a platinum filament, or by some other appropriate stimulus. To ignite a propellant, the primary element in the train (the primer) must produce a hot flame of sufficient temperature, size, and duration for reliable action. To detonate a high explosive, the primary element in the train (the detonator) must produce a shock sufficient to detonate the succeeding elements. The primary explosives most often used in naval ammunition today are lead azide, lead styphnate, DDNP, tetracene, and nitromannite. (Mercury fulminate, once the leading primary explosive, has now been superseded because of its disadvantages.)

Detonators and primers differ chiefly in auxiliary ingredients. Thus, oxidizing agents such as nitrates or chlorates are added to increase shock effect and sensitivity; abrasives like ground or powdered glass increase sensitivity to firing pin action; fuels such as antimony trisulfide increase flame energy. Explosive binders like nitrocellulose or nitrostarch are used to provide structure for the primary mixture and to hold it in place, and graphite or other electrical conductors are used to increase conductivity for electrical initiation.

Auxiliary Explosives

Auxiliary explosives are the middlemen of the explosive or propellant train. They function as "amplifiers" to transmit the relatively feeble

explosive shock or the intense but ephemeral flame produced by the primary element, increase it, and get the main charge of insensitive explosive to detonate or the propellant to start burning.

In explosive trains, the auxiliary explosive element is generally called a booster. For detonating large masses of bursting charge (as in some aircraft bombs and mines), more than one booster may be used. Auxiliary explosives widely used in munitions include purified granulated TNT (which is more sensitive than cast TNT), tetryl, and black powder.

Black powder is the principal auxiliary explosive in propellant trains. It is the oldest of explosives; its use in guns dates back to the 12th century. It is a mechanical mixture (not a compound) consisting mainly of saltpeter (sodium nitrate) with lesser proportions of charcoal and sulfur. The exact ratios of the components vary, depending on the application. It comes in varying grain sizes, which are used as indicated:

1. Large grains.—Impulse charges.
2. Granular.—Ignition charges for propellants and for saluting charges.
3. Fine-grain.—Primer charges; expelling charge in illuminating projectiles.
4. Meal.—Pyrotechnics and fuzes.

Except for application No. 1 above (which, as later chapters in this text will mention, is rapidly becoming obsolete), black powder is no longer used as a propellant. When it was so used in guns, it fouled the bore with unburned residue, made large quantities of irritating and easily visible black smoke, produced a brilliant flash when fired, caused excessive erosion, and even with scientifically shaped grains to retard burning rate, it burned much too fast for efficient use of the energy developed.

Black powder is considered the most dangerous explosive handled aboard a man-of-war. Although it possesses practically unlimited chemical stability if stored in airtight containers, it deteriorates irregularly when exposed to moisture, which it absorbs readily. Black powder is not affected by moderately high temperatures, nor is it subject to spontaneous combustion at ordinary storage temperatures. It is, however, highly combustible, very sensitive to friction, shock, sparks, or flame, and extremely quick and violent in its action when ignited. Black-powder dust is exceedingly dangerous, and its accumulation during the handling of any black powder should be prevented.

PYROTECHNICS

Pyrotechnics is based on the Greek name for fireworks. The Navy uses pyrotechnics not for celebration but for illumination, and signaling. A pyrotechnic charge is a mixture of chemicals (generally oxidizing agents and combustibles) which reacts to produce light or smoke. Other chemicals may be added to the mixture to color the light or smoke. Some pyrotechnic devices have small quantities of explosive or propellant materials to project the pyrotechnic components in a desired direction, or to scatter them.

The Navy utilizes a large variety of pyrotechnics, but only a few common examples, all used on surface vessels, can be taken up here.

Illumination Device

The illuminating projectile (colloquially called a "star shell") is a bright-burning flare that is conveyed to the desired location by firing it in a projectile body from a gun. A timing device causes the flare to be ejected from the projectile and ignited. It falls slowly, supported by a parachute. The illuminating projectile is the only pyrotechnic fired from a gun. The light of its flare is intended to illuminate the target and make it easier to aim other guns.

Signaling Devices

Three important pyrotechnic signaling devices are signal lights, Navy lights, and distress signals. Signal lights (often called by their older name of Verylights, but not because they are very light) look like shotgun cartridges, and are fired from a special small projector or a special pistol to a height of about 200 feet, at which time a red, white, or green "star" or small flare ignites and burns for 5 to 7 seconds. The Navy light is a hand-held flare, either blue or red, which burns steadily for 1 to 3 minutes. The distress signal is a hand-held double-ended affair which functions, like the famous pyre in Exodus, to produce smoke (orange colored) by day (from one end) or a bright light by night (from the other end).

CHEMICAL AGENTS

Chemical agents are of five main types, as described below. They may be used in any of several types of ammunition (depending on the

target and the effects desired), or may be released as free liquids or gases from projectors or sprayers. The types are:

Group A. Persistent vesicants. Vesicants blister the skin. The usual ones are mustard gas and lewisite. (Physically, both of these are liquids, not gases.)

Group A-1. Nonpersistent lethal gases. These gases, such as phosgene, injure the body when applied externally, breathed, or taken internally.

Group B. Lacrimators and smokes. A lacrimator such as CH causes weeping and irritation of the throat and lungs. Smokes such as FM and FS are used for screening but have an irritant and, in enclosed spaces, a toxic effect.

Group C. Spontaneously inflammable agents which can be used as incendiaries, such as WP (white phosphorus).

Group D. Readily inflammable mixtures such as TH (thermite), or napalm, a syrupy gasoline-plastic mixture, both of which burn rapidly and with extreme heat and are used as incendiaries.

Chemical warfare is a specialized field which calls for considerable special training. The storage of chemicals requires extraordinary safety precautions. Although poisonous gases were not used in World War II, the Navy was prepared for defense and for reprisal in case the enemy initiated such tactics. Chemical warfare creates many problems in ship protection and decontamination which are the responsibility of the Damage control officer and are outside the scope of this book.

DEMOLITION

Explosives intended for such uses as blasting, eliminating hazards to navigation and obstacles to amphibious landing, and destroying gear to prevent capture by the enemy, comprise demolition material.

Demolition techniques are taught in special Navy schools and will not be discussed in detail in this text. For major blasting operations, various forms of dynamite are used; but dynamite normally is not carried aboard ship.

Half-pound demolition charge blocks, consisting of either pressed TNT or cast TNT and tetryl, are issued to ships for general use. Large demolition charges, also consisting of TNT, and assembled with half-pound booster charges, are also issued for major projects, such as scuttling

vessels. Charges of both of these types are detonated by means of blasting caps, set off by electric current.

Highly classified instruments must be completely destroyed if capture or abandon ship is imminent. They are therefore equipped with tiny bombs called destructors, which can be actuated at a moment's notice. Usually, they contain lead azide or TNT-tetryl, with appropriate electric ignition elements.

AMMUNITION

In a general sense, ammunition includes anything that is intended to be thrown at the enemy or put in his path, to deter, injure, or kill his personnel, or to destroy or damage his materials. In this book, the term is used in a much narrower and more technical sense. Ammunition includes any projectile or explosive weapon, as well as components or parts thereof, but not guns or weapon launchers and their parts.

The next section is devoted chiefly to gun ammunition. Other types of ammunition to be taken up later in this book include mines, torpedoes, antisubmarine weapons, bombs, rockets, and grenades. This book, as mentioned in chapter 1, does not cover two other types of ammunition—nuclear weapons and guided missiles.

Service ammunition is ammunition fit for service use and including all explosive and propellant components. Inert (i.e., lacking explosive and propellant components) and partially inert ammunition of several types is used for test, training, and practice purposes. Dummy or drill ammunition (completely inert) which resembles service ammunition in appearance, size, and weight, may include functioning components that contain no explosive or propellant. It is used for training and test purposes. Cutaway ammunition (completely inert) has a section cut away to show inner construction and components; it is used for training and display purposes. Plaster-loaded or sand-loaded ammunition lacks the explosive burster charge, but is otherwise not inert; it is used for target practice and for testing of launchers, mounts, or projectors.

Two miscellaneous types of ammunition deserve brief mention for the sake of completeness. They are trench-warfare ammunition and blank ammunition. Trench-warfare ammunition includes hand and rifle grenades, mortar projectiles, and similar infantry weapons (issued

to Marines and landing forces) for ground combat. Blank ammunition is a type of gun ammunition with propelling charges but no projectile; it is used for saluting batteries, signaling, and training.

TYPES AND COMPONENTS OF GUN AMMUNITION

Components of gun ammunition are called ammunition details, and all the ammunition details required to fire one shot are said to comprise a complete round. Ammunition details include propelling charges, projectiles, primers, boosters, cartridge cases, etc.

Gun ammunition comprises four types: bag, semifixed, fixed, and small arms (fig. 4-3). The distinction between the first three depends on the manner in which the charge is assembled. In bag (formerly called separate-loading) ammunition, the primer, propelling charge, and projectile are separate units. In semifixed ammunition, the primer and propelling charge are contained in one unit, while the projectile is separate, so that the complete round comprises two pieces. In fixed ammunition, all three components are assembled in one unit. Small-arms ammunition, used in small-arms weapons, will not be discussed in this text.

The principal components of gun ammunition are propelling charges and projectiles. The propelling charge functions to develop thrust that ejects the projectile at the proper initial velocity or I.V. (defined as the velocity, generally measured in feet per second or fps, at which the projectile is moving at the instant it leaves the muzzle of the gun). The projectile generally contains explosive, or it may contain an inert filler or no filler. The propelling charge as an assembly is considered to include the propellant train as well as the propellant itself with its container. The projectile as an assembly includes the fuze, the burster, and the explosive train, as well as the projectile body.

Bag Type Propelling Charge

A complete round of bag ammunition (fig. 4-3A) consists of three separate ammunition details as follows:

1. A lock combination primer (so called because it fits into a firing mechanism called a firing lock, and has a combination arrangement which enables it to fire either on an electric firing impulse or by percussion).

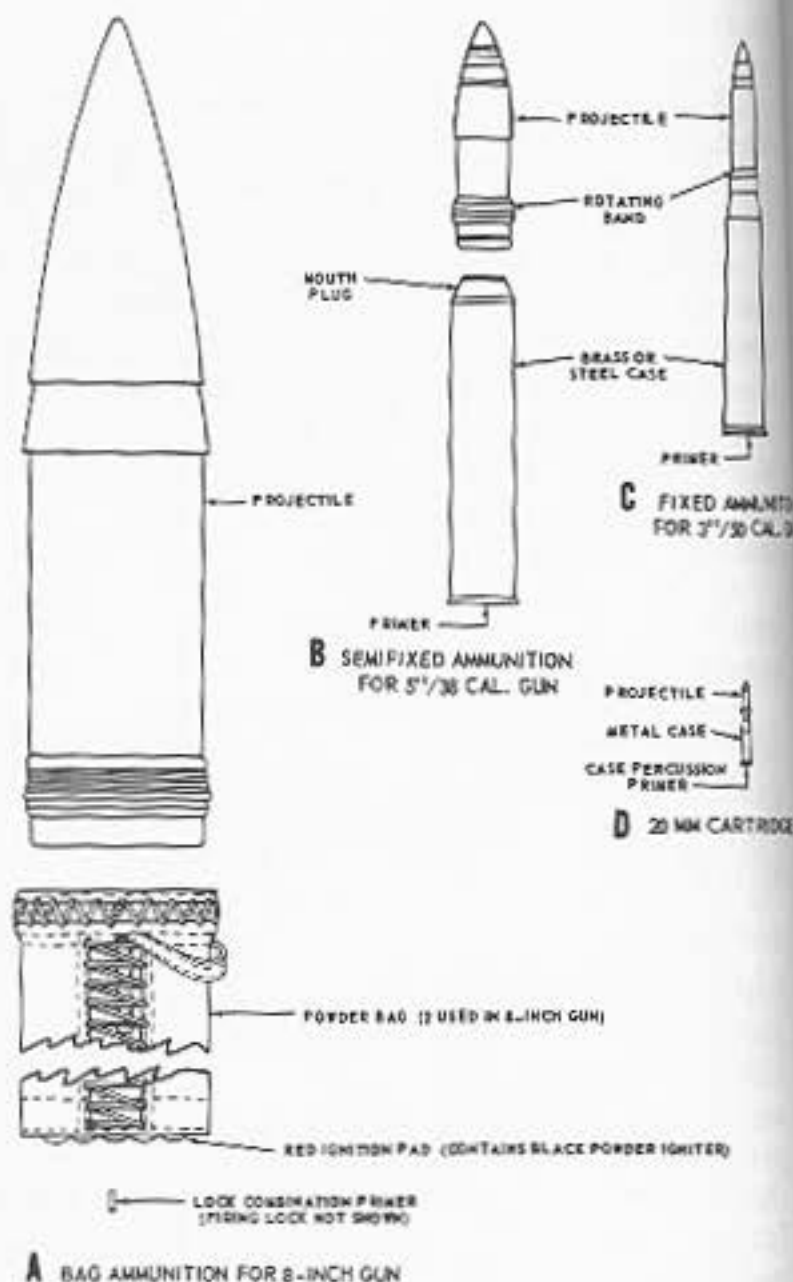


Figure 4-3.—Complete rounds of gun ammunition, A, Bag. B, Semifixed, C., D, Fixed.

2. Two or more powder bags.
3. A projectile.

Large guns must burn large quantities of propellant to develop the projectile initial velocity required. In a gun as large as 16-inch, several hundred pounds of propellant are needed for one full service round. By dividing this into several fabric bags, each of which can be handled by one man, the gun can be loaded in a relatively brief time. Each bag is made of silk (because silk will burn without leaving a smoldering ash), has silk straps for handling and silk lacing to cinch it up, and in red-dyed quilted silk pockets at one end has coarse black powder to serve as the igniter in the propellant train. The bags

are kept in airtight steel tanks until just before use.

Even as late as the beginning of World War II, many naval guns 5-inch and 6-inch in caliber used bag propelling charges. With the increased mechanization of ammunition handling, to which propelling charges in bags are not well suited, the use of bag ammunition has declined until it now is rarely if ever used in the active fleet, and then only in 8-inch turret guns of cruisers.

A complete loaded round of bag ammunition is shown in a cross-sectioned gun in figure 4-4. The primer, a small cylindrical metal container with one end open and the opposite end closed and rimmed, is loaded manually into a firing lock in the breech plug. The projectile is pushed into the gun by a power-driven manually controlled rammer. Next, the gun crew rolls the propelling charge into position for the rammer to push it into the gun behind the projectile. The last step in loading is for the gun crew to close the breech manually by swinging the breech plug into place and locking it. The gun can now be fired. This is done either by passing a small electric firing current through the primer, or manually operating a mechanical percussion device on the firing lock (not illustrated). The primer produces a spit of flame which travels through a bore or vent in a mushroom-shaped spindle in the breech mechanism and sets fire to the igniter in the after end of the rearmost bag. This sets off the remainder of the charge.

After the projectile has left the muzzle, the breech can be opened, and an air blast from a gas ejector clears the gun bore of residual gases. After inspection to verify that there is no burning residue in the bore, the next round can be loaded.

Case Type Propelling Charges

Gun ammunition which has its propellant charge in a metal case or cartridge instead of a bag is called case ammunition. (The term "cartridge" may also be applied to a complete round of small-arms ammunition.) Both semifixed and fixed ammunitions are of this type. The primer in all case ammunition is inserted in the base of the case at the ammunition depot and is not removed or changed aboard ship.

The designs of various sizes of case ammunition are similar, as may be seen from study of figure 4-5. The case assemblies are similar up to the point at which the mouth is sealed. In fixed ammunition the projectile is the seal; a mouth plug is used in semifixed ammunition.

There are four steps in the assembly of case ammunition: (1) priming, (2) loading the propellant, (3) fitting a wad and sometimes a distance piece, and (4) inserting the projectile or mouth plug. In priming, the primer used is either screwed (40-mm and larger) or force-fitted (smaller cartridge ammunition) into the base of the case. The desired weight of smokeless-powder grains is then dumped loosely into the

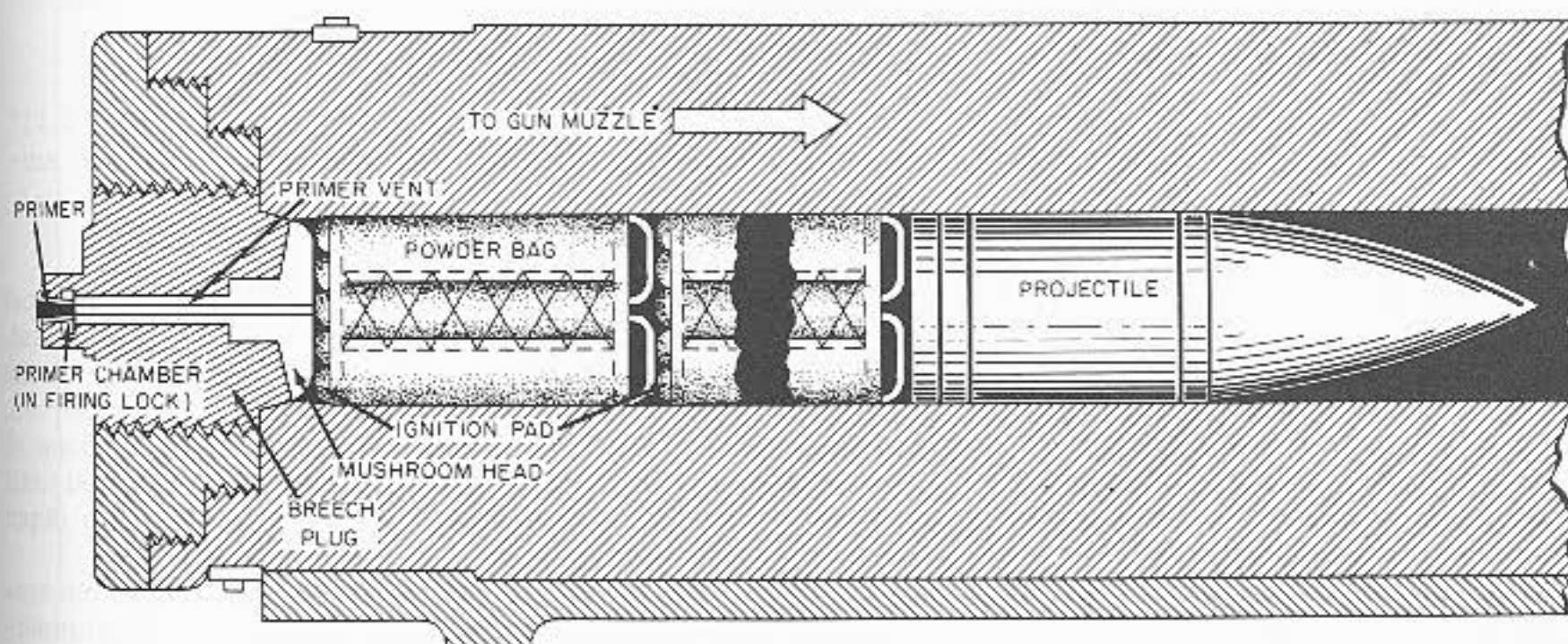


Figure 4-4. — Complete round of bag ammunition, loaded and ready for firing. Cross section.

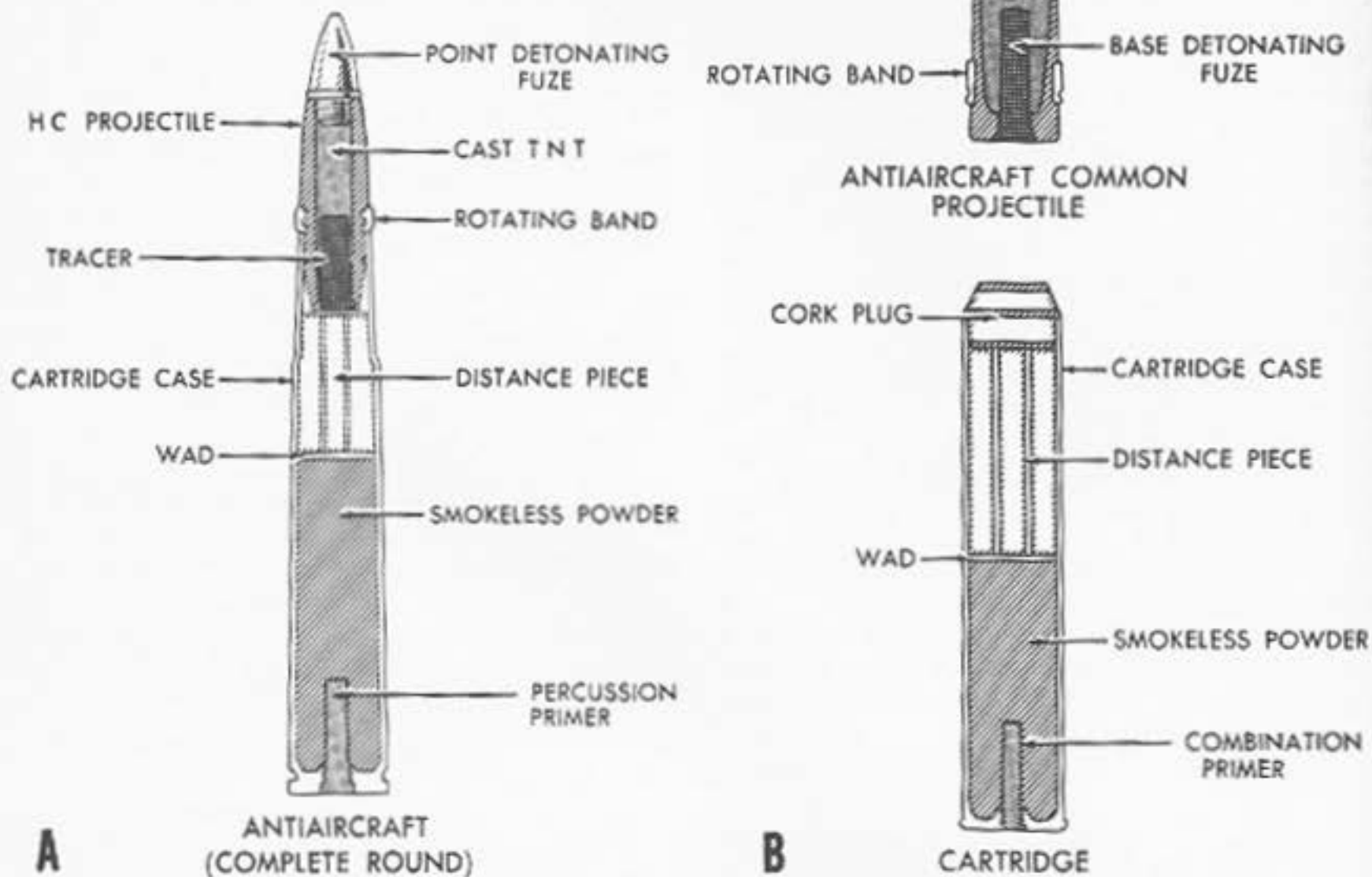


Figure 4-5.—Case ammunition. Cross sections. A. Fixed ammunition (40-mm). B. Semifixed ammunition (5 1/8"). 3,117

case. In 40-mm and larger guns, a cardboard or wad is forced into the case and a distance piece, if one is needed, placed on top. (This prevents shifting of the powder during handling.) The mouth of a semifixed case is then sealed by a mouth plug. In fixed ammunition, the mouth of the case is sealed by forcing the base of the projectile into the case.

The case is cylindrical but tapers slightly from base to top, and has an annular groove and rim at the base end. Cartridge cases have in the past generally been made of brass (hence the term spent brass to designate used cases aboard

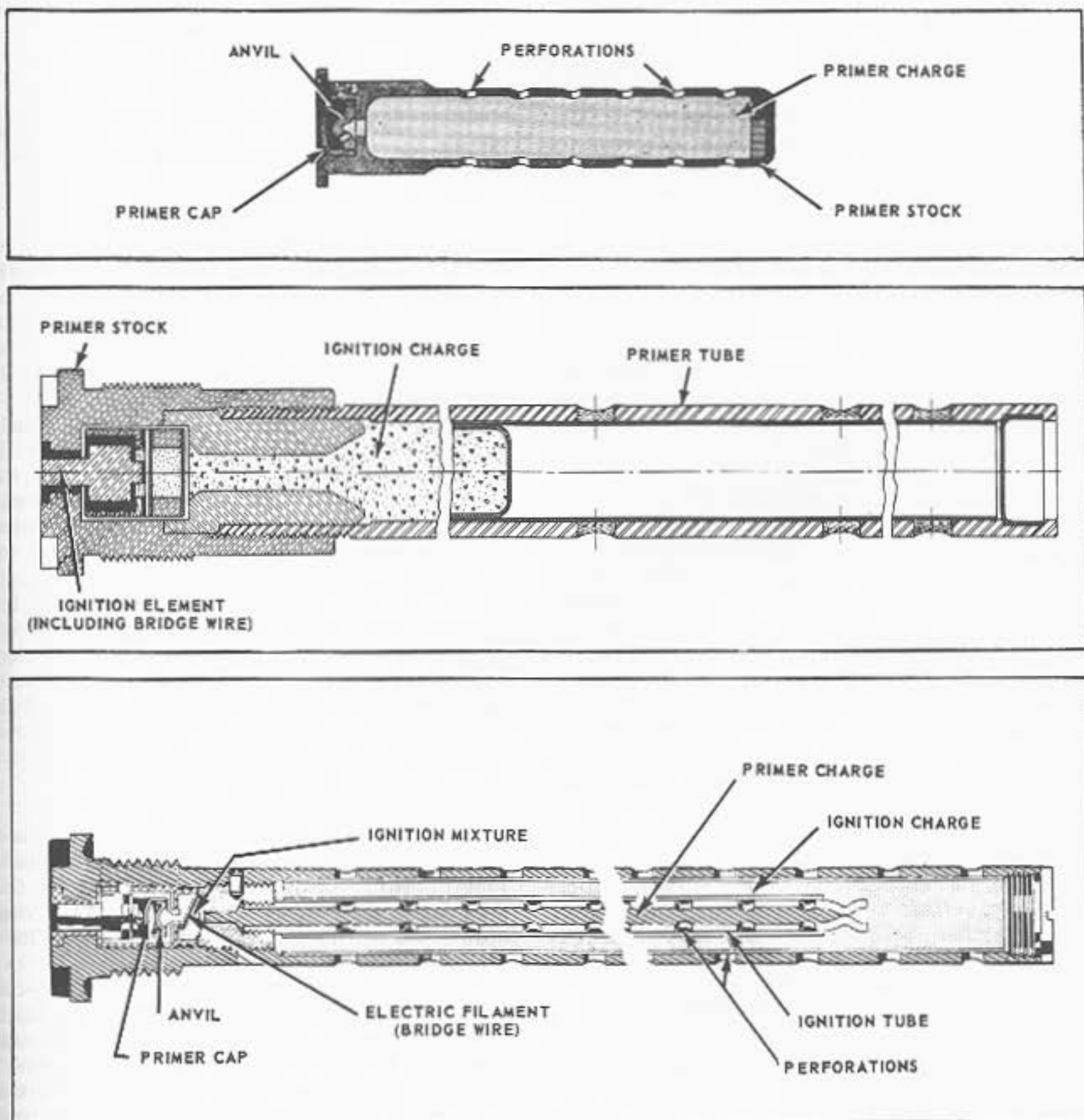
ship). Steel cases are now the standard in most calibers. Plastic cases are under development. Regardless of what it's made of, regulations require that spent "brass" must be conserved. After a brief ventilation period (to dispose of residual powder gases), it must be stowed until the ship can return it to an ammunition depot to be reused.

The primer-igniter arrangement in case ammunition is different from that in bag ammunition. The primer is always secured to the center of the base of the case. Primers for ammunition of larger caliber than 3" include an igniter

charge (black powder); smaller ammunition generally does not require an igniter, although black powder may be present in the initiator mixture.

Figure 4-6 shows the three types of primer. In percussion primers, the impact of a firing

pin (in the gun) on a primer cap imparts a blow to a sensitive initiating mixture between the cap and a metal anvil. This initiates an explosive reaction whose flame ignites the remainder of the primer charge. In electric primers, a brief pulse of firing current heats a small bridge wire



110.44

Figure 4-6.—Case primers. A. Percussion primer. B. Electric primer. C. Combination primer.

which ignites the initiating mixture; the flame thus produced is transmitted to the ignition charge, which in turn sets off the propelling charge. The combination primer has both a bridge wire and the cap-anvil arrangement; either can start the reaction. Electric firing is preferred with combination primer ammunition.

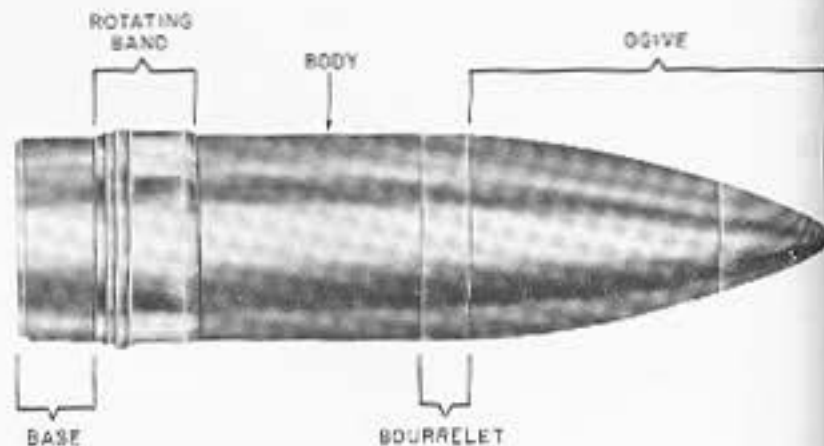
PROJECTILES

The projectile is the part of a complete round of service gun ammunition that is expelled at high velocity from the gun bore by the burning of the propelling charge. Modern projectiles are cylinders with pointed noses. Such a projectile can give stable ballistic performance only if it spins about its long axis while in flight—otherwise it will tumble erratically. As will be explained later in further detail, the bores of modern guns are spirally grooved (rifled) so that the projectile will develop this spin as it travels along the bore.

Modern small-arms and machine gun projectiles often consist of solid metal; projectiles used in larger guns, however, are assemblies of several components. The three essential parts are the metallic body, the explosive bursting charge, and the fuze which sets off that charge. There may also be a tracer to make the projectile more readily visible during flight.

The solid bullet damages by impact alone. Assembled projectiles, however, inflict damage primarily by the blast of the high-explosive charge and resulting high-velocity fragments.

EXTERNAL FEATURES OF PROJECTILES. The external shape of the projectile is designed to obtain the desired flight characteristics of stability and minimum air resistance. The form of forward end which best fulfills these conditions is the ogival curve (generated by revolving an arc of a circle about a chord). In a projectile the chord is the axis of the projectile and the radius used is about nine times the diameter (caliber) of the projectile. In small-caliber projectiles a cone is sometimes used instead, but this part of the projectile is still called the ogive. Aft of the ogive the projectile is cylindrical. The cylindrical shape may continue to the base (making a square base); or the after portion may be slightly tapered, (making it boat-tailed). Near the after end of the projectile is the rotating band; forward of this is the bourrelet (fig. 4-7). These two surfaces, slightly larger in diameter than the body, support and steady the projectile in its passage through the gun.



110.45

Figure 4-7.— External features of gun projectile.

In small projectiles the entire body forward of the rotating band may be finished to bourrelet diameter. On large-caliber projectiles additional bourrelets, forward of the rotating band, are added to provide better support. The bourrelet is very slightly smaller (0.015 to 0.030 inch) than bore diameter.

The rotating band, on the other hand, is actually larger than bore diameter. Its three main functions are (1) to seal the bore, (2) to position and center the rear end of the projectile, and (3) to engage the helical rifling grooves in the gun bore so as to impart rotation to the projectile. It also holds the projectile in position in the gun after loading and ramming so that it will not slip back when the gun is elevated.

Rotating bands are generally made of copper, either pure or alloyed. (Experiments have been made with rotating bands of sintered metal; these have not been adopted for service at present.)

Projectile Identification

Distinguishing colors and markings are necessary to properly and rapidly identify projectiles. Identification of Ammunition, OP 2238 (latest revision), serves as a guide for identifying by color, markings, and lettering projectiles and other Navy ammunition.

Presently there are two different color-coding systems used by the Navy to identify ammunition. These systems are classified as the old and the new system and are explained in OP 2238. The old system applies only to ammunition manufactured before the new system of color coding became effective. All projectiles (and other ammunition) newly produced must have the new color code and markings applied.

Projectile Weight

Within limits, a gun can fire projectiles of different weights. The weight of U. S. Navy projectiles is determined by the formula

$$W = \frac{d^3}{2}$$

in which: W = weight of projectile in pounds, and
 d = caliber of gun in inches.

The weight of the projectile per square inch of bore is called sectional density. It is represented by the expression

$$SD = \frac{W}{A}$$

in which: SD = section density.

W = weight of projectile in pounds.

A = area of bore, including grooves in square inches.

This ratio varies with the size of the gun, averaging approximately six-tenths of the caliber.

The distribution of weight in a projectile is a matter of considerable importance. The center of gravity should be in the longitudinal axis and close to or abaft the center of form.

Classification of Projectiles

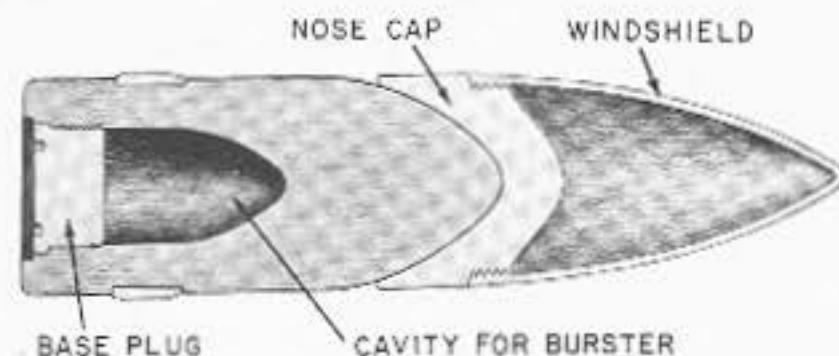
All gun projectiles, other than small arms, share the characteristics so far described. Since targets differ in character, projectiles must differ in design to defeat them most effectively. There are three general classes of projectiles:

1. Penetrating.
2. Fragmenting.
3. Special purpose.

In each class are one or more types, each designated by a specific letter code.

Penetrating projectiles. Penetrating projectiles include armor-piercing (AP) and common (COM). They are designed to penetrate, respectively, heavy and light armor. The usual bursting charge for these types is Explosive D, which is insensitive enough to permit penetration without premature detonation.

Figure 4-8 shows the construction of a typical AP projectile. The body has thick walls, a relatively small burster charge cavity, a nose cap,



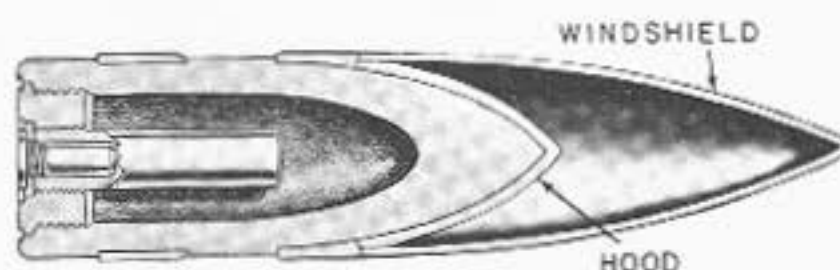
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Figure 4-8.—3-inch armor-piercing projectile. Cross section.

and a thin metal windshield. To function effectively, an armor-piercing projectile must keep its burster charge intact until it has penetrated its target. The projectile body, of tough steel, backs up the hardened but somewhat brittle steel nose cap, which is so shaped that it will dig into and cut through an armor-plated target, rather than ricochet. However, in flight the blunt nose cap, which is shaped for penetration of armor, not for streamlining, would give the projectile the ballistics of a brick. Hence the windshield, which collapses upon impact with the target, is screwed on to give the exterior of the projectile a satisfactory ogival shape. AP projectiles in larger calibers are not efficient against lightly armored targets, because of their small bursters. The projectile is delay-fuzed to burst after penetration.

The common projectile, illustrated in figure 4-9, has a hood instead of the armor-piercing cap, a larger burster, and thinner walls, and is suited for more lightly armored targets than AP projectiles.

Fragmenting projectiles. Fragmenting projectiles are designed to damage by both blast effect and fragmentation—that is, breaking up



84.10.3

Figure 4-9.—3-inch common projectile. Cross section.

into high-velocity fragments. Such projectiles characteristically have relatively thin walls and large cavities for the burster. Under this general classification are the following types:

1. High-capacity (HC). A typical HC projectile is illustrated in figure 4-10. This type is used against unarmored surface targets, shore objectives, or personnel. Since no penetration ability is required, explosives more sensitive than Explosive D may be used.

2. Antiaircraft (AA) projectiles are designed for use against airplanes in flight. Except for fuzing they are substantially the same as HC in the larger calibers. In smaller sizes the explosive often contains an incendiary element.

3. Antiaircraft common (AAC) projectiles are a dual purpose design, combining the qualities of antiaircraft projectiles with the toughness necessary to penetrate steel plating not of armor thickness. The type of fuzing will depend on the use. The walls may be heavier than those of the other thin-walled types, and the filler is usually Explosive D.

Special purpose projectiles. The special purpose classification includes types not intended to inflict damage by blast or fragmentation. If the filler includes any explosive, it is a small charge designed to expel the contents of the projectile. See figure 4-11. The common varieties are:

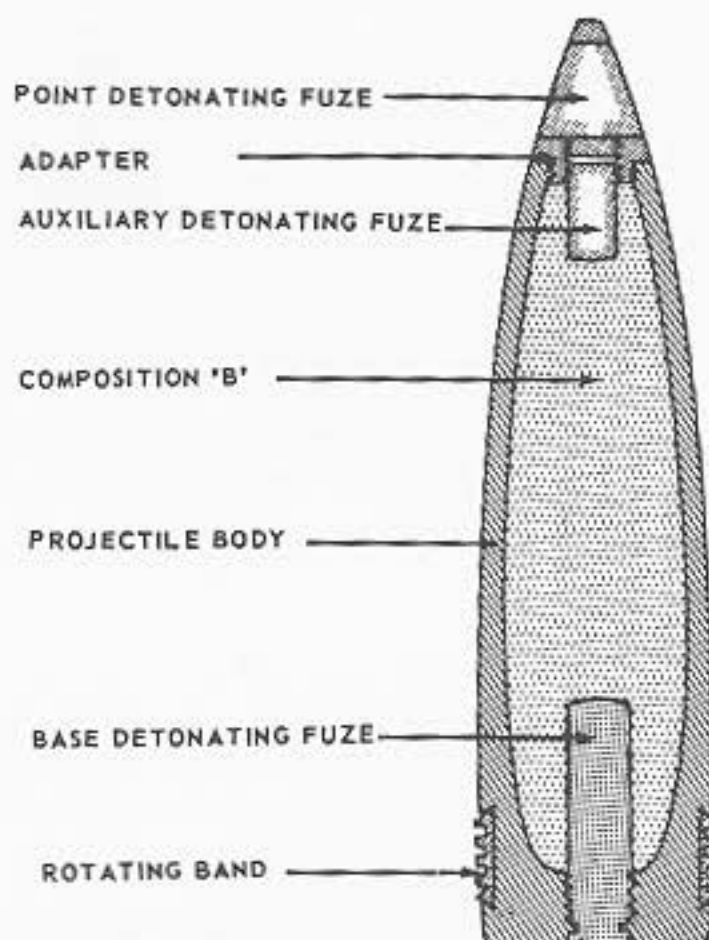
1. Illuminating (ILLUM) projectiles, often called star shells (SS), contain a bright flare attached to a parachute; these are expelled from the projectile by a small black-powder charge which also lights the flare. As the parachute slowly lowers the flare, it illuminates the target.

2. Smoke projectiles contain tubes of white phosphorus (WP) which are scattered and burst by a small black-powder charge. White phosphorus produces a screening smoke, and has an incendiary effect.

3. Window (W) projectiles contain metal foil strips, which are scattered high in the air by a small burster charge to confuse enemy radar.

4. Nonfragmenting ("nonfrag") projectiles are used for antiaircraft gun practice. They contain a smoke-producing substance, available in various colors, to make observable bursts without destroying the target by fragmentation.

5. Target or blind-loaded (BL) projectiles contain sand or other inert substance to give the same weight and balance characteristics as explosive fillers.

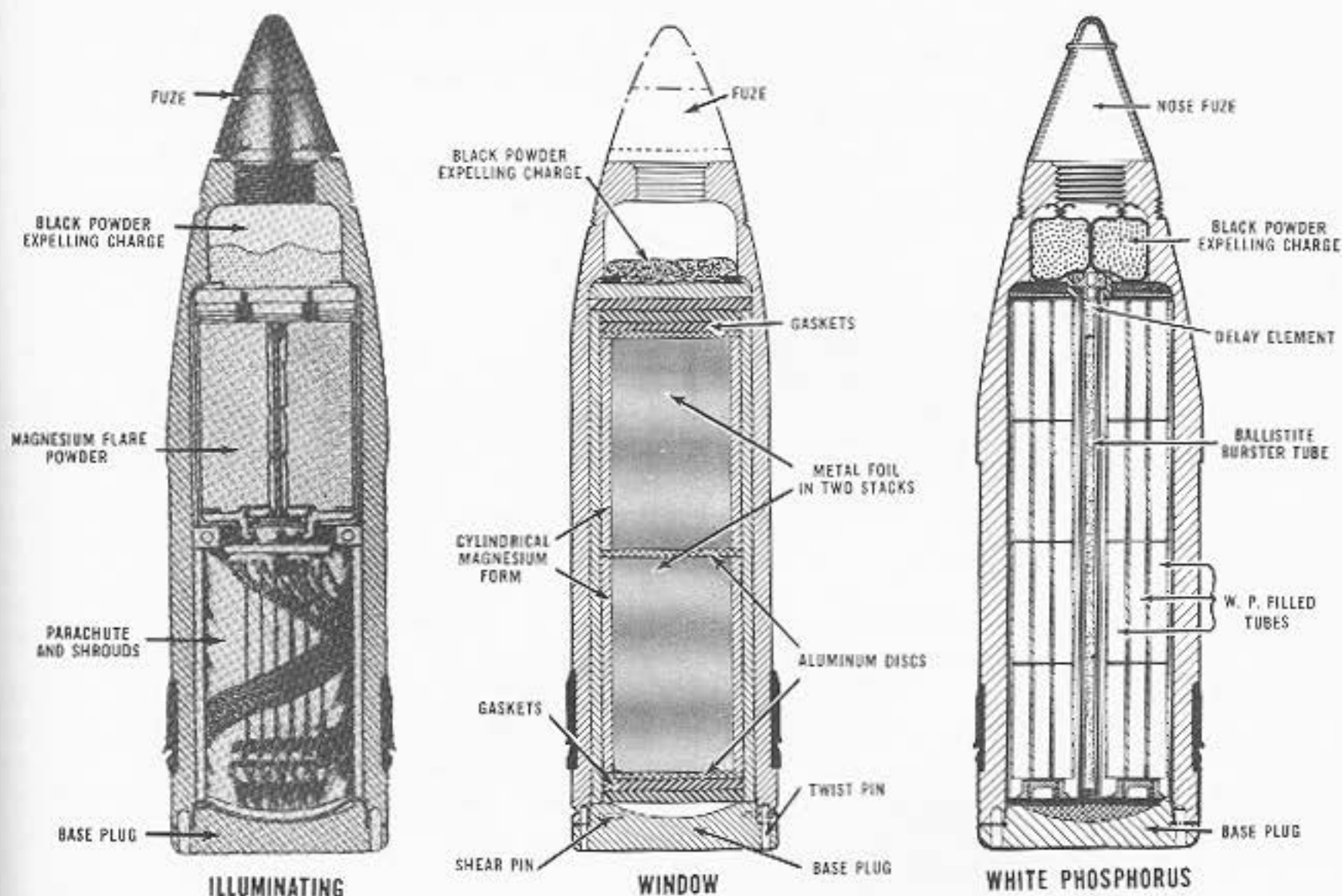


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Figure 4-10.—6-inch high-capacity projectile.

Rocket Assisted Projectiles

A rocket assisted projectile (RAP) is fired from a gun at the same initial velocity as a standard projectile. The RAP is not a replacement for existing gun-type ammunition but an addition to it that extends its range several hundred yards. Rocket assisted projectiles are used primarily against personnel and light-material shore targets. A secondary use, however, is against enemy shipping at extended ranges. Operational skill and maintenance level required aboard ships are not affected by the addition of the RAP.

RAP DESCRIPTION.—Each RAP round consists of a projectile and a gun cartridge (full charge). The projectile consists of a solid-propellant rocket motor with a delayed ignition element, an explosive filler warhead, and either a controlled variable time fuze (CVT) or a point detonating fuze (PD). Cartridges used to fire RAPs are the same as those used to fire standard projectiles. Figure 4-12 is a cutaway view of a 5"/38 rocket assisted projectile.



110.47

Figure 4-11.—Special-purpose projectiles.

RAP OPERATION.—When the projectile is fired, gun chamber pressure flexes a spring which strikes a percussion primer assembly in the base of the projectile. The primer in turn ignites a pyrotechnic delay column that burns for a definite period of time (23 seconds for a 5¹/₃₈ RAP). After the delay period, the delay column burns the ignition charge which ignites the rocket motor. The rocket motor gives the projectile a "boost", increasing its velocity and its range. The details of the ignition element used in the RAP are illustrated in figure 4-13. The igniter is a gun-gas-triggered, percussion-activated delay igniter, sealed into the base of the motor case and blown out upon motor ignition.

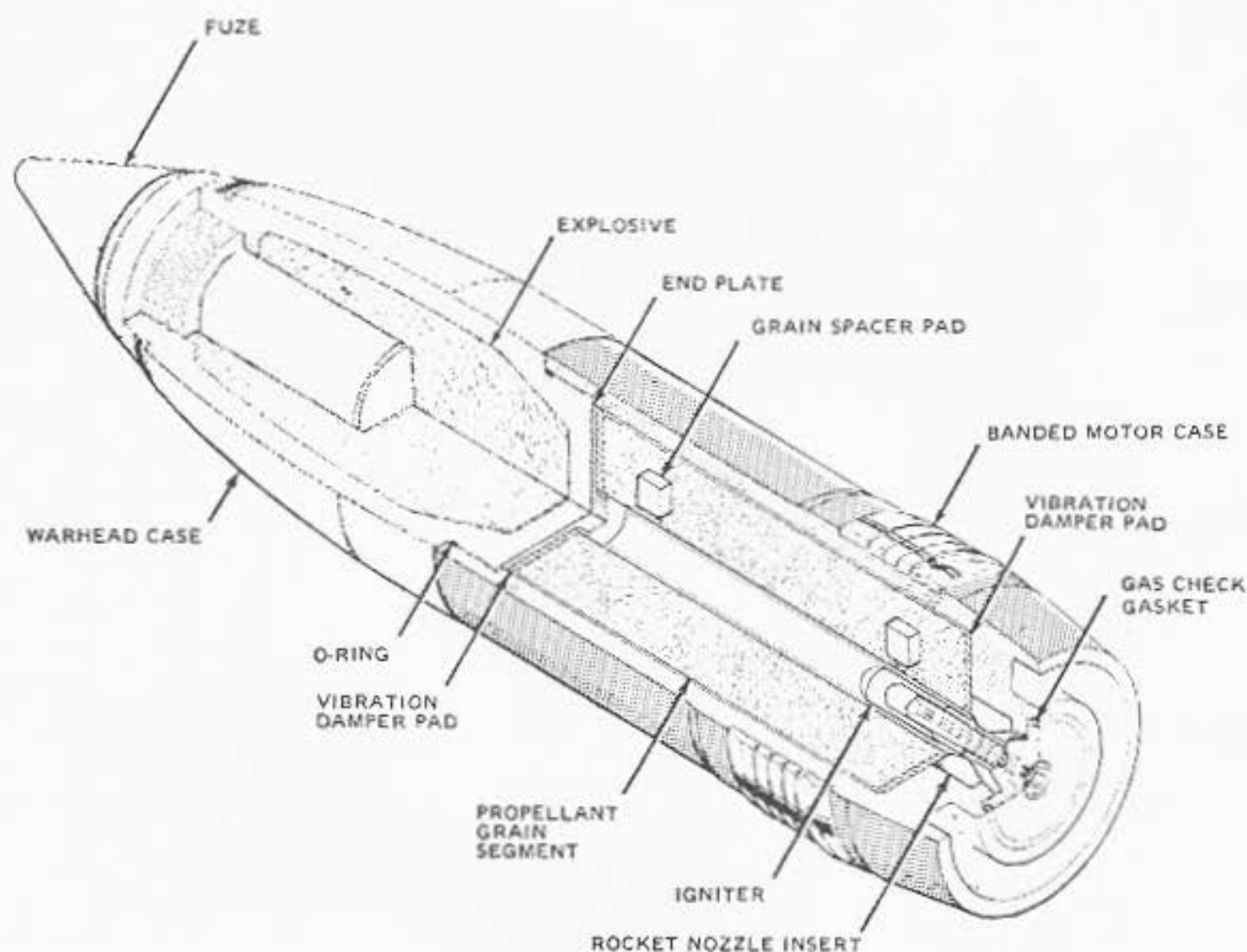
SAFETY PRECAUTIONS.—RAP ammunition should be handled carefully at all times. Stowage conditions for RAPs must meet the same requirements applicable to standard projectiles.

Because of the similarity in appearance between a standard projectile and a RAP and the dissimilarity of impact points, positive and correct identification by handling crews becomes a major safety factor. For example, crews could be under the impression that they are firing RAPs over the heads of our assault forces when actually they are firing standard projectiles into the midst of these forces.

FUZES

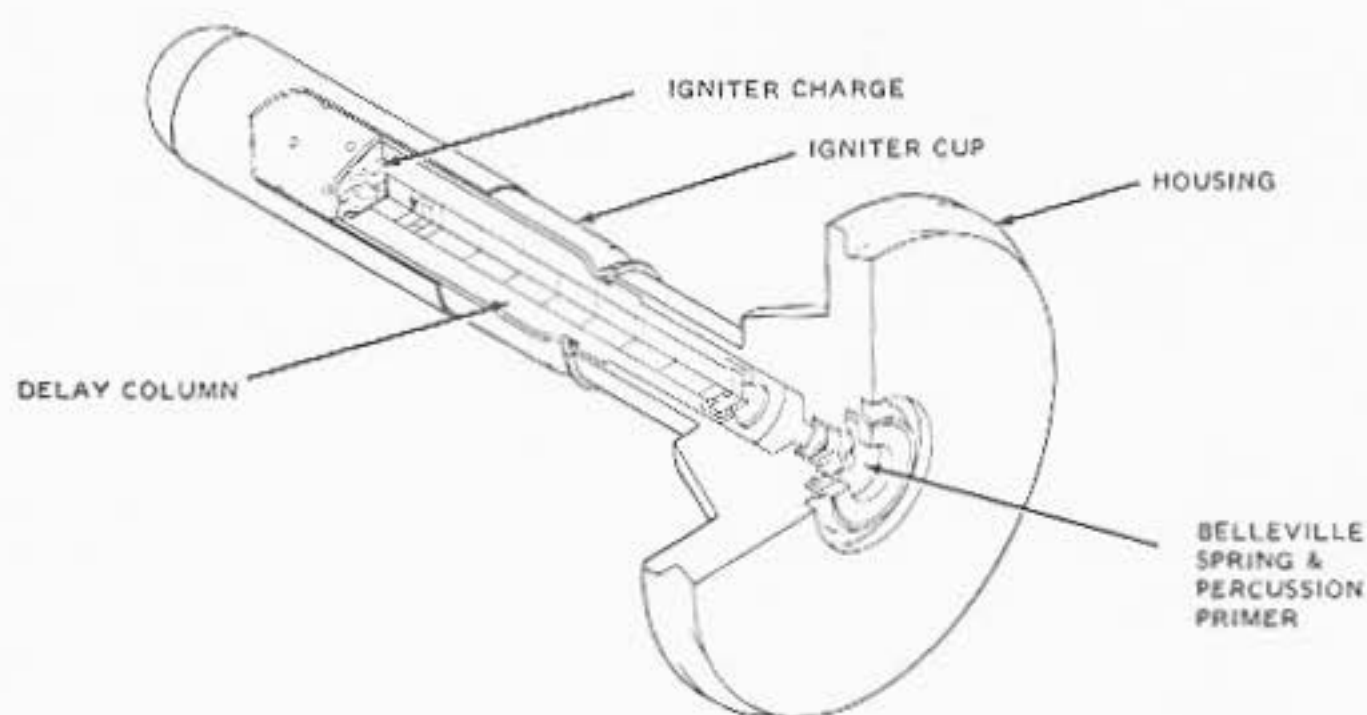
A projectile fuze is a mechanical or electronic device which will detonate or ignite a charge in a projectile at the time and under the circumstances desired.

Fuzes may be classified according to function (impact, time, auxiliary, or proximity), the position of the fuze in the projectile (nose or base), type of mechanism or principle utilized (mechanical time or variable time—VT), and specific



84.304

Figure 4-12.— 5''/38 rocket assisted projectile (RAP); cutaway view.



84.305

Figure 4-13.— Ignition element; cutaway view.

action at time of functioning or initiation (ignition or detonation). Figure 4-14 illustrates locations of typical fuzes.

Typical examples of nomenclature for Navy fuzes are as follows:

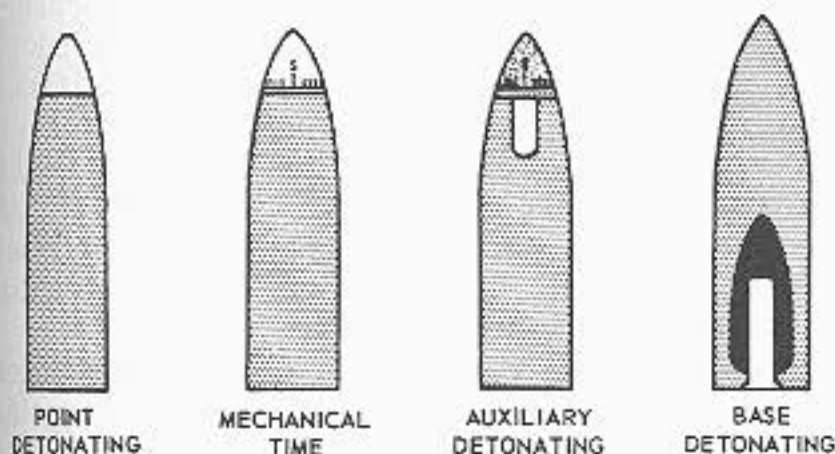
1. Auxiliary detonating (ADF).
2. Base detonating (BDF).
3. Mechanical time (MTF).
4. Point detonating (PDF).
5. VT or proximity (VTF).

Point detonating, time, and VT fuzes may all be called nose fuzes because of their location in the projectile. Fuzes are designated as detonating when they contain within themselves a high-explosive charge sufficient to set off a high-order explosion in the burster. Ignition fuzes contain black powder sufficient to ignite the burster of small projectiles. In larger projectiles such fuzes function indirectly through an auxiliary detonating fuze.

For safety reasons a fuze must be inoperative until the projectile is clear of the muzzle and the firing ship. A fuze is said to be armed when it is set to permit initiation of the explosive train. It is unarmed when set to prevent initiation.

A satisfactory fuze must:

1. be safe to handle; that is, the fuze must not arm if dropped or joggled.
2. be safe after firing until it is at a safe distance beyond the gun bore. A fuze with this characteristic is said to be boresafe.
3. function to initiate the explosive train at the proper instant, and not before or too late.



84.13

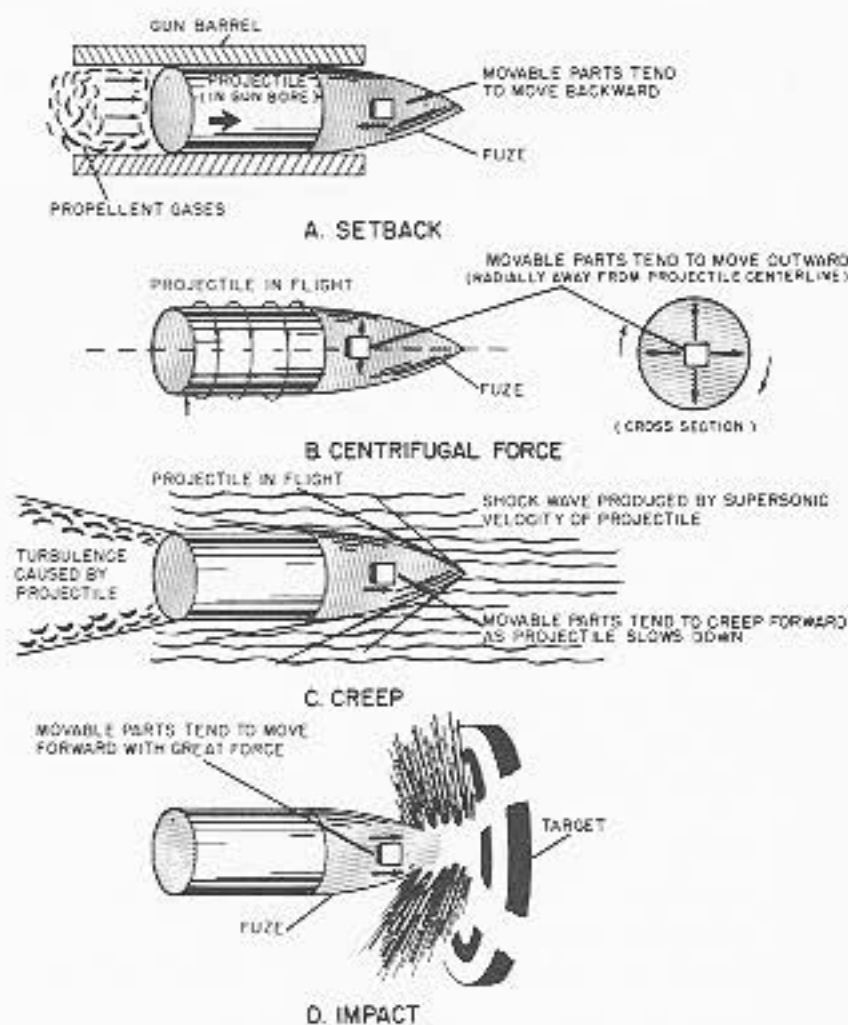
Figure 4-14.—Fuze locations.

Forces That Operate Fuzes

From the instant of firing until it strikes its target, a projectile and its components are subjected to a succession of forces that can be utilized to start or drive a fuze's mechanism. Many fuzes are complicated and use more than one of these forces (listed below), in addition to other energy sources.

1. **SETBACK.** When the propelling charge is fired, the projectile is (a) accelerated forward and (b) twisted clockwise (as seen from the base). Because of their inertia, movable parts of the projectile consequently develop, during the period of projectile acceleration and twist, a rearward force called setback (fig. 4-15A) and a rotational force or torque in the counterclockwise direction (i.e., in the direction opposite to the twist). This torque is called angular setback.

2. **CENTRIFUGAL FORCE.** In accordance with Newton's laws of motion, any moving particles



84.12

Figure 4-15.—Forces that work on fuzes. A. Setback. B. Centrifugal force. C. Creep. D. Impact.

tends to keep moving in a straight line. Consequently, because of its inertia, a revolving particle develops a radial thrust (centrifugal force) away from the center of revolution. As shown in figure 4-15B, the fuze parts therefore develop a continuous outward thrust from the rotating projectile's centerline while it is in flight.

3. CREEP. The projectile while in flight is gradually slowed by air resistance acting on its exterior surface. Since the parts inside the projectile are not in contact with the air and do not meet this resistance, they tend because of inertia to continue in motion at the same velocity. Thus, as illustrated in figure 4-15C, they exert a continuous forward thrust, called creep.

4. IMPACT. When a projectile strikes, its parts because of inertia tend to continue moving forward; this develops considerable force. Impact is generally used to initiate the explosive train (fig. 4-15D).

5. TARGET CONTACT (not illustrated). When a firing plunger or other part of a projectile contacts the target, it is driven toward the rear with respect to the remainder of the projectile. Target contact is used to start the explosive train.

Types and Applications of Fuzes

Auxiliary detonating fuzes are used in conjunction with all types of nose fuzes in projectiles of 3-inch and greater caliber except illuminating and special purpose projectiles. They prevent detonation if the nose fuze is accidentally actuated before the auxiliary detonating fuze is armed.

Base detonating fuzes are used alone in AP and COM projectiles, and in combination with nose fuzes in such dual purpose projectiles as AAC and HC. In the latter their functioning is completely independently of the nose and auxiliary fuzes. All base detonating fuzes function on impact; some, however, have a delay time (0.02 to 0.033 second) after the projectile hits, to allow time for armor penetration.

Mechanical time fuzes (MTF) are clockwork mechanisms which begin to function upon firing, and initiate the explosive train at a selected time following firing. They are used in high explosive, illuminating, and various special purpose projectiles. When used in high explosive projectiles, these fuzes work in conjunction

with auxiliary detonating fuzes. MTFs contain a gear train and an escapement mechanism which starts to operate immediately after the inertia force of setback has ceased. Centrifugal force acting on weights, with or without the aid of coiled springs, supplies the energy to run the clock mechanism. After the predetermined and preset time interval, a spring-loaded firing pin is released and strikes the initial element of the fuze explosive train.

MTFs are used in projectiles with high fragmentation qualities to provide air bursts. Air bursts are effective against personnel if they are timed to burst, say 50 feet above a trench or other occupied area. Gunfire support requirements call for these bursts to be 25 to 50 feet above the target.

Even though they can be used in antiaircraft fire, MTFs are used more often against surface or shore targets. Obvious is the superiority of timed projectiles, throwing fragments in all directions, over those which require target contact before detonation. A direct hit is improbable on a small, fast-moving target, but the 5" AAC projectile has been designed to increase the probability of a hit by utilizing a timed air burst. An AA common projectile may have a point detonating fuze, a base detonating fuze, auxiliary detonating fuze, and mechanical time fuze making it a very versatile projectile.

Point detonating fuzes are designed to function on impact. They are faster acting than BDFs and are used chiefly against lightly armored targets in gunfire support. Point detonating fuzes are found in high capacity (HC), AAC, and white phosphorous (smoke) projectiles. These fuzes are inserted into the projectile's nose in an unarmed condition; they are armed by centrifugal force after the projectile has been fired.

VT fuzes are proximity fuzes, used in all of the types of projectiles that can use mechanical time fuzes, except illuminating and window. The VT fuze is a self-contained radio transmitter-receiver which receives echoes of its transmission as reflected by a target. When the returning signal is of sufficient strength, as the projectile nears the target, the firing circuit closes. The fuze is rugged and compact; it fits into the nose of a projectile.

VTs are also effective against personnel ashore but are used mainly against air targets. If a VT bursts in the vicinity of an air target, it is considered to be a hit in wartime firing and for peacetime firing practice evaluation. The burst is called a TTB (target-triggered-burst).

CHAPTER 5

GUNS, GUN MOUNTS, AND TURRETS

INTRODUCTION

The gun has been used in warfare ashore and afloat for several hundred years. Its effectiveness as a weapon has increased over this period, but this development has not been a slow, steady growth. For the first 400 years the technology of gunnery changed so little that a sailor of early Elizabethan times would have had to learn very little that was new to have served a gun at Trafalgar (1805). Most of the basic features that have made the modern Naval gun the effective weapon it is today were developed in the past 135 years; most of them began to become important only after 1900.

The guns aboard modern United States Naval vessels, complex though they are in detail, are based on a relatively few fundamental features. Once these are grasped, the student will find it easier to understand the details of structure of any gun mount or turret he encounters.

The fundamental principles of how guns, gun mounts, and turrets are constructed and how they work is explained in the first part of this chapter. Details of their construction and functioning are described later in the chapter.

Features of gun mounts and turrets that are discussed in the following paragraphs are those that are referred to in this book as "conventional," which means that they represent standard practice in the gun and mount design as it existed in the U. S. Navy about the middle of the 20th century. New developments and improvements in guns and mounts are, of course, always in progress.

SOME BASIC DEFINITIONS

Before proceeding with the study of gun mounts and turrets, study the following brief list of definitions. They amplify or more precisely delimit some terms to be discussed later in the

chapter. Other definitions may be found in the appendix glossaries.

GUN.—The term GUN properly designates the tube or barrel, but it is commonly used to refer to the whole assembly of which the barrel is but a part.

MOUNT.—The mount is the entire structure between the gun and ship's structure. It supports the gun, secures the gun to the ship's structure, and provides for the gun's elevation, train, and (in guns larger than 20-mm) recoil and counter-recoil. There are several types of mounts, but all of them must accomplish these functions. Larger mounts have other functions as well.

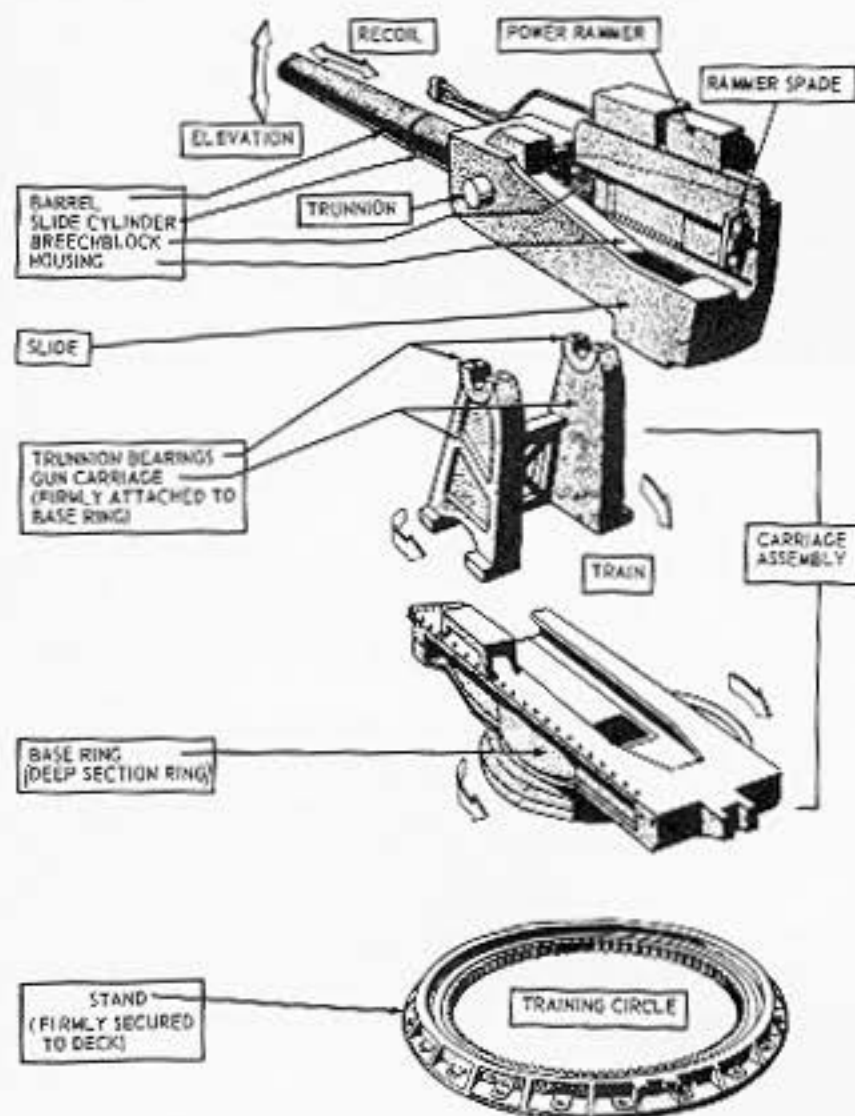
TRAIN.—Train angle of a gun is the position of the axis of the gun's bore in a plane parallel to the deck measured from the ship's centerline. Training the gun is rotating the gun in bearing. The trainer is the gun crew member who controls the training of the gun. The training gear is the equipment used to train the gun.

COMMON STRUCTURAL ARRANGEMENT OF NAVAL GUN MOUNTS

Figure 5-1 shows the "skeleton" of the structure of a typical 5-inch naval gun mount. In general these parts, their arrangement, and their nomenclature are typical of other naval gun mounts, both larger and smaller.

Serving as the mount foundation is the stand, a steel ring bolted to the deck. The training circle is an internal gear inside the stand.

Supported by the stand, and capable of rotating in train in roller bearings on it, is the base ring, also called the deep section ring or lower carriage. Mounted on it is the upper carriage,



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Figure 5-1.—Main assemblies of a 5-inch mount.
Exploded view.

a pair of massive brackets braced to hold the trunnion bearings, large roller bearings into which the gun trunnions fit. The trunnions are part of the slide, a rectangular weldment which supports all the elevating parts of the gun. The housing slides in recoil in the slide; the barrel fits into the housing's forward end, and the breechblock can slide up and down in a breechway just behind the barrel. Arrows show the movement of which each part (except the breechblock) is capable.

Figure 5-2 shows how the base ring fits into the stand, and how the mount trains. Holding-down clips bolted to the base ring fit under the stand so that the carriage will not tip when the gun fires or when the ship pitches and rolls. The base ring can turn on the stand in two large-diameter roller bearings. One, the roller path, takes up vertical thrust, the other, horizontal. The function of the training circle also

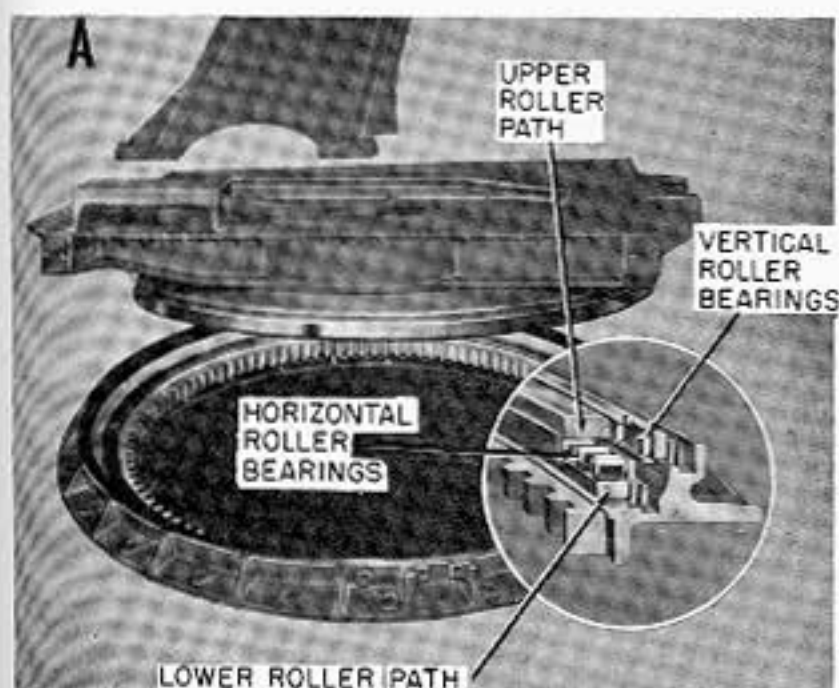
is illustrated in figure 5-2. A pinion in the carriage engages the training circle gear teeth to train the mount.

The carriage assembly comprises two parts—the lower carriage (base ring) and upper carriage (fig. 5-3). The base ring supports the upper carriage and platform; the shield (in enclosed mounts) is secured to it. It also supports the mount power drives and other components. In mounts equipped with powder and projectile hoists, the hoists hang from the base ring and train with the mount. The upper carriage supports the trunnion bearings. The trunnion bearings and trunnions, besides supporting the elevating parts, provide connections for air lines (for gas ejection) and mechanical linkages (for percussion firing and for transmission of elevation movement to firing stop mechanisms).

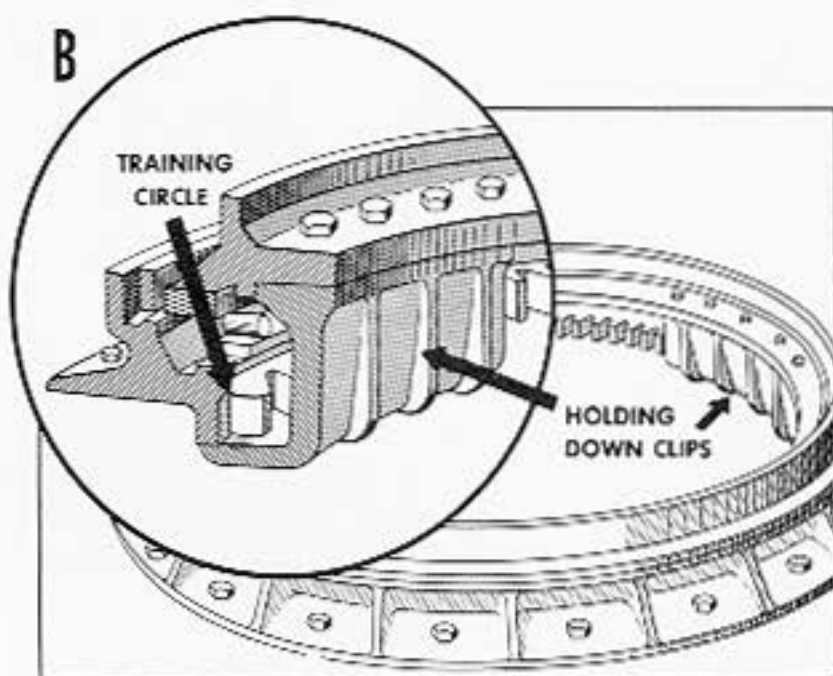
The trunnions are part of the slide (fig. 5-4). The slide is conventionally a rectangular steel weldment which houses or supports all the parts of the gun and mount that move in elevation. In modern mounts designed to engage either air or surface targets, the limits of elevation movement are from minus 10 to 15 degrees (that is, with gun barrel depressed 10 to 15 degrees below the horizontal) to about plus 85 degrees (that is, with the gun barrel within 5 degrees of pointing straight up).

The slide (fig. 5-4) contains the ammunition feed mechanism (or the power rammer if ammunition feed is performed manually with mechanical assistance), the recoil brake, the counterrecoil mechanism, the elevating arc, and the gun housing. Figure 5-4 shows how the elevating arc positions the slide in elevation. The arc, a gear sector secured to the slide, engages a pinion (which may be driven manually or by a power drive) in the carriage.

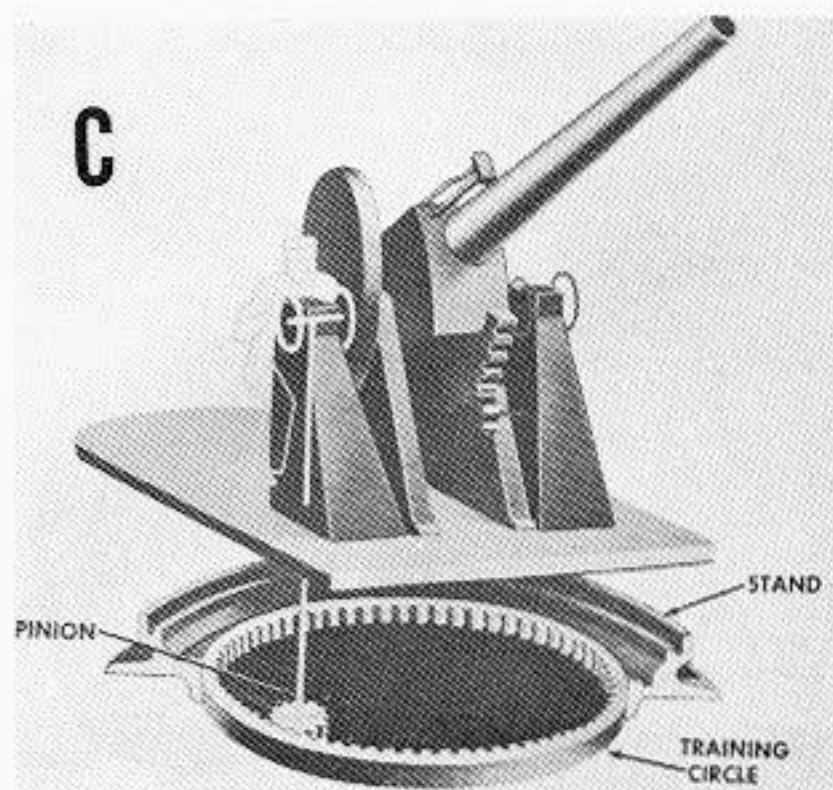
As you know from the last of Newton's three laws of motion, any action produces an equal and opposite reaction. The thrust which propels the gun projectile out of the barrel is accompanied by an equal thrust in the opposite direction. This thrust produces a rearward movement, called recoil, of parts of the gun. After the projectile and high-pressure propellant gases have left the barrel, recoil thrust ceases. The recoiling parts of the gun are then forced forward. This forward movement is called counterrecoil, and it continues until the parts that recoiled are restored to their original position before firing.



A. Roller bearings.



B. Training circle and holding-down clips.



C. Principle of training gear.

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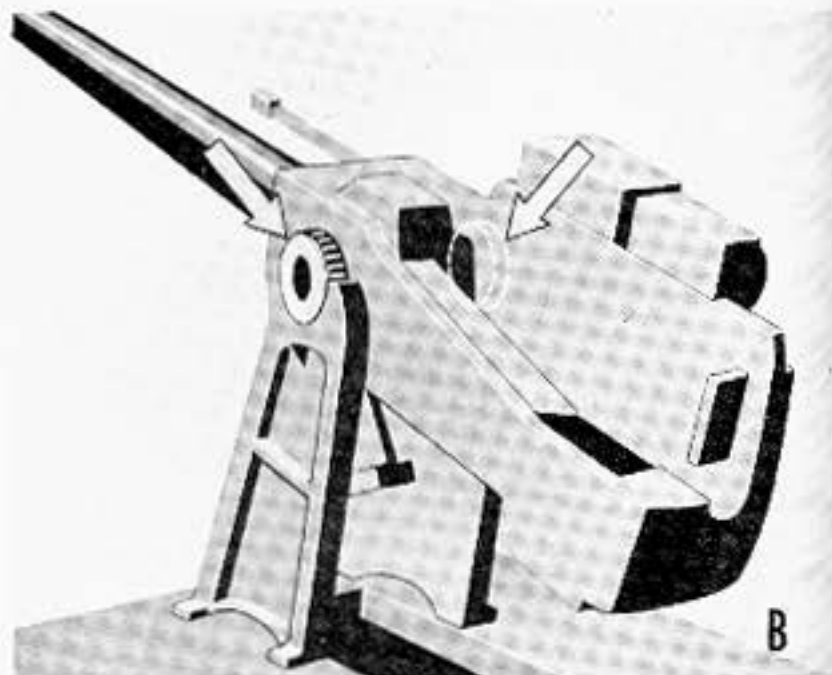
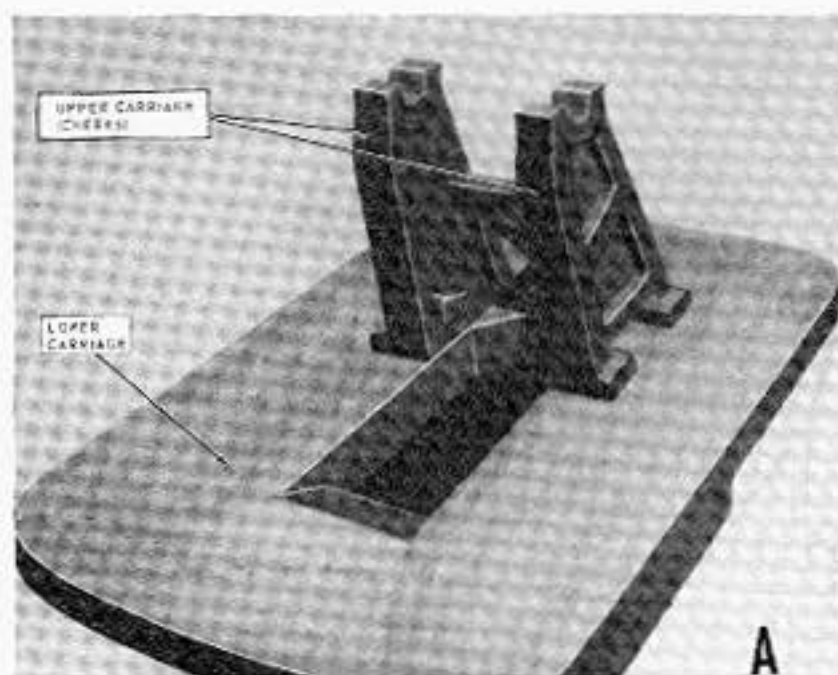
Figure 5-2.—Details of the stand and carriage.

This is called battery position, and the gun is now said to be in battery. Note that in all modern naval guns, only parts of the gun mount recoil; the gun mount as a whole does not recoil with respect to the ship's structure.

The recoiling parts of a conventional naval gun are either attached to or housed in the gun housing or breech housing (fig. 5-5). (Some turret guns and 20-mm guns differ considerably from this type of conventional design; this description is not intended to apply to them.) Secured to the forward end of the housing is

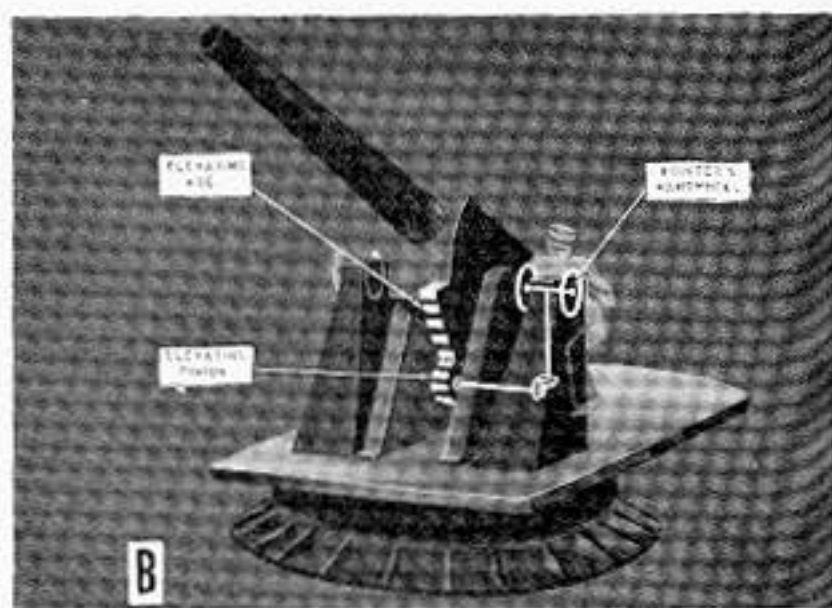
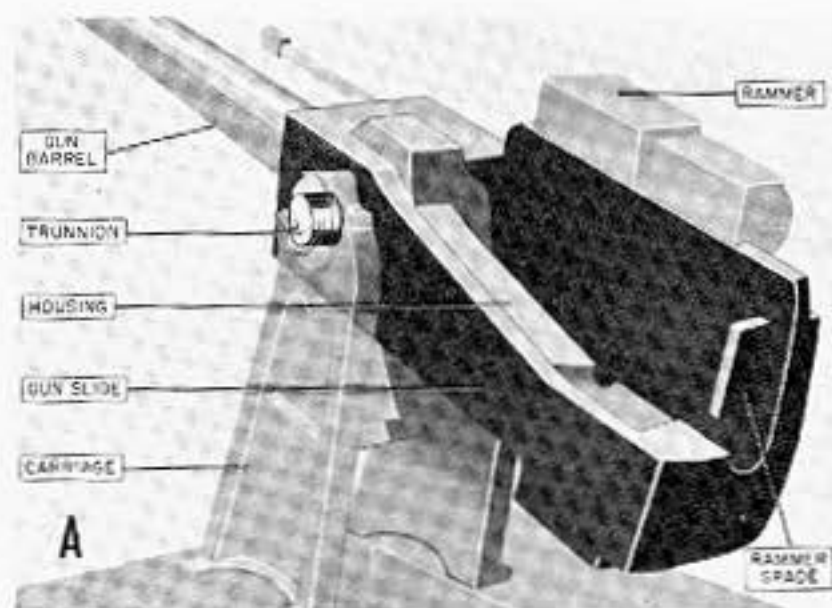
the gun barrel itself. The commonest method of attaching gun to housing is by use of an interrupted-screw joint, with a key to lock the barrel against possible rotation. The housing can move parallel to the gun bore axis in WAYS in the slide. It is normally forced to the battery position by a counterrecoil mechanism (described later).

When the gun fires, the reaction of the barrel forces the housing aft; this movement is opposed by the counterrecoil mechanism and by a hydraulic recoil brake to be described later.



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Figure 5-3.—The carriage. A. Upper and lower carriage. B. Trunnion bearings.



84.153

Figure 5-4.—The slide. A. Main features. B. Principle of elevating mechanism.

Figure 5-5 also indicates the location and some features of the breech mechanism. The conventional type, illustrated here, is called the vertical sliding-wedge type.

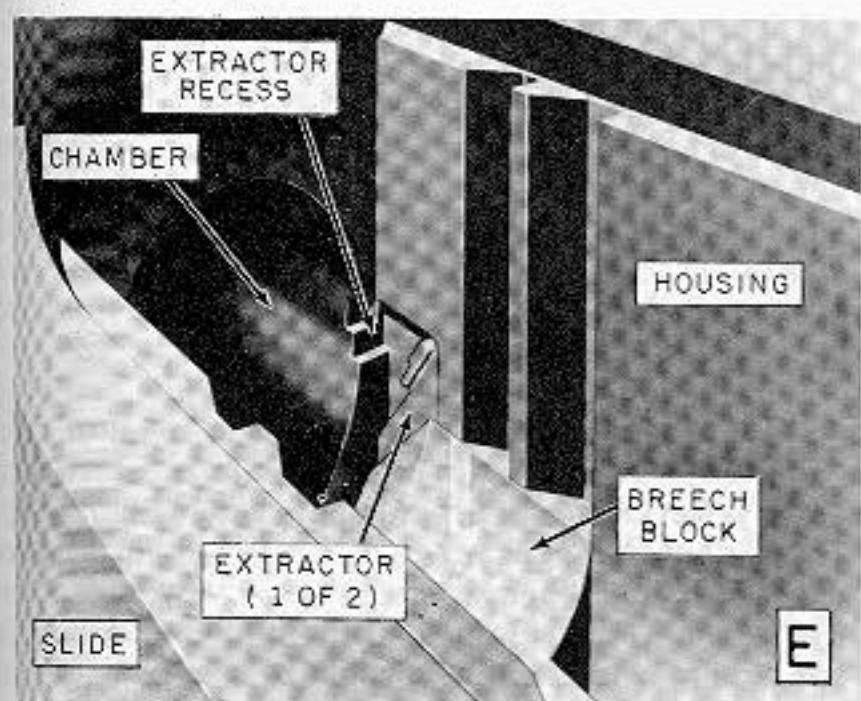
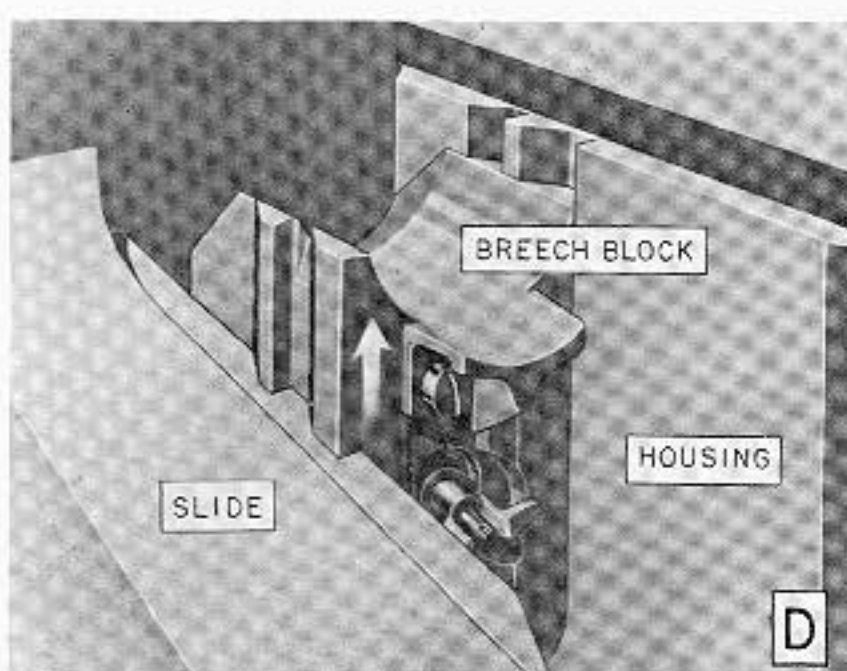
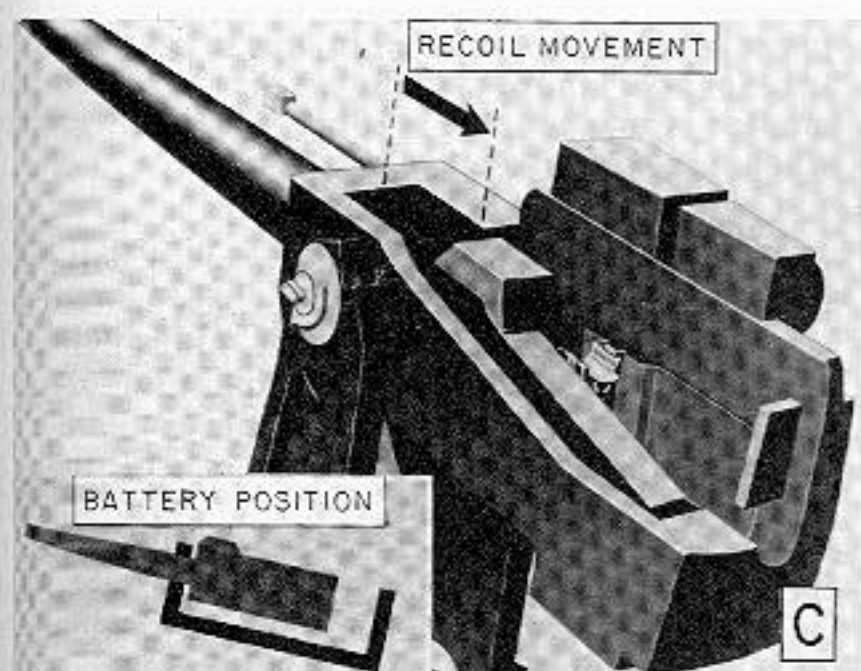
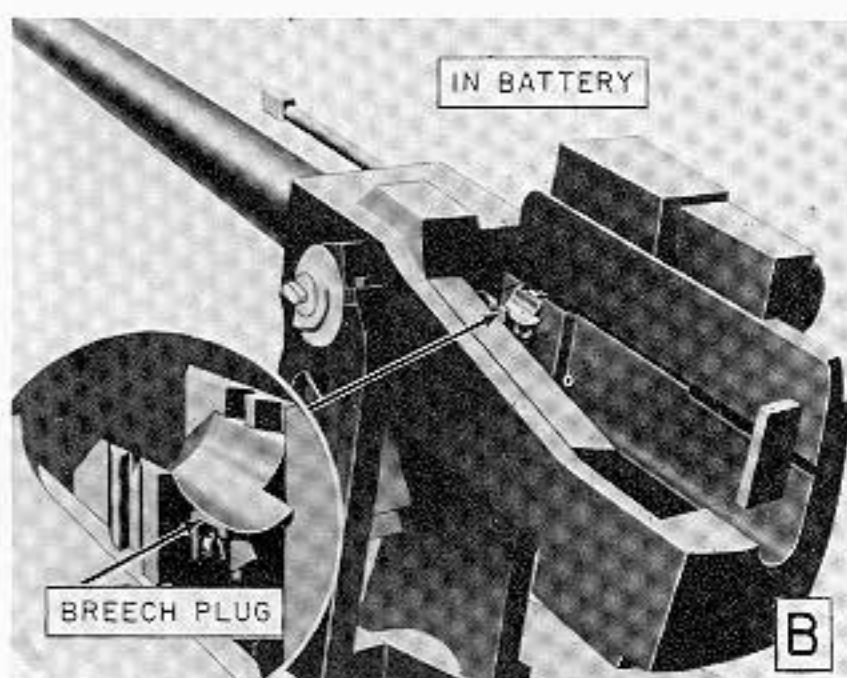
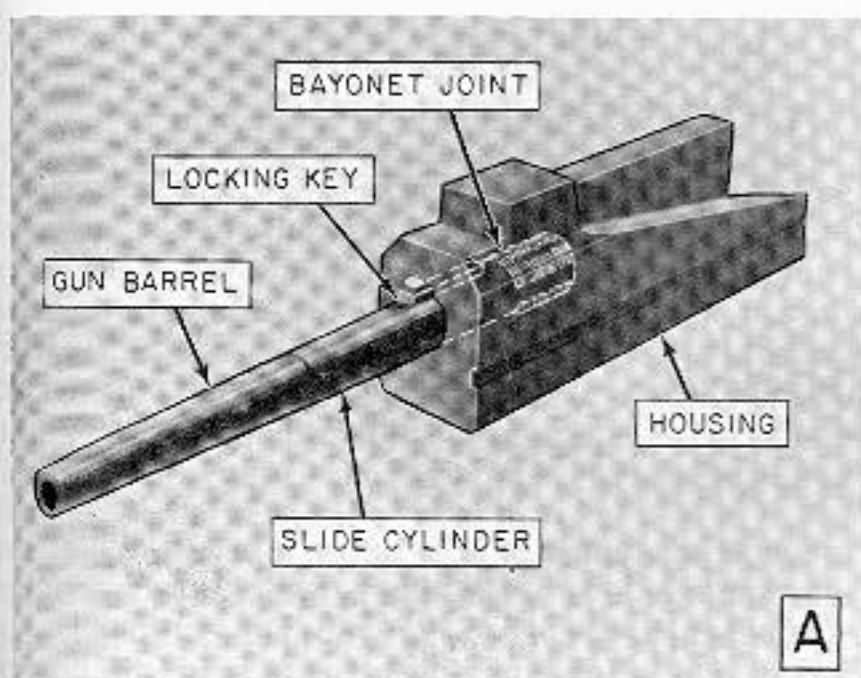
length of guns of 3-inch caliber and above is usually expressed calibers that are equal to:

$$\frac{\text{length of gun in inches}}{\text{diameter of gun in inches}}$$

Thus a gun with a bore diameter of three inches and a length of 150 inches would be designated 3"/50 caliber ($\frac{150''}{3''} = 50$).

DESIGNATION OF GUNS BY CALIBER

The caliber (bore diameter) of U.S. Naval guns is expressed in inches or millimeters. The



A. How barrel secures to housing.

B. Location of breech plug.

C. Recoil movement.

D. Breechblock rising to closed position.

E. Breechblock dropping to open position.

84.140
Figure 5-5.—The housing.

Guns most likely to be found on Navy ships today, in the active and/or the reserve fleet, are:

Guns	Carried on
* 16"/50 cal.	Battleships.
8"/55 cal.	Heavy cruisers.
6"/47 cal.	Light cruisers; guided missile cruisers.
5"/54 cal.	Large carriers; destroyers; frigates; tactical command ships.
5"/38 cal.	Battleships; cruisers; destroyers; carriers; destroyer escorts; auxiliaries.
3"/50 cal.	Any ship from patrol craft to battleship.
40-mm	
20-mm	

*Reserve fleet only.

SIGNIFICANT FEATURES OF MODERN GUNS AND MOUNTS

The effectiveness of modern guns, as contrasted with the primitive naval weapons mentioned at the beginning of this chapter can be attributed directly to the following significant and characteristic features:

1. Improved metallurgy and barrel construction.
2. Rifling.
3. Breech-loading mechanisms.
4. Percussion and electrical firing systems.
5. Recoil and counterrecoil systems.
6. Power-driven ammunition hoists.
7. Power rammers and mechanical ammunition feed.
8. Safety features—salvo latch, safety link, gas ejection.
9. Sighting and fire control equipment.
10. Power drives for elevating and training.

GUN BARRELS

Figure 5-6 shows in cross section a typical modern gun barrel.

At the rear or breech end of the gun is a breech housing, which houses the breechblock or plug; this can be opened for loading and closed for firing by a breech mechanism of which it is an important part. Just forward of the plug is an enlarged chamber that holds the

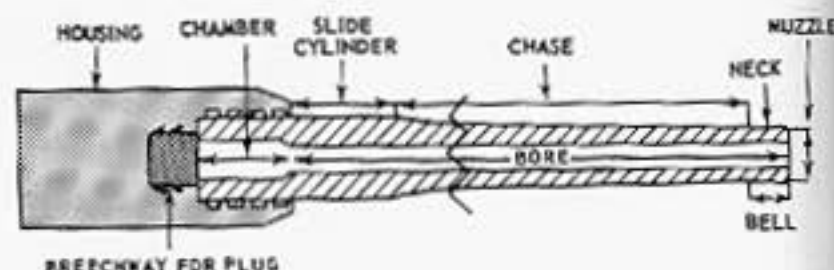


Figure 5-6.—Main parts of a gun barrel. Cross section.

propelling charge. The forward end of the chamber tapers down to the bore, which has a constant diameter to the front or muzzle end of the gun. In all but a few special purpose guns the bore is rifled—that is, a set of spiral grooves is engraved into its surface. In larger guns, which tend to wear more rapidly per round fired than smaller weapons, the rifling is cut in a liner which can be replaced when worn.

The bulkiest part of the gun is at its breech end, where the metal is thickset to withstand high propellant gas pressures. The cylindrical after part of the barrel is the slide cylinder, which moves in bearings in the slide during recoil. Forward of the slide cylinder the barrel tapers (this tapering part is the chase), then (in many gun designs) thickens to form a bell, which discourages any tendency for the metal to split. The narrow part of the barrel just abaft the bell is the neck. In newer gun designs the muzzle has no bell, but may have lugs which serve to anchor a jack used in replacing the liner.

All modern gun barrels are of steel, and they are generally prestressed to make them more resistant to internal pressures. Prestressing methods will be discussed in further detail later.

RIFLING

Early cannon were smoothbores and generally fired round (spherical) shot. Other things being equal, a light projectile will travel a lesser distance, and be more affected by wind and air resistance, than a more massive one. Since the maximum volume of a sphere depends on its radius, the mass of the early gun projectile was limited by the density of its material. An elongated projectile can, of course, be made more

massive by making it longer, but it will be unstable and erratic in flight—unless it can be made to spin on its long axis.

Figure 5-7 shows how this problem is solved in a modern naval gun. The projectile is elongated, with an ogival forward end. The gun bore is rifled, and the rifling grooves are helical or spiral (fig. 5-7, part A). In all naval guns and small arms except the .45 caliber pistol, the rifling has a right-hand twist. The twist may be uniform (generally around 1 in 15 or 20 times the bore diameter), or increasing (as in the 40-mm gun) so that the twist becomes sharper as it nears the muzzle.

The caliber of a rifled gun is measured from the top of one land (the high surfaces between grooves) to that on the opposite side of the bore. Since the rotating band for the projectile is slightly larger than the nominal gun bore diameter, the rifling cuts into or engraves the softer metal of the rotating band when the projectile is rammed (fig. 5-7, part B). When the gun is fired, the projectile spins at an increasing rate as the propellant gas accelerates it. (With right-hand twist in the rifling, the spin is clockwise as viewed from the breech.) Moreover, because of the close fit between rotating band and rifling, the gas is sealed behind the projectile. Figure 5-7, part C, shows how a projectile might look as it leaves the muzzle, spinning rapidly and with rotating band deeply engraved.

BREECH MECHANISMS

The breech mechanism comprises the breech-block or plug that closes off the after end of the gun, and the linkages and other mechanical parts required to operate it. The breech mechanism, as it happens, invariably incorporates part of the firing system.

All naval guns other than small arms (which are not taken up in this book) utilize one of two principles of operation in their breech mechanisms. The older, and nowadays by far the less used, is the interrupted-screw breech mechanism. The newer is the sliding-wedge breech mechanism.

Only bag-type guns use the interrupted-screw breech mechanism in today's Navy, and only a few heavy cruisers have bag guns. This type of breech mechanism will therefore not be described in this text. Sliding-wedge breech mechanisms are used in all present guns larger than small arms, up through 8-inch caliber. Larger case guns (6-inch, 8-inch, and the automatically loaded

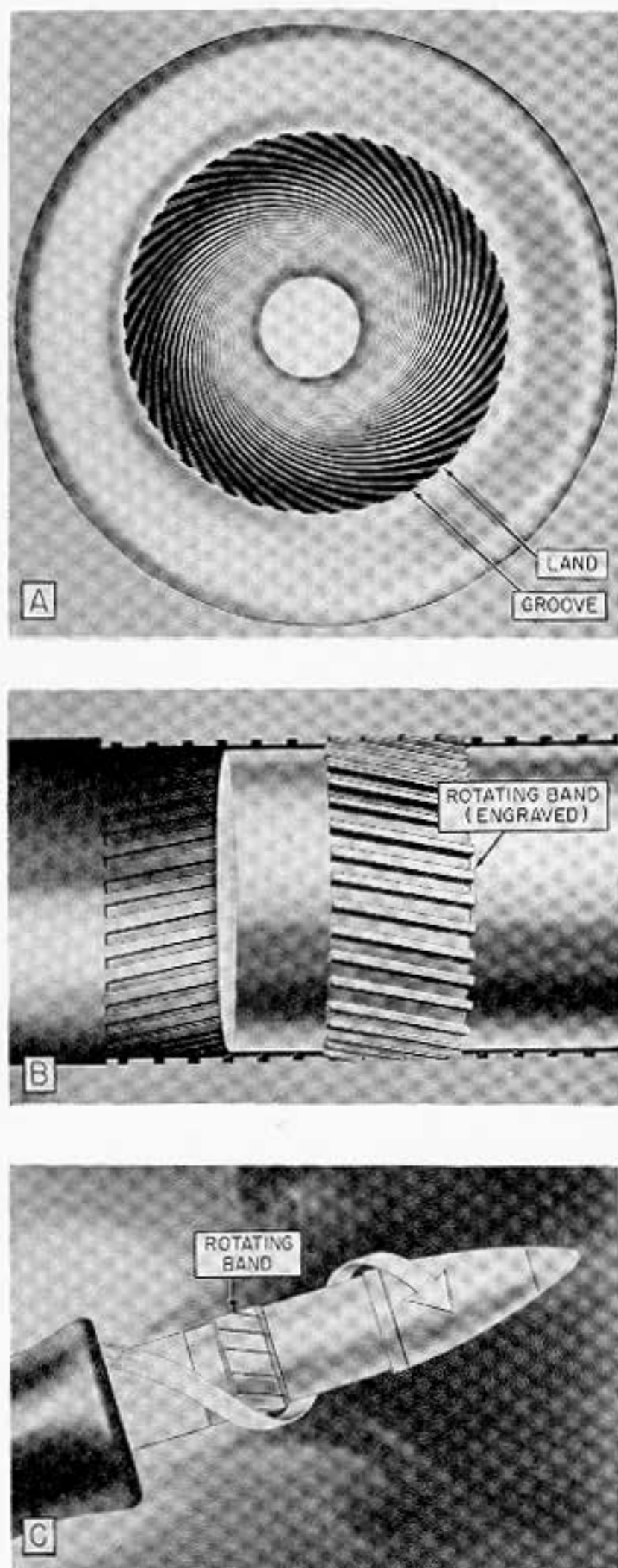


Figure 5-7.—Rifling. A. Rifled bore (viewed head on). B. Rifling engraves the rotating band. C. Projectile spin in flight.

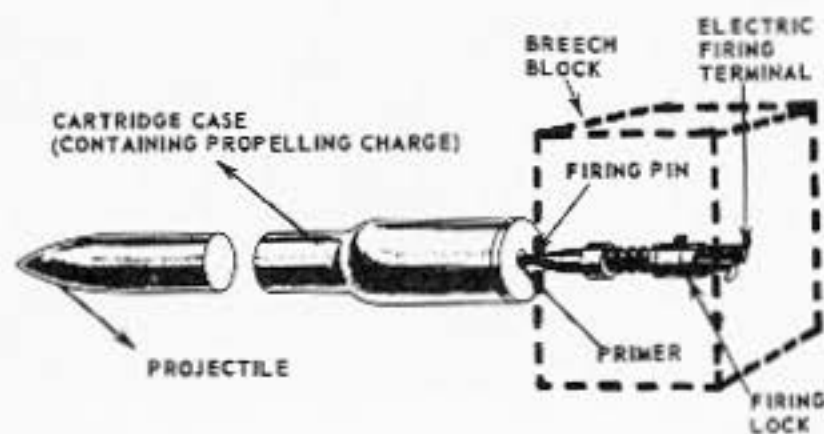
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5-inch Mk 42) use hydraulically actuated sliding-wedge breech mechanisms. In other guns the sliding-wedge breech mechanism is driven through the camming action during recoil and counterrecoil.

FIRING SYSTEMS

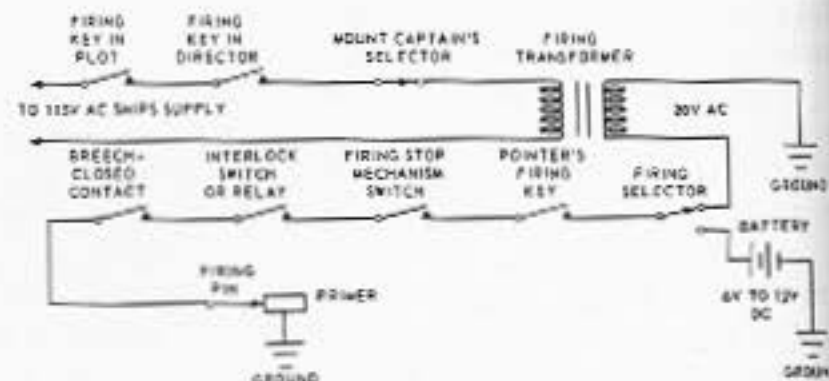
Figure 5-8 shows the principal common firing system elements that are housed in the breechblock of a case gun 40-mm or larger. The 40-mm mechanism and the mechanisms of a few obsolescent hand-loaded 3-inch guns are capable only of percussion fire, 5-inch guns earlier than Mk 42 are capable of either percussion or electrical fire as desired, and all other case guns now in service are designed for electrical fire only (except for special "short cases" used to clear a gun by percussion fire in an emergency).

Common to all case gun firing systems is the firing mechanism (also called the firing lock) in the breechblock (fig. 5-8). This is secured in the breechblock, but is not considered part of the breechblock, and is easily removed for servicing or replacement. In combination and electric firing systems the firing pin is electrically insulated and is part of the electric firing circuit. The pin makes contact with the primer of the loaded propelling charge case when the gun is loaded and the breech is fully closed. The pin is withdrawn into the breechblock when the breech is not fully closed. In combination and percussion firing systems the firing pin can deliver a blow on the primer when actuated by a mechanical firing linkage, provided the gun is in battery, and the breech is fully closed.



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Figure 5-8.—Sliding-wedge breech elementary firing mechanism.



110.50

Figure 5-9.—Representative electrical firing circuit. Schematic.

ELECTRIC FIRING CIRCUITS.—The firing mechanism proper—which has as electrical elements only an insulated firing pin and a quick-disconnect terminal to which a firing lead or cable is attached—is only the final part of the electrical firing system.

Figure 5-9 shows schematically the elements that will be found in a typical electrical firing system for a mount or turret. The diagram does not show the physical locations or appearance of the elements.

Under normal service conditions, guns fire by using the ship's 115 v. a-c supply. Trace the circuit beginning with this source. Switches (not shown on the schematic) in the fire control plotting room (plot) determine where control of remote fire will be placed. That is, whether the director or plot has control. There are spring-loaded normally open firing keys at each station which can assume control. These are all on the 115-volt line to the primary of the firing transformer at the mount. The mount captain, when told to do so, operates his firing selector switch to the "plot" (meaning remote) or to the "local" position. In "local" the primary supply is always present in the firing transformer.

The firing transformer's secondary feeds 20 v. a-c to a firing selector switch at the mount. This switch has two positions, "battery" and "motor-generator." Batteries in these circuits, while still part of the schematic, are no longer installed due to the extra maintenance they require. So, this firing selector switch will always be in the motor-generator position except during maintenance.

The pointer's firing key is generally on one of the elevating handwheels and is connected to the circuit by a flexible cable. The firing stop mechanism switch is part of the firing stop

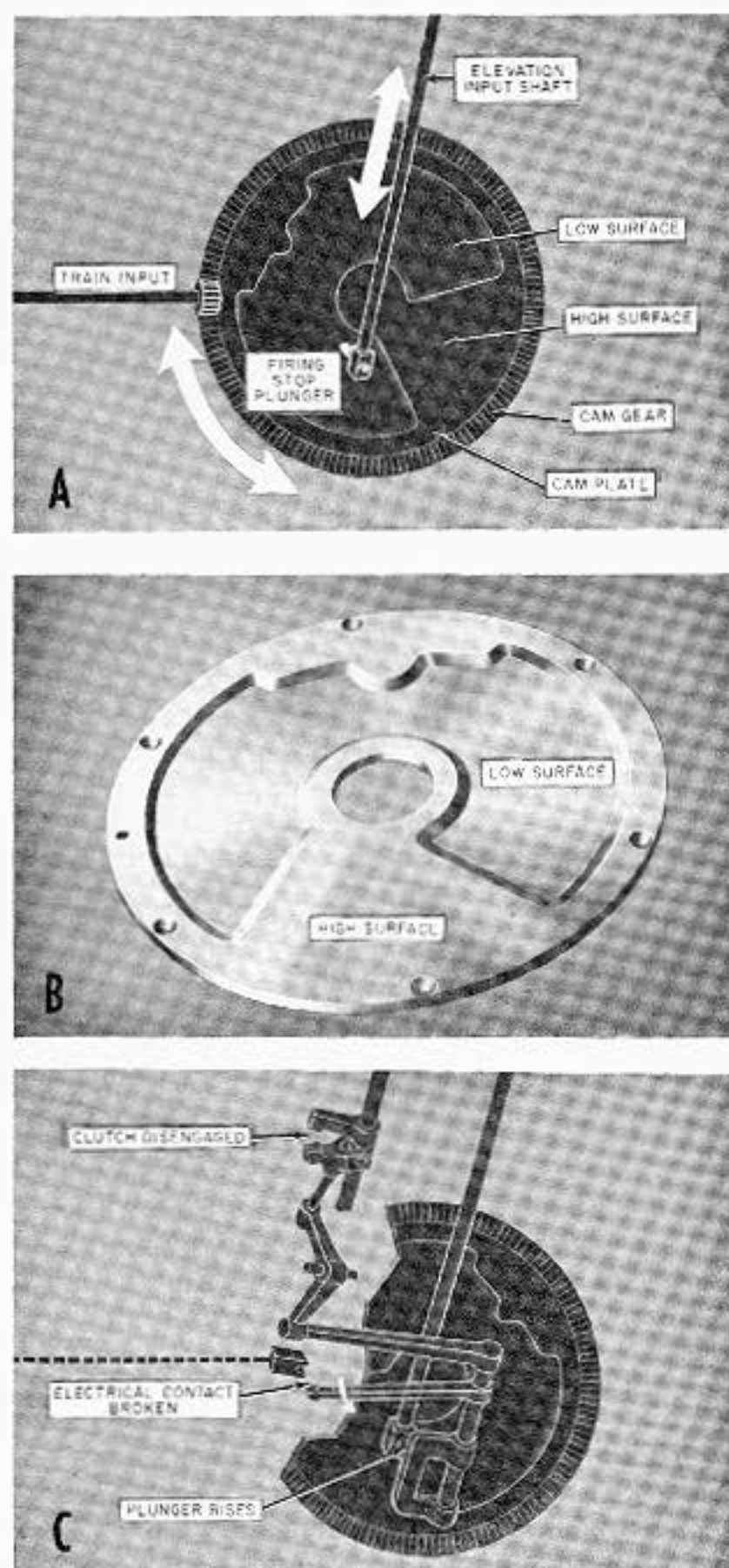
mechanism (to be described later). It opens the firing circuit when the gun endangers part of the ship's structure. Some mounts have no interlock switch or relay, but such interlocks are common with automatic loading equipment or hydraulically operated breech mechanisms. The one shown in the schematic may represent up to six or more, each of which registers that a certain mechanism or part is in a position that is safe for firing. The breech-closed contact is a common variety of interlock. In addition (and not shown in the schematic) are the safety devices in breech and firing mechanisms which prevent contact between primer and firing pin when the breech is not fully closed or the gun is not fully in battery.

The last part of the circuit is the firing pin's contact to the electric primer. The circuit is completed through the filament in the primer, the cartridge case, and ground return to the firing transformer.

FIRING STOP MECHANISM.—At any considerable range, the axis of a gun's bore deviates from the line of sight to the target. The greater the range, the greater the deviation. This makes it possible, particularly in enclosed mounts, for a pointer or trainer looking through a telescope to see no obstacle in the line of sight, while the gun's bore may be in line with some part of the ship's structure, so that firing the gun will damage the ship. It is therefore necessary either to prevent pointing the gun bore toward the ship's structure, or to prevent it from firing under these conditions. The latter method is more common. This is the function of the firing stop mechanism, which disables the firing system when the gun is so aimed as to endanger the ship it is mounted on.

Figure 5-10 shows the basic mechanism. It is essentially a plate or disc type cam, in which the inputs are gun train (which rotates the cam) and gun elevation (which moves the cam follower approximately radially across the cam). The elevation input shaft moves toward the center of the cam plate when the gun elevates, and toward the edge when it depresses. At the end of the elevation input shaft is a spring-loaded plunger which contacts the cam plate. Each point on the surface of the cam plate corresponds to a specific position (in train and elevation) of the gun barrel; the complete surface is a profile map of the gun's safe and unsafe firing areas.

When the gun mount is installed, part of the cam plate surface is cut away so that when the



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Figure 5-10.—Principle of firing stop mechanism. A, Mechanical inputs. B, Profile cam plate. C, How fire is interrupted.

gun is in a position where it is safe to fire, the spring-loaded cam-follower plunger will be depressed, while in unsafe positions of the gun, the plunger will be forced upward. Therefore the cam plate areas corresponding to safe firing positions are cut away, and the unsafe areas are not cut. The plotting of a firing cutout mechanism is explained in a later chapter. Figure 5-10C shows how the plunger action can both open the electrical firing circuit and interrupt the percussion firing linkage (if there is one) when it is riding on a high area of the cam.

RECOIL AND COUNTERRECOIL SYSTEMS

Novels about life aboard naval vessels of a hundred years ago or more frequently have a scene in which a naval gun mount breaks loose—either in battle, during a storm, or both—and thunders, an uncontrollable Juggernaut, across the deck as the ship rolls in heavy seas. This is something that can scarcely happen aboard a modern naval vessel; other gear may break loose, but how can a gun mount? Why were not the guns in the days of sailing vessels simply secured to a fixed mounting, as guns are today?

The answer is that modern guns have recoil and counterrecoil mechanisms, and ancient guns did not. A naval gun can be rigidly secured to the deck, but without some provision for its recoil it will break loose when fired.

Note the general functions of recoil brakes and counterrecoil mechanisms:

1. A recoil brake is primarily designed to absorb the force of recoil and "spread" it so that the sudden heavy shock is converted to a thrust exerted over an appreciable distance through which the recoiling parts of the gun are permitted to move. In the mechanical sense, work is done by the recoil force in pushing the gun and housing aft against the resistance of the recoil brake; the energy absorbed in the brake appears as heat.

- a. A secondary function of all recoil brakes in naval gun mounts is to bring to a smooth stop the forward movement (counterrecoil) that follows recoil.

2. A counterrecoil mechanism is a device that stores some of the energy of recoil and uses it to force the recoiling parts forward into battery after the projectile has left the gun muzzle. (The energy of recoil can, of course, be traced ultimately to the combustion of the propellant.)

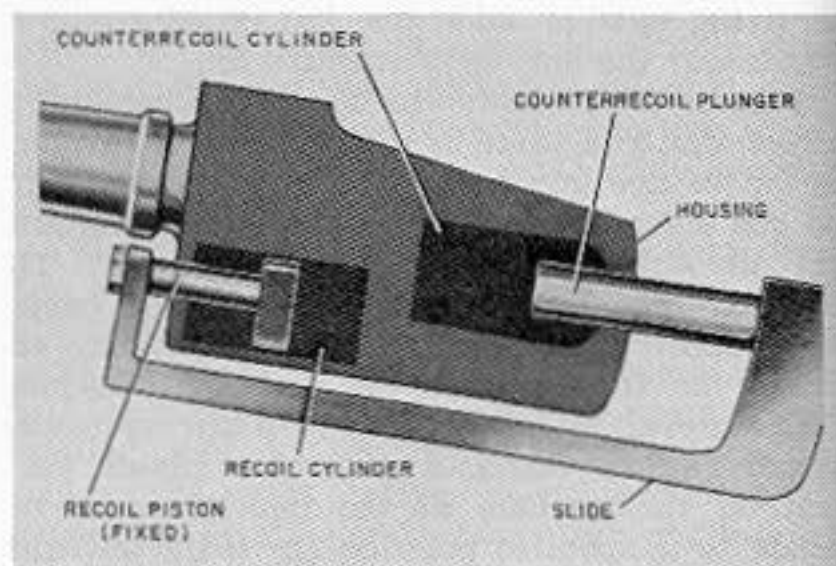
Recoil and counterrecoil mechanisms are designed to work together. Figure 5-11 shows in a general way where the recoil and counterrecoil systems are located in a conventional 5-inch mount.

There are many different types of recoil and counterrecoil mechanisms used in land artillery and elsewhere. The U.S. Navy uses, in naval gun mounts, one general type of recoil brake (in either of 2 variants) and two kinds of counterrecoil mechanism.

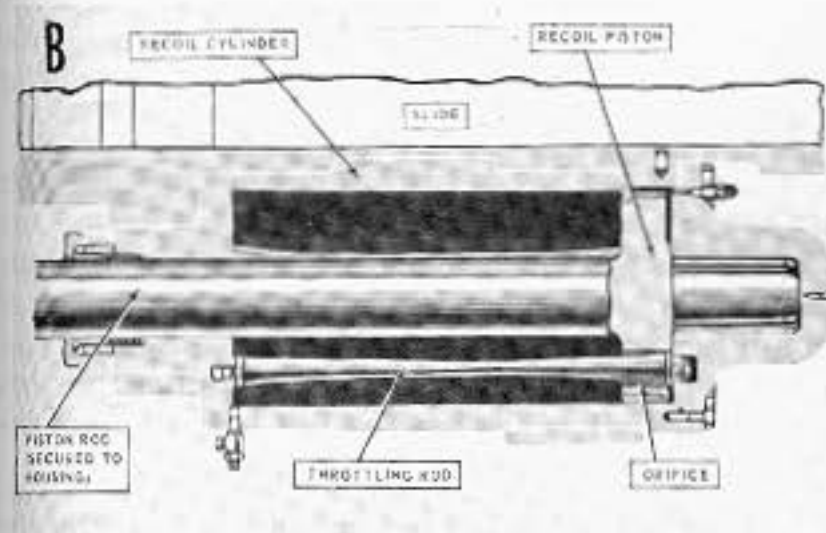
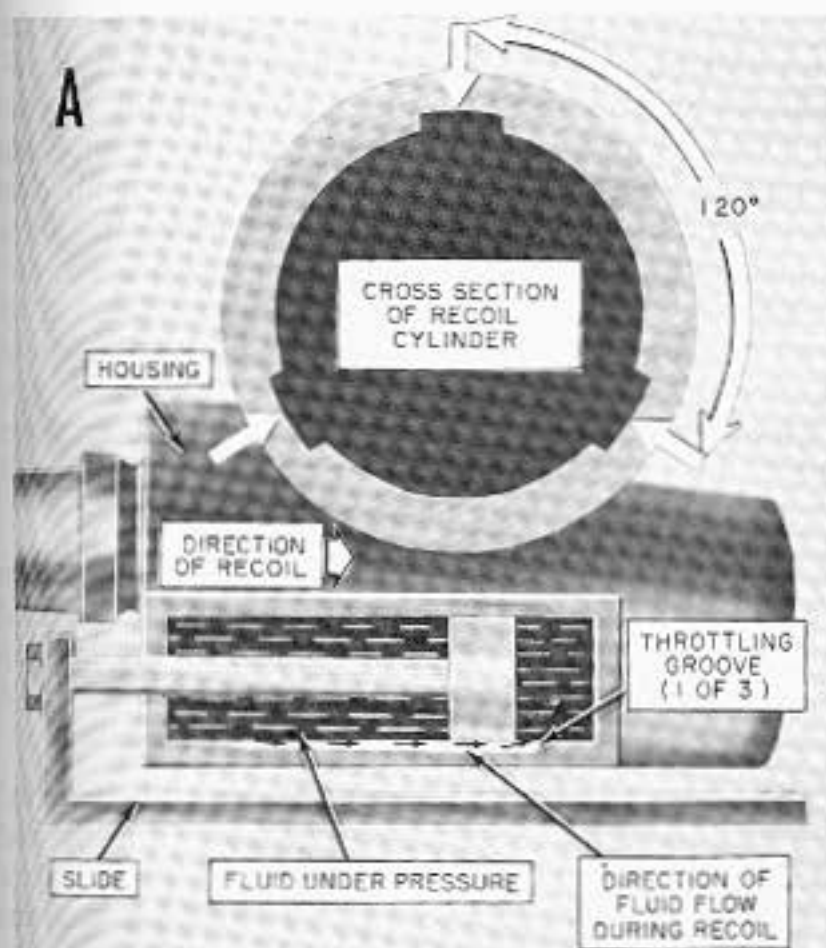
RECOIL SYSTEMS.—All present day recoil systems for naval guns larger than 20-mm use hydraulic recoil brakes. A hydraulic recoil brake is a mechanism of the type commonly termed by engineers a "dashpot." Its piston and a cylinder can move with respect one to the other. The liquid in the cylinder can move from one side of the piston to the other, but its rate of movement is restricted or "throttled."

The two variants of this device are shown in figure 5-12. In one variant (A in the figure), the piston is solid, and each cylinder is filled with recoil fluid (usually a mixture of water with glycerin). In the wall or liner of each cylinder are cut three throttling grooves 120° apart. They are shallow at the forward end of the cylinder and deepen toward the after end.

The principle of functioning of the throttling-groove type (fig. 5-12A) was described in chapter 3. The other major type of recoil brake (part B of figure 5-12) uses three fixed tapered throttling rods which pass through orifices or



84.147
Figure 5-11.—Recoil and counterrecoil systems in a conventional 5-inch mount. Simplified schematic.



110.51

Figure 5-12.—Hydraulic recoil brakes. Simplified schematic. A, Throttling-groove type. B, Throttling-rod type.

holes in the piston. (Only one rod is shown in the figure.) This arrangement functions like the throttling-groove brake, except that the fluid flow is regulated by the varying cross section of the rods in the holes.

COUNTERRECOIL SYSTEMS IN GENERAL.—

There are 2 basic types of counterrecoil systems used in United States naval guns. Guns smaller than 5-inch use 1 or more counterrecoil springs. (These are sometimes termed recoil springs in OP's and elsewhere, but the function is the same.) Guns 5-inch and larger use pneumatic recuperators, which depend on compressed gas (generally air or nitrogen) to provide counter-recoil thrust. Since the very high-pressure gas used in such systems is sealed by use of packings under hydraulic pressure, such systems are often called hydropneumatic counterrecoil systems.

The functions of any counterrecoil system are (1) to return the recoiling parts of the gun to battery after recoil, and (2) to hold the recoiling parts in battery. Thus a counterrecoil system must not only provide thrust during counterrecoil, but must also develop enough continuous thrust at all times to hold them there except while the projectile is actually being propelled through the bore. (Recoil brakes develop their "reverse thrust" for braking only while the gun is actually moving in recoil.)

Because its thrust "follows through" to the end of the counterrecoil stroke, any counter-recoil system tends to drive the recoiling parts into battery with considerable shock. Hence all counterrecoil systems for guns 40-mm and up must have a counterrecoil buffer to take up this terminal shock.

SPRING COUNTERRECOIL SYSTEMS. In all naval guns smaller than 5-inch, coil springs provide counterrecoil thrust. In late 3"/50 mounts and most 40-mm mounts, the springs surround the exterior of the barrel.

HYDROPNEUMATIC COUNTERRECOIL SYSTEMS.—A pneumatic counterrecoil system requires a cylinder or bore (in the housing) charged with inert gas (generally nitrogen or air, never oxygen or other chemically active gas). Gas pressure in a conventional 5-inch system is around 1,500 psi. A plunger (fig. 5-11) fitting into the after end of the housing is forced to the rear by the gas pressure against the after end of the slide. The thrust exerted by the plunger against the slide holds the housing in battery and returns it to battery after firing.

The complication of this arrangement lies in the packing which surrounds the plunger in the housing. Ordinary packing, unsupported, will not withstand the gas pressure in the counter-recoil chamber. Therefore the packing used is a chevron type "inflated" by oil under pressure

(fig. 5-13). The oil pressure in the packing is always higher than that of the gas in the cylinder. The device that ensures this pressure relationship is the differential cylinder. Chapter 3 explains in detail the principle of this device. Gun mount maintenance personnel inspect the cylinder daily, and pump additional oil in if the rod protrudes more than three inches.

Counterrecoil buffers are dashpot devices used to control the velocity and cushion the impact of counterrecoiling parts at the end of counterrecoil. In present designs, they are physically located in the recoil mechanisms, and incorporate needle valves which can be adjusted (within limits) to modify the speed of the counterrecoil stroke.

AMMUNITION TRANSPORT EQUIPMENT

The effectiveness of a gun as a weapon depends, other things being equal, on the number of rounds per minute it can put on target. This in turn depends on the efficiency of the personnel and equipment responsible for transporting

the ammunition from its stowage spaces to the mount and feeding it to the gun.

Figure 5-14 shows in cutaway form the ammunition transport arrangements for a 5-inch twin mount. At the lowest level is the magazine, in which are stacked the propelling charges. The magazine partly surrounds the lower handling room, which is separated by a flameproof bulkhead from the magazine. Powder cases stored in the magazines are passed by hand through scuttles in the magazine bulkhead to the lower handling room. (Projectiles are normally stored in the lower handling room itself, in racks in the upper handling room, and on the gun-house bulkheads.)

The powder cases and projectiles are then loaded into the 2 dredger hoists (1 for each of the 2 guns in the mount) which haul them up to the upper handling room. Each dredger hoist handles both projectiles and powder cases.

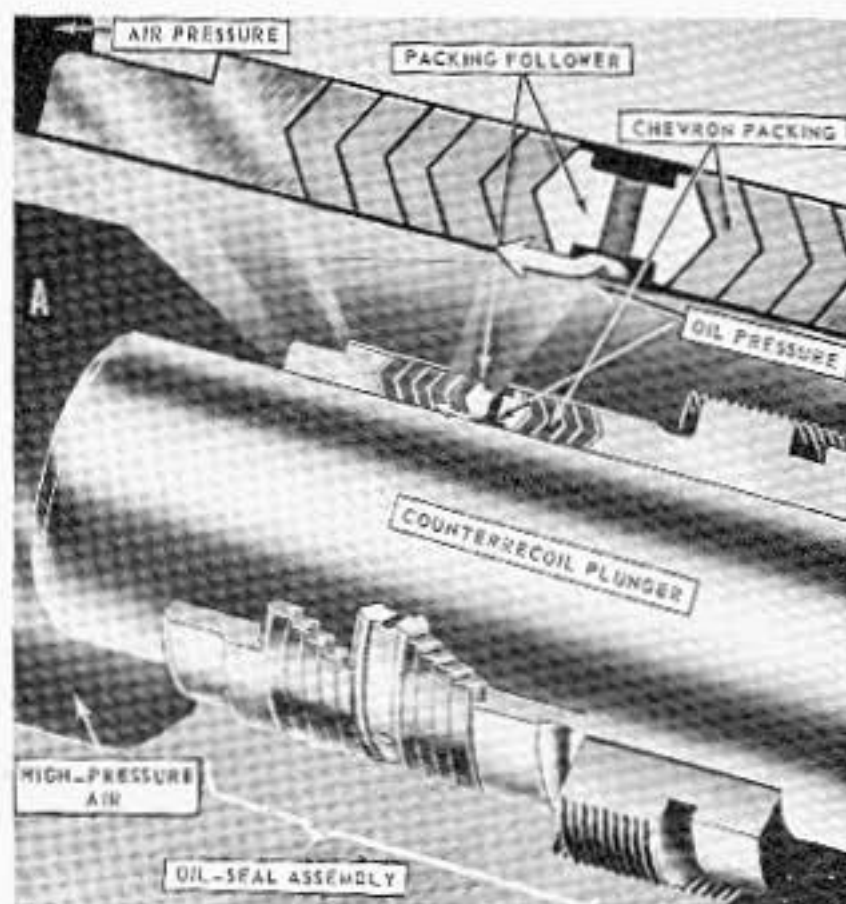
On the upper handling room deck are located the upper ends of the 2 dredger hoists, and around the central column in the room are mounted the 2 sets of projectile hoists and powder hoists, 1 projectile hoist and 1 powder hoist for each gun. The handling room crew removes the projectiles and powder cases from the dredger hoists, loads projectiles into the projectile hoist, and loads the powder cases into the powder hoists. Fuze setters in the projectile hoists automatically set the projectile fuze during hoisting.

Most of the propelling charges are stored in the magazine, and most of the projectiles are stored in the lower handling room. To begin ammunition service without delay, a number of complete rounds are maintained in ready racks in the upper handling room. For long periods of sustained fire, however, the entire ammunition supply system must be in action.

All hoists are driven by electric-hydraulic power units.

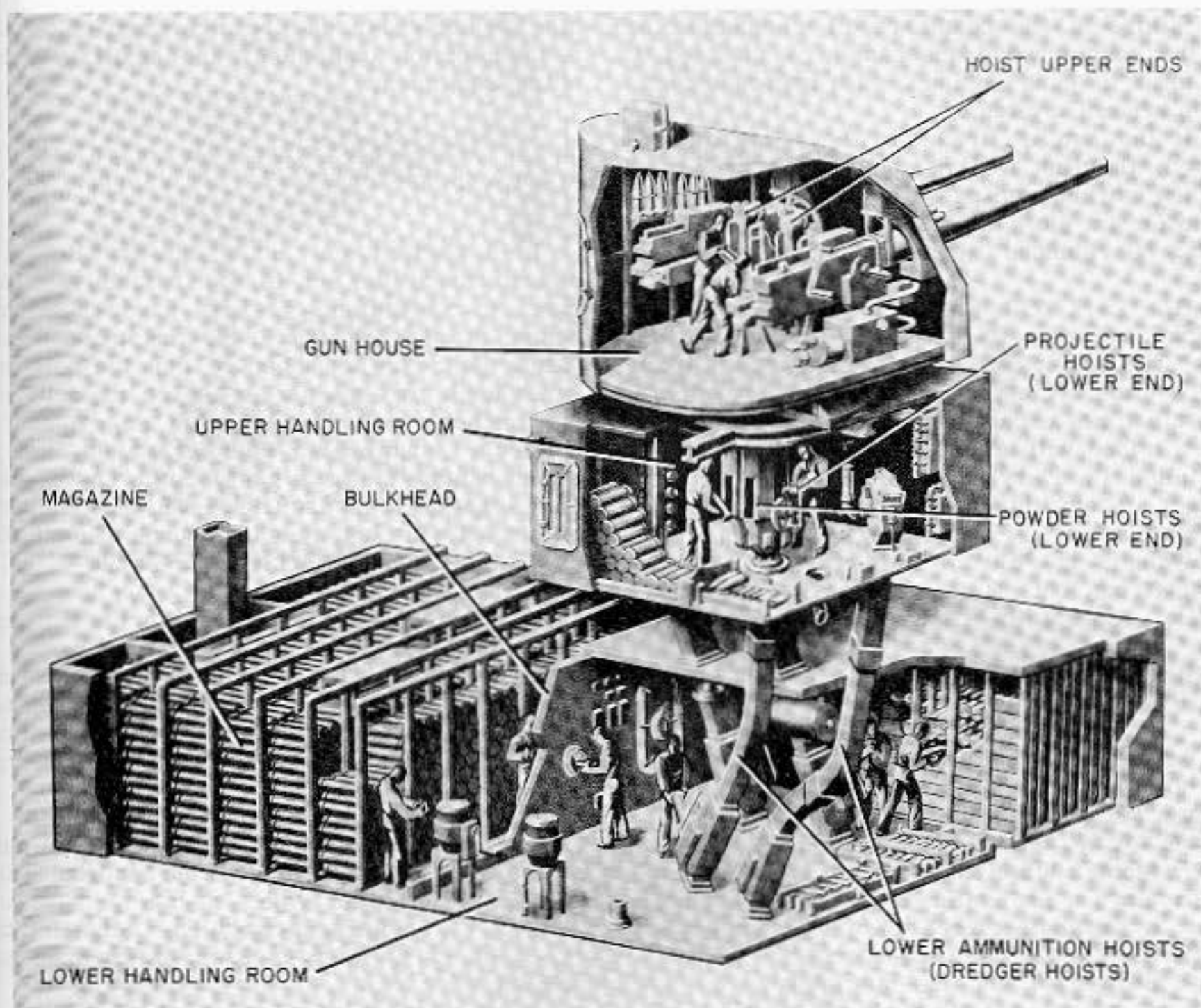
AMMUNITION FEED EQUIPMENT

Ammunition feeding and loading devices on the gun or at the gun deck level include power rammers, slide-mounted ammunition loading gear, and equipment used to transfer ammunition from ammunition hoists to the gun slide. These vary considerably in design from one type of mount to another.



110.52

Figure 5-13.—Hydropneumatic counterrecoil system. Detail of oil-pressure type chevron packing.



110.53

Figure 5-14.—Ammunition supply system for 5"/38 twin mount.

MISCELLANEOUS SAFETY FEATURES

Some of the safety features of modern gun mounts and turrets have been taken up in connection with the other mechanisms or systems discussed above. But several additional noteworthy ones are briefly discussed below:

SALVO LATCH. This is a device that locks the breech closed. It can be opened only by deliberate effort. Its function is to prevent accidental manual opening of the breech in

event of misfire (i.e., an apparently unsuccessful attempt to fire). The reason for this is explained in the safety appendix of this book.

Salvo latches are part of the breech mechanisms of all guns larger than 40-mm, except for automatically loaded guns like the 8-inch case gun used in Salem class turrets.

The salvo latch is a positive lock, cammed to open automatically during recoil. It will not open automatically if the gun does not recoil.

SAFETY LINK.—The safety link is a metal strip that couples the breech yoke (in bag guns) or housing (in case guns) to the slide. It is

intended to hold the gun in battery in the event of failure of the counterrecoil mechanism, or if the counterrecoil mechanism is disabled. It is used in guns equipped with hydropneumatic counterrecoil systems.

If the gun is fired with the safety link engaged, the link will part. However, it is part of the normal gun operating procedure to disconnect and stow the link before firing. The link must be replaced when the mount is secured.

GAS EJECTOR.—When a shot is fired from a gun, the bore is filled with residual powder gas. The gas is unsafe to breathe, and is likely to be either combustible or actually burning; it is sometimes capable of spontaneous combustion when mixed with air. The gas ejector, which is installed in every enclosed mount 5-inch and larger, forces this residual gas out of the bore by air blast.

When a gas ejector fails, the gun can continue firing, but caution is necessary to ensure safety. The rate of fire may have to be reduced.

SIGHTING AND FIRE CONTROL EQUIPMENT

Getting the gun projectile to hit its target is not as simple as aiming, say, a searchlight beam. A projectile, when fired, travels in a curved path rather than a straight line, and many factors affect the shape of its path. Moreover, since a projectile requires an appreciable time to reach its target, the position of the gun when fired must take into account the distance that the target and the gun will travel with respect to each other during the projectile's flight. To do this requires that all these data be measured and their effects solved mathematically so that the solution indicates how the gun must be positioned for the projectile to hit the target.

The techniques for doing this are called, collectively, fire control. Most of the fire control work is done elsewhere than on the gun mount, but the gun mount does incorporate certain fire control gear—notably the sights. Sights are optical devices which can be used to position the gun with respect to a straight line (the line of sight or LOS) from the gun to the target. Certain more complex sighting equipments (called lead-computing sights) incorporate computing mechanisms which automatically establish gun position with respect to the LOS while a crewman on the gun mount is tracking the target (i.e., keeping the LOS aligned with

the target). On-mount fire control gear may also include radar, data receivers and indicators, communication equipment, and auxiliary computing equipment.

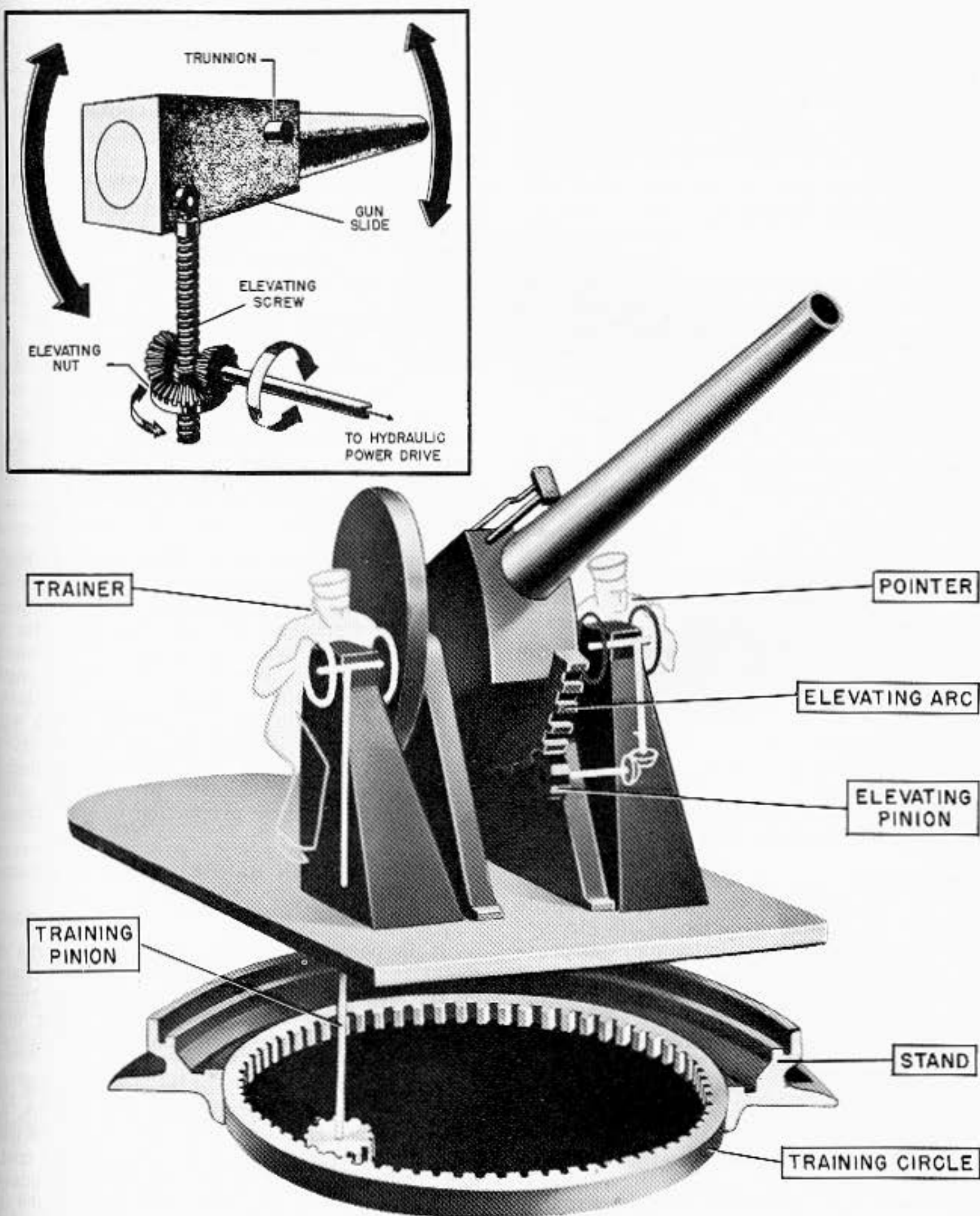
TRAIN AND ELEVATION MECHANISMS

In a modern gun mount, the trunnions are placed where the gun is approximately in balance. In conventional designs, handwheels connected through gearing to the training and elevating gear are arranged so that the pointer's handwheels are at his station on the left, and the trainer's at his station on the right. The pointer's handwheels, in gun mounts, turn a pinion which rotates a gear sector on the slide called the elevating arc (fig. 5-15). The trainer's handwheel, through gearing, turns a gear that engages the training circle in the stand.

In turrets using bag ammunition the elevating gear turns an elevating nut which engages a screw pivoted to the gun slide (fig. 5-15 inset). Turrets using case ammunition must be capable of much greater elevations than are practical with this arrangement. They therefore use arc-and-pinion elevating gear.

All turrets, and mounts larger than 20-mm, normally use power drives for positioning the gun. The two main types of power drive are electric-hydraulic and amplidyne electric; the principles of these were described in an earlier chapter.

The conventional arrangements described above in this article do not apply in the newest mounts. For example, in the automatically loaded 3"/50 mounts, the gun cannot be manually elevated and trained from the gun-laying stations on either side of the mount. The controls there provide only for operating the mount through the power drives. The left gun layer's station is used for positioning the mount when firing on air targets; the right gun layer's station is in control for surface targets. Either station, or the director, may be in full control. When either gunlayer station is in control, mount train and elevation are both controlled by that station. Hence there is no "pointer's" station or "trainer's" station on this mount. And manual elevations and train are used only for positioning the mount for maintenance or alignment-checking purposes.



84.152
Figure 5-15.— Training and elevating gear (simplified). (Insert: Screw-type elevating gear.)

GUN BARREL CONSTRUCTION AND MAINTENANCE

Commonly, the term gun applies to the entire assembly of which the barrel is but one part. In this section, gun, tube, or barrel designates the gun tube only, and not the remainder of the gun assembly.

ESSENTIAL REQUIREMENTS OF A GUN

A gun may be considered as a tube designed to withstand a given pressure from within. In constructing such a tube, we must first consider what pressures it will have to withstand at the various points of its length, and then make it strong enough to insure perfect safety. The bore should also be of such material as to stand the wear and tear of firing a large number of rounds without being so damaged by expansion or abrasion as to interfere with the shooting.

STRESSES IN A GUN CYLINDER

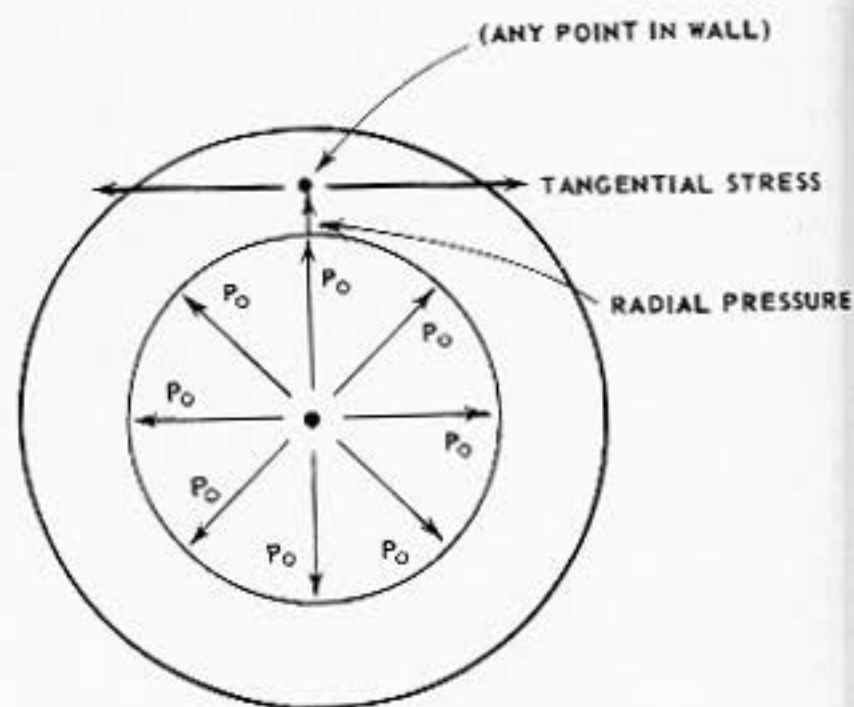
Considering a gun only as a cylinder, we find that the two principal stresses (fig. 5-16) to which such a cylinder is subjected upon firing are:

1. A tangential stress or tension, coupled with a radial stress, tending to split the gun open longitudinally.
2. A longitudinal stress tending to pull the gun apart in the direction of its length.

Experiments have shown that the greatest stress on the metal of the gun is the tensile stress set up in the direction of its circumference (tangential stress) by powder gas pressure. In addition, the gun also experiences a longitudinal stress of relatively small value. If this longitudinal stress may be considered constant (and in guns it may be so considered without great error) we may lay down "Lame's law," as follows:

At any point whatever, in a cylinder under fluid pressure, the sum of the tangential tension and the radial pressure varies inversely as the square of the radius.

This law says, in effect, that in a simple hollow cylinder under internal pressure, points in the metal close to the bore experience a large proportion of the stress, whereas those at a



110.54

Figure 5-16.—Tangential and radial stresses in a gun cylinder. Schematic.

greater radius experience only a small proportion. Thus in a simple hollow cylinder of homogeneous metal, we soon reach a limit beyond which any thickness of wall aids but little in enabling the cylinder to withstand pressure.

Because of this severe limit on the strength of a simple hollow cylinder, however thick, guns must be built on a principle which will enable them to withstand more internal pressure than would be possible with the simple cylinder construction. The problem is to make the outer layers take a proper proportion of the stress.

METHODS OF GUN BARREL CONSTRUCTION

It is possible to make the outer layers of metal in the gun barrel bear a greater share of the load by prestressing the gun tube. There are two types of gun construction using this principle—built-up construction and radially expanded construction.

The "built-up" method of prestressing is to heat steel ring-shaped jackets, or hoops, to high temperatures, then slip them over the gun tube and allow them to cool. As the hoops cool, they contract, until at the end of the process they squeeze the gun tube with a pressure of thousands of pounds per square inch. Guns so constructed have been in recent years made only in sizes over 8-inch.

About the time of World War I, the same principle was applied to monobloc (one-piece) guns in the radial-expansion or autofrettage process. In this process, a gun tube with bore slightly smaller than the caliber desired is expanded by hydraulic pressure. When the pressure is released, the outer layers of the tube tend to return to their original dimensions, while the enlarged inner layers tend to maintain their enlargement. Thus the inner layers of metal are severely compressed by the contraction of the outer layers, as if a hoop had been shrunk on.

The built-up and radially expanded methods may be incorporated in a single gun. The 8"/55 caliber gun, for example, has a jacket shrunk on a radially expanded tube.

Smaller guns are made from a single steel forging with neither radial expansion nor hoops. The pressures in small guns may be higher than in large guns, but the forging, which is not excessively large in any event, can be made bigger. This type of construction is, at the present time, limited to guns of 3-inch caliber and smaller.

DETERIORATION IN THE GUN BORE

The "working surfaces" of the gun are the interior of its bore and chamber. As time passes, and as round after round is fired, these surfaces will deteriorate, and maintenance is required to ensure their continued usefulness. The main causes of deterioration are (1) erosion, (2) corrosion and dirt, (3) copper fouling, and (4) constriction.

Erosion

Erosion is the deterioration and wearing away of the bore surface caused by firing projectiles through it. Erosion is not merely the direct effect of friction which causes the bore surface to wear away as the projectile passes through. The exact mechanics of erosion are not known with precision, but the following are recognized as the principal causes:

1. The bore surface becomes intensely heated in firing, and the rush of hot gases across this hot metal has a scouring effect.

2. The hot powder gases react with the metal, changing the carbon content on the surface of the bore. Since this surface is designed with

an optimum carbon content, any change results in a weakening of the metal.

3. The alternation of intense heat and rapid cooling affects the temper of the metal.

4. The propellant gases are forced into and out of the pores in the metal surface as they open and close during the expansion and contraction which accompanies such drastic temperature changes.

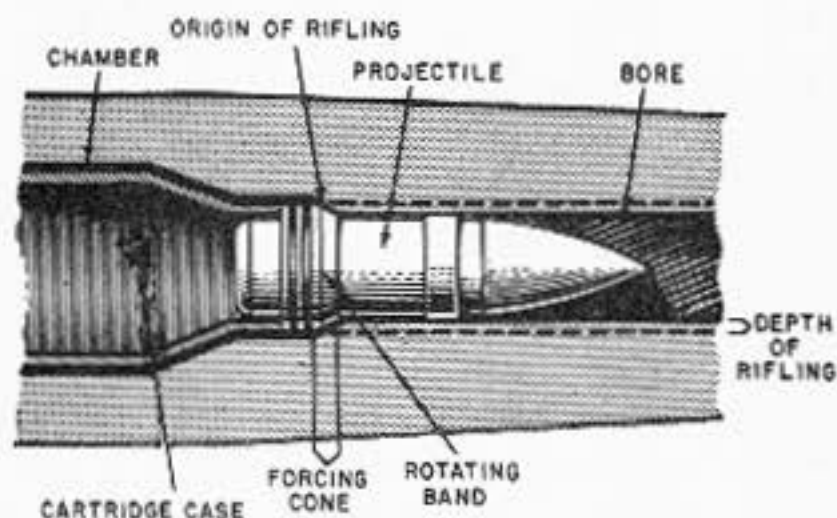
5. Heat cracks may develop.

6. Gases escaping around the projectile act as high-velocity jets, scouring the bore and causing damage, especially where there are heat cracks.

Erosion is always greatest at the origin of rifling (fig. 5-17) and the tops of the lands wear away faster than do the bottoms of the grooves.

Erosion at the origin of rifling, in guns using semifixed ammunition, tends to permit the projectile to seat farther and farther toward the muzzle. This reduces the density of loading (density of loading is explained later in this chapter) and therefore the I.V. (initial velocity). In guns using fixed ammunition, this effect does not apply, but in all guns erosion at the origin of rifling permits gas to escape around the projectile, and this in turn increases erosion.

As the lands wear, not only does more gas escape around the projectile but the rifling engraves the band less deeply, reducing materially both the initial forcing pressure and the resistance of the projectile to the gas pressure. The effect is a material drop in muzzle velocity.



84.235(110A)

Figure 5-17.—Erosion areas in a gun chamber and bore.

CONTROL OF EROSION.—All erosion factors are related to (1) the temperature of the expanding gases and (2) the duration of their confinement in the bore. Hence larger guns, with their slower powders and longer barrels, suffer more erosion per round firing than smaller guns. On the other hand, smaller guns have a higher firing rate, which permits less cooling time between rounds.

Chromium plating of gun bores has reduced the effects of erosion; the use of molybdenum will probably make for even better erosion resistance in the future.

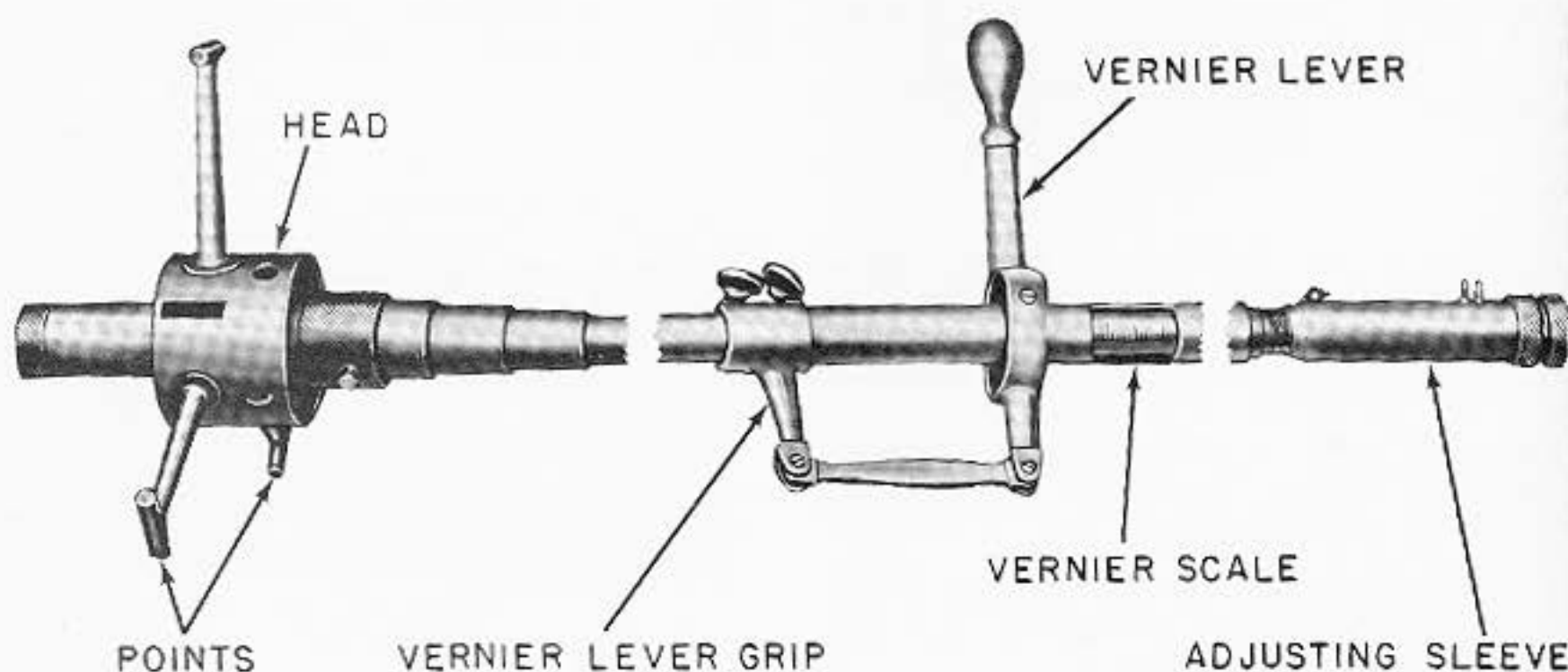
Some smaller guns are cooled by water jackets around the barrels, and there have been experiments on introducing a coolant between the tubes and the liners of larger guns. Also under development are cooler propellants. Any development that reduces the heat of explosion will aid in erosion control.

There are, for each class of gun, data sheets furnished to ships showing relationship between the enlargement of the bore and the initial velocity to be expected from the gun. The data sheets show this information in the form of plotted curves. If the actual diameter is frequently checked, velocity loss becomes predictable, proper allowance for it can be made in aiming, and barrels or liners may be replaced before their performance becomes noticeably erratic.

In some minor-caliber guns, measurements of bore enlargement is made at the origin of rifling only. This is done with a wear gage, which is a truncated cone that can be inserted directly in the breech. In larger guns, erosion is measured at several points in the bore with a star gage.

The star gage (fig. 5-18) consists of a head mounted on a long tube, with metal points 120° apart extending radially from it. These three points form a Y and press against the bore of the gun. Points of suitable length are provided for each caliber of gun to be measured. The bases of the points are spring-loaded to bear against a tapered expanding plunger; as the plunger (operated by the vernier lever) moves lengthwise, the points are cammed outward or inward. Measurements are read from the vernier scale.

Stargaging is performed by highly skilled personnel in tender or shore-based facilities. The object is to measure the amount of erosion along the bore (and especially its origin) so that the corresponding predicted loss in I.V. can be included in the solution of the fire control problem. Tables, charts, graphs, and equations are provided in OP 551 (latest revision) for use in converting erosion losses into usable I.V. information. Although this particular OP is for a 5"/38, there is a similar publication for each type of gun.



110.55
Figure 5-18.—Star gage.

Obviously, since stargaging is done in port, and ships are usually at sea, a stopgap is necessary to compute the correct I.V. The stopgap is called EQUIVALENT SERVICE ROUNDS (E.S.R.). Immediately upon receipt of stargage data, the ship converts these data into an E.S.R. for each gun so gaged. The gun E.S.R.s for a battery are then averaged, the applicable OP is consulted for conversion factors, and the resultant I.V. is set into the computer which serves the battery. This is a usable I.V. only as long as no rounds are fired from the battery. As soon as more rounds are fired another quantity must be added to the I.V. computation. That quantity is called PSEUDO EQUIVALENT SERVICE ROUNDS (P.E.S.R.). P.E.S.R. comes from estimates which are based on the fact that each round fired causes a certain amount of erosion. Projectiles which are propelled by full-service powder charges are counted as one P.E.S.R., while reduced-charge firing may be equivalent to about 1/6 of a P.E.S.R. per round fired. (The Navy uses reduced charges for reverse-slope firing.) P.E.S.R. is added to E.S.R. for I.V. computation, but kept separately in records so that comparison can be made with the E.S.R. from the next stargaging. That is, was the P.E.S.R. an accurate estimate of the actual erosion?

Without periodic stargaging, the E.S.R. procedure would not be accurate, mainly because the P.E.S.R. quantity does not reflect the rate of fire. Rounds fired with very short cooling intervals cause more erosion than the same number fired at a normal rate. For practical gunnery, however, this method is considered sufficiently reliable for use.

I.V. MEASUREMENT.—At proving grounds gun projectile velocity is measured by a device called a chronograph. The projectile cuts wires when it passes through two successive screens, or it passes through two magnetic coils, and the exact time of each passage is recorded. This yields the projectile velocity between the screens, and from this I.V. can be reckoned.

Chronographs require special setups of coils or screens, careful gun placement and aim, much auxiliary equipment, specially skilled technicians, and a good deal of time. They are consequently not practical for shipboard use. But because erosion and I.V. are significant factors in fire control, the Navy has developed devices on far different principles which can actually measure the velocities of service rounds fired on shipboard. These velocity-measuring

devices are incorporated in some gun fire control systems.

Corrosion and Dirt

Great heat, great pressure, and complicated chemical changes accompany the burning of the propelling charge. Some but not all the residue of the burning is blown out of the muzzle after the projectile. What remains in the gun (powder fouling) is in the form of corrosive salts. Standard procedure is to remove it by washing out the bore with a hot soda solution and applying a thin film of oil before securing until the next firing. Chromium plating of gun bores has reduced the powder fouling problem.

Dirt in a gun bore not only encourages corrosion but is a source of danger if it offers sufficient resistance to the projectile. To guard against accidental admission of dirt, spray, or moisture into the gun, a solid plug called a tompion (pronounced tom-kin), is inserted into the muzzle. This is only a partial solution, because under certain weather conditions considerable condensation accumulates in the bore. In fair, dry weather, tompions are removed to air out the barrels.

Tompions cannot be used under combat conditions; a tompion accidentally left in a gun would be very dangerous if the gun were fired. However, dirt and water, especially salt water, must be kept out of the gun; so canvas or plastic muzzle covers are used. In an emergency, the projectile can be fired through such covers without bursting the barrel, subject to certain limitations. Projectiles with supersensitive nose fuzes cannot be fired through muzzle covers of any sort. In cold-weather operations, when canvas covers may become ice coated, they should be removed before firing.

Constriction

More immediately dangerous than corrosion or dirt is metallic constriction of the bore. Before and after each firing, barrels are tested for this condition with a plug gage, which is a steel cylinder accurately machined to slightly under the diameter of the bore (fig. 5-19). If the plug gage will not pass through the bore without undue forcing, the nature of the constriction must be determined. If it is caused by an accumulation of copper, it is dealt with as described in the next topic. This is the more likely cause. However, constriction can also be caused by distortion of the steel surface of the



110.56

Figure 5-19.— Plug gage (left) and lapping head.

bore. This has been known to occur in built-up guns. The friction of the projectile on the bore tends to drag the liner along with it. This tendency is resisted by the shoulders of the liner and the tube. With continued firing, the shoulders of the liner tend to override those of the tube, forcing the walls of the liner inward. As with coppering, steel constriction can be removed by lapping and polishing.

Continued firing may also elongate the liner and cause it to protrude from the muzzle. This is not serious. When the extension amounts to as much as half an inch, it is simply cut off.

Copper Fouling

Copper fouling is essentially a form of constriction. It consists of metallic deposits on the bore, left behind by the rotating bands of projectiles. Even an amount of copper too slight to impede the projectile will affect its accuracy. Metallic lead foil in the powder charge, while increasing muzzle flash, has been used in some powders to control coppering. The lead serves as a lubricant and discourages new copper deposits, while existing deposits will be abraded by the passing projectile. New propellants incorporate a trace of lead carbonate.

Copper fouling may be removed with an acid treatment, but this is not authorized for ship-board use. Approved mechanical means for decoppering consist of rubbing with a wire bore brush or lapping head (fig. 5-19). The head is covered with a fine abrasive material and is drawn back and forth at the location of the constriction until the plug gage can be passed through without forcing. Special scraping or decoppering heads, fitted with steel blades, are supplied for certain guns.

3"/50 RAPID—FIRE GUNS AND MOUNTS

The 3"/50 rapid-fire (RF) guns are semi-automatic guns with automatic power-driven

loaders, installed in open or enclosed twin or single mounts. They are primarily intended for air defense, but can be used against surface targets. They were planned during World War II when a need developed for a rapid-fire gun with a larger explosive-projectile that could stop suicide planes or dive bombers. The 3"/50 mount was not completed in time to be used in combat in World War II, but it has since proved itself very effective, and since World War II has virtually displaced its predecessors—40-mm twin and quadruple mounts—on combat vessels. It is generally used with relative-rate fire control systems.

The 3"/50 rapid-fire mounts now operational in the fleet are the outwardly identical twins Mk 27 and mods and Mk 33 and mods (fig. 5-20), and the single Mk 34. All use the same gun and similar loading mechanisms (except that in the twin mount the assemblies are of opposite hand). The two marks of twins are similar in nearly all details except the slide.

Two mods of the Mk 33 are enclosed twin mounts with aluminum shield. The other mods are open twins with modifications for installation of a fire control radar antenna, or for substitution of aluminum platforms instead of steel. The Mk 34 mount is an open or enclosed single, similar in controls and equipment to the twin, with a right-hand slide and loader assembly.

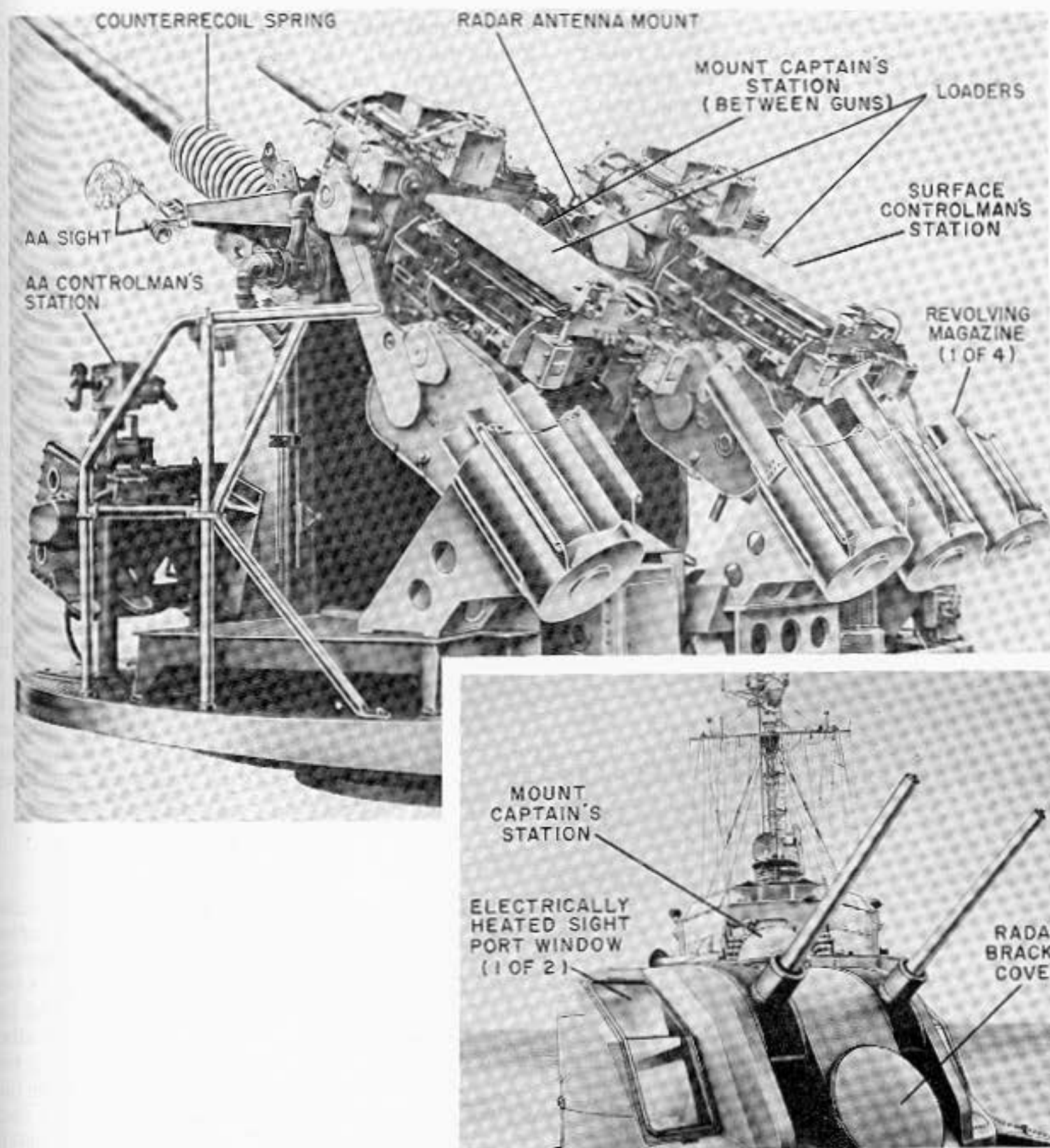
General Characteristics of 3"/50 RF Mounts

Bore caliber (inches)	3.
Length (calibers)	50.
Initial velocity (feet per second)	2,700.
Range, horizontal (yards)	14,200.
Range, ceiling (feet in 85° elev.)	30,400.
Design rate of fire (rounds per minute)	45.
Ammunition type	Fixed, electric primed.
Fuze type	VT.

*Approximate weight, complete mount (pounds):

Mk 27	31,000.
Mk 33	31,000.
Mk 34	17,000.
Train rate (degrees/second)	30.
Elevation rate (degrees/second)	24.
Maximum elevation (degrees)	85.
Maximum train (degrees)	720.

*Not counting off-mount equipment.



3.122

Figure 5-20.— 3''/50 RF twin mount Mk 27 Mod 3. (Mk 33 is externally similar.) Insert: 3''/50 twin mount Mk 33 Mod 4.

CONSTRUCTION

The barrel of the 3''/50 gun is a one-piece, rifled, chambered tube, with breech end locked to the housing by a bayonet type joint. The

housing contains the vertical sliding-wedge breech mechanism. The slide supports the recoiling parts (gun barrel and housing) on bearings. Recoil and counterrecoil movement are controlled by a hydraulic recoil cylinder and a large counterrecoil spring surrounding the barrel.

The slide, gun, and housing are supported by the carriage. The slide trunnions rest in roller bearings at the top of the carriage. The elevating arc on the slide meshes with the elevating pinion of the mount elevation power drive system.

The stand is a deck-flange, base-ring design which includes the training circle and the stationary roller path. In train, the mount is driven by a power motor which rotates the training pinion.

BREECH MECHANISM

In OP language, the 3"/50 breech mechanism is "an automatic, vertically sliding, block type which is unlocked during gun recoil action and is opened downward by gun counterrecoil energy. Its opening action extracts the empty cartridge case and sets a mechanism that holds the breech against the load of a breech closing spring. Ramming a fresh round releases these devices to automatically close the breech."

The breechblock is cammed by operating shaft rotation, as in the 5"/38. In automatic operation the breechblock is lowered and the operating spring compressed on counterrecoil when the operating-shaft crank is rotated by the operating-shaft cam plate in the slide. The breech is closed by the operating spring. The positive type salvo latch on one end of the operating shaft prevents unintentional opening of the loaded breech before the gun has fired. The breechblock houses a firing mechanism.

The general principles of sliding-wedge breech mechanism construction and operation described later in the section on 5"/38 mounts apply to the 3"/50 gun, but two design features peculiar to the 3"/50 deserve some brief but close examination. These features are:

1. A BREECHBLOCK HOLD-DOWN MECHANISM holds the breech open until the loader completes delivery of a round, and, with a novel extractor arrangement, increases the sensitivity of the breechblock-unlocking action.

2. A BREECH INTERLOCK MECHANISM prevents repetition of the loading cycle until the round has been fired and the breechblock dropped.

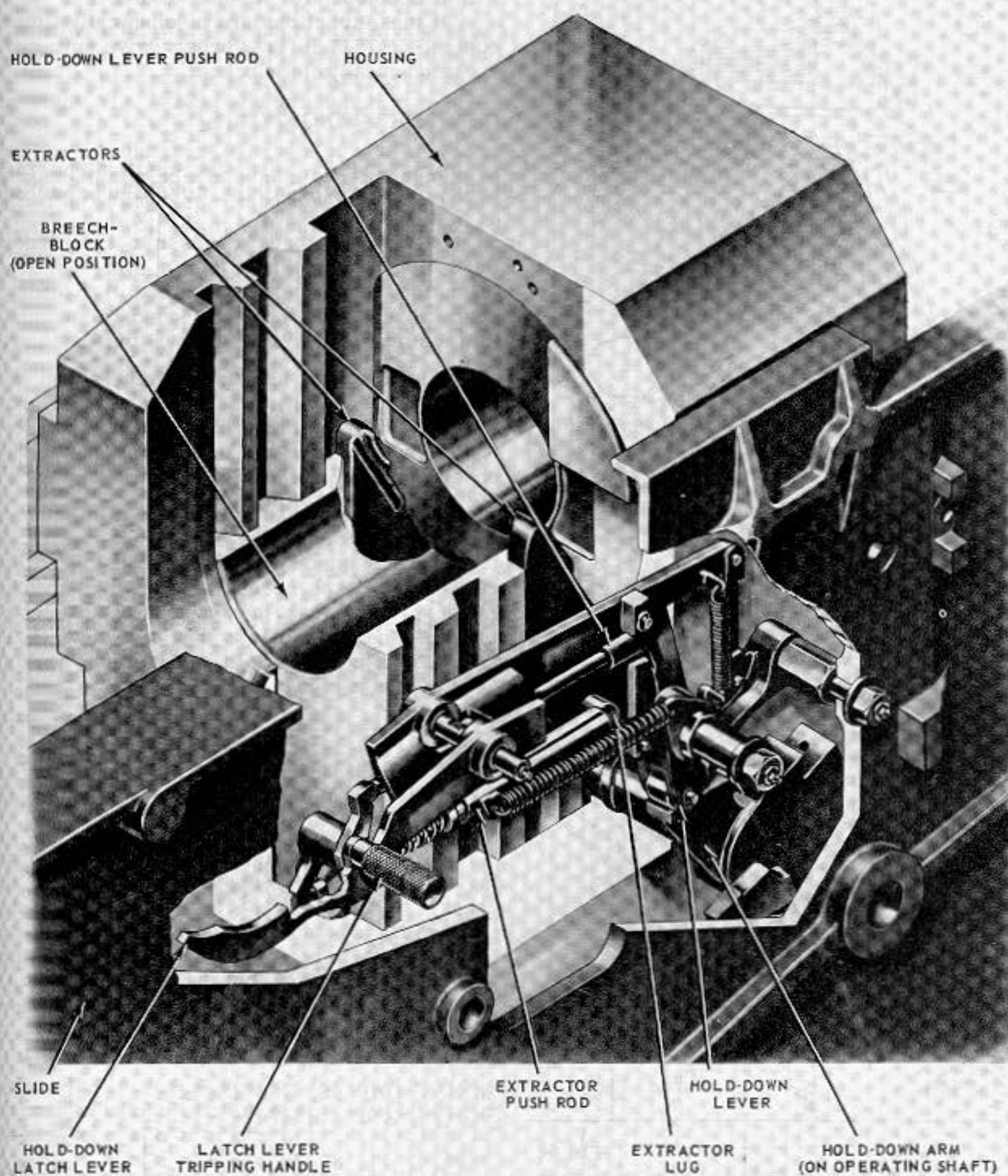
As you remember from earlier studies, ammunition is fed into the chambers of most naval guns by ramming—by a mechanically delivered push that "follows through" until the projectile is seated. In contrast, each gun on a 3"/50 mount is equipped with a mechanical loader (to be described later in this section) which catapult

each round into the chamber. Since there is no follow-through, the breech mechanism must be "triggered" into closing by the momentum of the catapulted round as it is thrown forward by the loader at about 9.5 feet per second. This triggering function is performed by the hold-down mechanism, shown in figure 5-21. The hold-down lever is pivoted near its center. When the gun is in battery and the breechblock is held down, the hold-down lever bears on the hold-down arm of the breech operating shaft to prevent rotation of the shaft and closing of the breech. The hold-down latch lever interlocks the breech mechanism with the loader, unlocking the hold-down device when a new round is to be catapulted into the breech. The hold-down mechanism when unlocked will allow the breechblock to rise (to breechclosed position) when the rim of a catapulted cartridge case trips one of the extractors, which operates a push rod to trigger the mechanism.

The breech interlock mechanism, which is technically a part of the loader, is a system of mechanical linkages which functions automatically to stop the loader from delivering another round to the breech whenever there is a round in the bore or the breechblock is up, or the gun is out of battery. When either a round is rammed or the block is raised, it actuates the loader control lever to prevent the start of a new loading cycle.

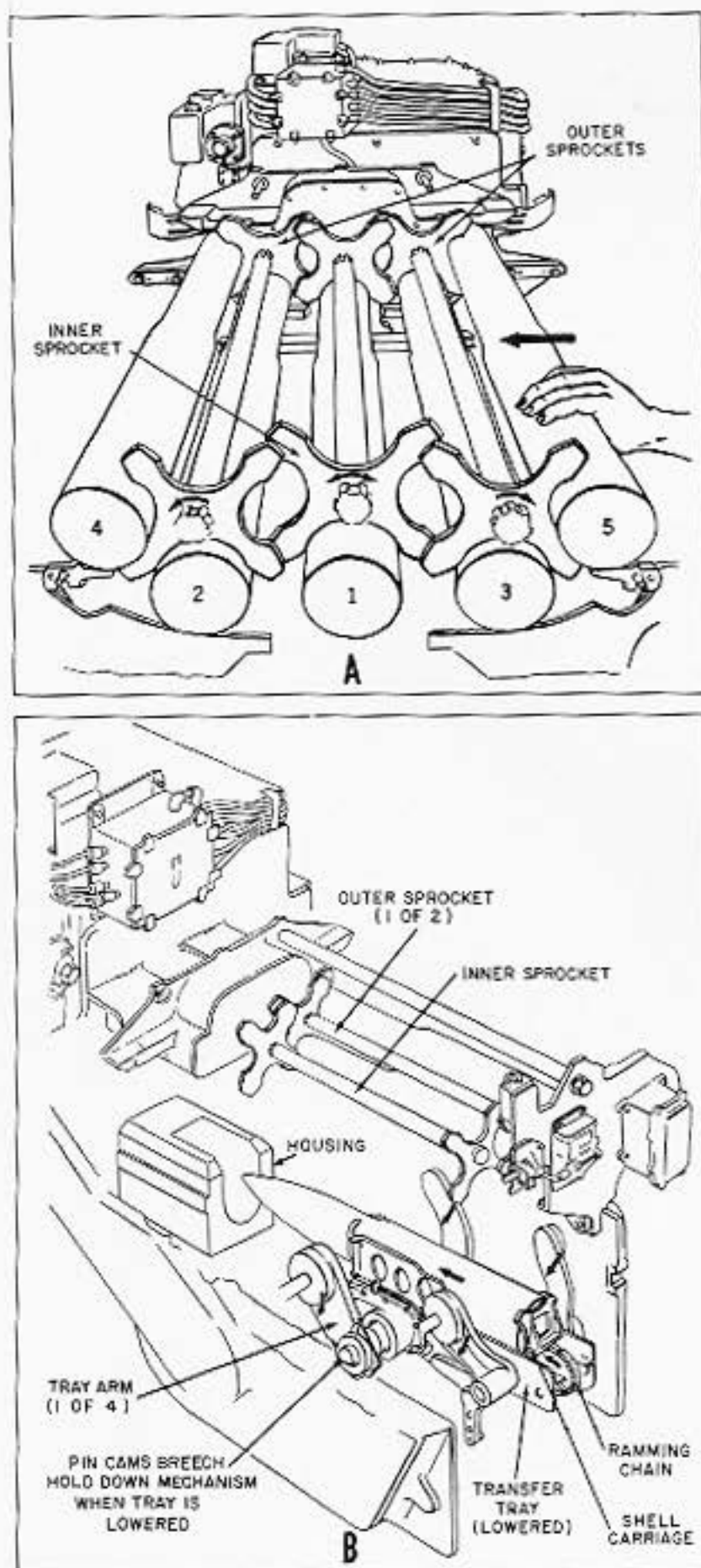
LOADER

The loader (figs. 5-20 and 5-22) is an independent, electric power-driven machine mounted on the after part of the slide. It mechanically loads each gun at the rate of 45 rounds per minute as long as ammunition is served and the firing control is operated. It is bolted to the after end of the gun slide, and is fed manually by two crewmen, who insert the fixed ammunition one round at a time into the feed sprocket on each side (fig. 5-22A). The outer sprockets alternately shift the rounds to the center sprocket, which centers the round to be loaded above a gate mechanism. When the breech is open, the gates admit the round to be loaded to a shell carriage mounted on a tray which is parallel to the gun bore axis. The loaded tray swings down on its four arms until it is aligned with the chamber, then the shell carriage, driven by an electric motor, catapults the round into the breech (fig. 5-22B). After the round clears the carriage, the tray swings upward into position to accept another round.



84.165

Figure 5-21.—3"/50 rapid-fire gun. Breech mechanism and hold-down mechanism.



110.68
Figure 5-22.—3''/50 loader. A. Sprockets being loaded. (Center sprocket alternates direction of rotation each cycle. Rounds numbered in sequence of loading.) B. Cartridge being catapulted into breech housing.

The breech interlock automatically blocks repetition of the loader operating cycle until the gun has fired, recoiled, and returned to battery with breech open for the next round.

All these functions are mechanically timed by control devices in the loader drive unit, and all are sequentially interlocked.

GUN OPERATING CYCLE

Here, briefly, are the main steps in the cycle of operation of the 3''/50 gun and loader:

1. Crewmen load rounds into the hopper of the loader (fig. 5-22A). Three cycles of loader operation are necessary before the loader is ready to catapult the first round of ammunition into the breech, which it does on the fourth cycle.

2. As the tray approaches the bottom of its swing (fig. 5-22B), the shell carriage moves forward to catapult the round into the gun breech. At the same time, a pin on the tray cams a lever on the breech hold-down device to unlock it.

3. As the round flies forward into the breech, the cartridge rim engages the extractors. Extractor movement releases the unlocked hold-down device (see preceding step) and the operating spring raises the breechblock to close the breech. The breech interlock and several electrical interlocks keep the loader from recycling until the proper time.

4. As the breech closes fully, the firing pin contacts the cartridge primer much the same as in the 5''/38 mechanism. When the firing circuit closes, the gun fires, recoils, and counter-recoils.

5. As the gun counterrecoils, a breech opening cam on the slide engages the operating shaft crank. This rotates the breech operating shaft, pulling the breechblock down until the hold-down device locks it open. The extractors (not shown) haul the fired case out while the block goes down. The gun is now ready for the loader to catapult the next round.

MOUNT DRIVES, CONTROLS, SIGHTS, AND CREW

All 3''/50 rapid-fire mounts have amplidyne power drives for both train and elevation.

There are no provisions for manual drive, except handcrank arrangements (not illustrated) intended only for stowing and servicing the

mount. But there are two types of local control—AA LOCAL and SURFACE LOCAL, plus automatic remote control from a director. Each side of the mount has a separate control station.

In AA local, the left gun layer (AA operator) controls the mount in both train and elevation, and fires the mount. The left gun layer uses a ring sight (fig. 5-23A) and a one-man gun-laying control unit with firing key. The right gun layer's controls (part B) consist of a telescope and open sight, and a one-man gun-laying control unit with firing key. Handwheels are not used in local control for positioning the mount; the gun layers train the mount by rotating the control units about a vertical axis, and elevate by rotating the control handles about a horizontal axis. However, automatic control (with the gun layers merely standing by) is the preferred type of control.

The surface sight is a combination open sight and telescopic unit with provision for sight setting. With the AA sight, it is mounted on a yoke astride the slide. The surface gun layer uses the open sight to get the target into the comparatively restricted field of view of the telescope. Then he shifts to the scope, adjusting mount position with his controls to keep the crosshairs on the target. A sightsetter can crank in deflection and sight angle values in accordance with telephoned orders. There are no synchros transmitting these values to the sight setting mechanism (not illustrated).

In addition to the AA and surface gun layers and sightsetter already mentioned, the 3"/50 RF mount crew includes a mount captain, four shellmen, and four shell passers (fig. 5-24). The mount captain is the supervising gunner and crew captain. His operations are directed by phone by the control officer. He controls both guns with the mount captain's controls. His controls allow him to select the control station, switch to single or automatic fire, select the gun or guns to fire, and control the loaders. He also has power-drive emergency stop buttons and two banks of neon indicators to enable him to check the loader. His firing key must be closed before the loaders will function. It can be latched closed when control of fire is to be at either left or right control station or at the director.

Two shellmen for each gun load ammunition into the hoppers of the loaders. Shell passers keep the shellmen supplied.

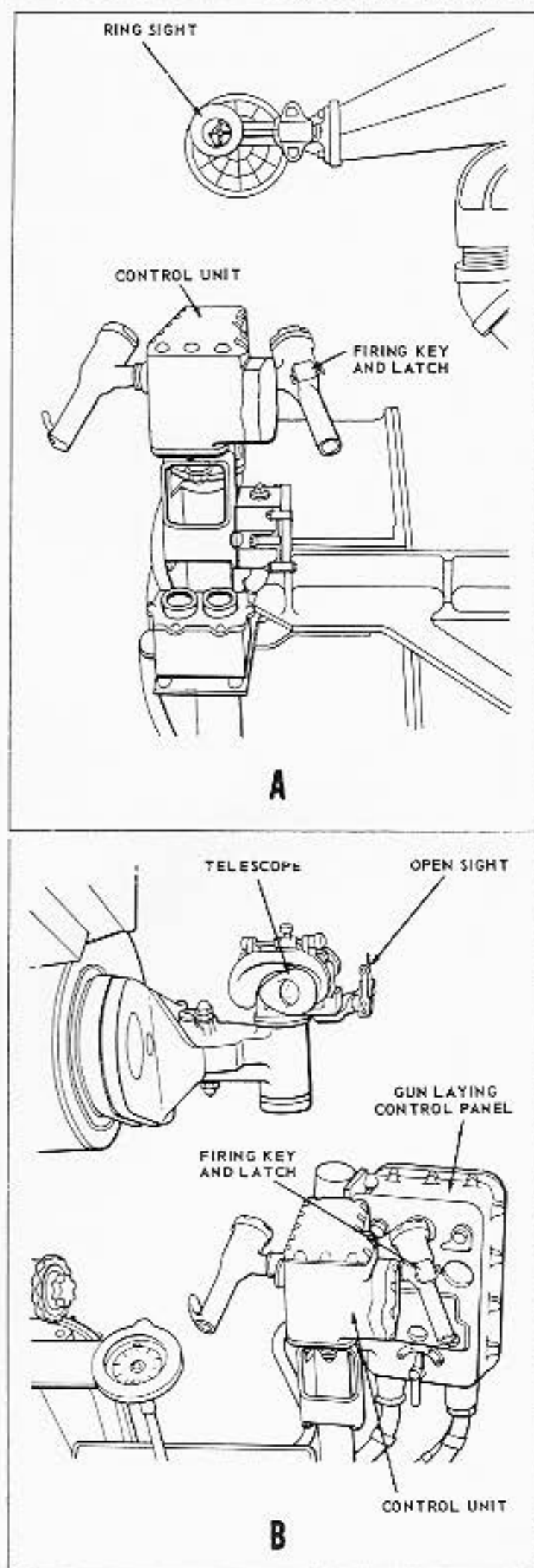
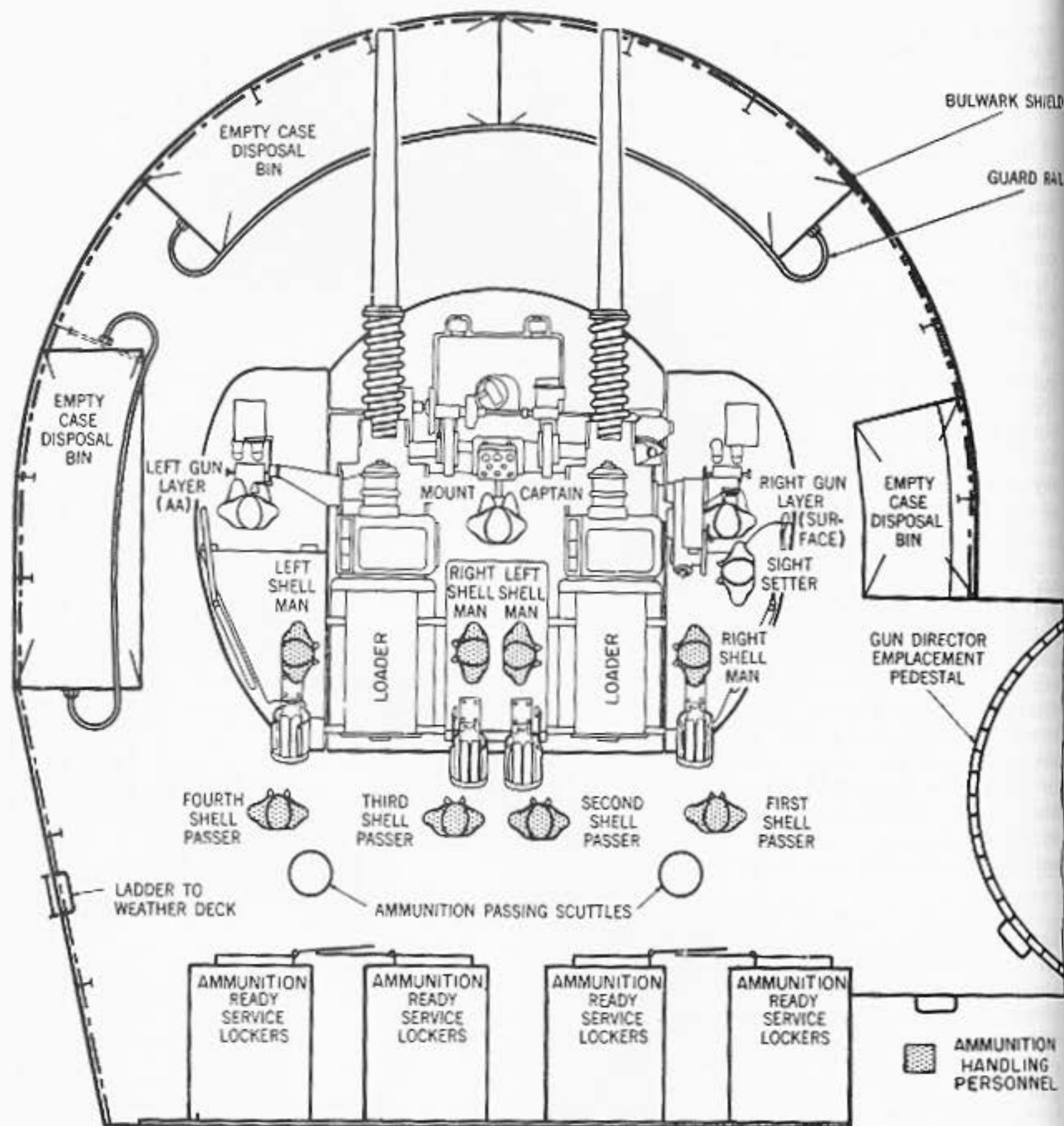


Figure 5-23.—3"/50 mount. A. Left (AA) gun layer's station. B. Right surface gun layer's station.

110.69



110.70

Figure 5-24. — 3"/50 rapid-fire twin mount. Crew stations.

5"/38 GUNS AND MOUNTS

The 5"/38 gun is one of the most widespread naval weapons in the fleet today. It is not a new design, but its reliability and the essential soundness of its design have continued its usefulness

into a day when it is far outranged by spectacular new weapons. Many of its design features persist in the very newest gun designs in the fleet, but on the whole it can be considered the prototype of the "conventional U.S. naval gun." It is the weapon characteristically used with linear-rate fire control systems.

The 5"/38 gun appears in the following general types of mounts:

1. Enclosed twin mount with ammunition-handling room beneath the mount. The type of mounts is a standard installation on many cruisers, and destroyers, and some aircraft carriers.

2. Enclosed single mount with ammunition-handling room beneath the mount. This is the old standard destroyer-type mount. It is now found on many minelayers and auxiliaries developed from the older classes of destroyers, on destroyer escorts, and on many large auxiliaries (repair ships, destroyer tenders, etc.).

3. Open single mount with ammunition-handling room beneath the mount. This mount is used on auxiliary ships.

4. Open single mount without ammunition hoists or handling room. Because mounts of this type can be installed without extensive reconstruction, it is used on converted merchant vessels.

Another mount similar in design to the 5"/38 is the 5"/54 (Mk 39), which is used on Midway class aircraft carriers. It has a longer barrel and an amplidyne all-electric power drive in contrast to the electric-hydraulic power drive used in all 5"/38 mounts. Do not confuse this mount with the automatic-loading 5"/54 (MK 42) which is covered later.

GENERAL DESCRIPTION OF 5"/38 MOUNTS

The 5"/38 caliber gun is a semiautomatic, dual purpose, base-ring-mounted gun which uses semifixed ammunition. Its principal features are:

1. Vertical sliding-wedge breech mechanism.
2. Hydraulic recoil and hydropneumatic counterrecoil systems.
3. Power-operated rammer.
4. Power-operated elevating and training gear.
5. Movable-prism telescopes.
6. Power-operated fuze-setting projectile hoist.
7. Power-operated powder hoist on all twin mounts and some singles.

The 5"/38 mount uses semifixed ammunition consisting of a 54-pound projectile (weight varies somewhat with type of projectile) and a case

assembly weighing about 28 pounds, which includes a 15-pound powder charge. Ballistic performance obtained with a 15-pound service charge (full charge) is as follows: initial velocity, 2600 feet per second; maximum horizontal range, 18,000 yards; maximum vertical range, 37,300 feet. (the Mk 39 5"/54 uses heavier ammunition and has longer ranges.) The gun is capable of sustained firing at a rate well in excess of any which can be attained by the loading crew. An experienced crew can load about 15 rounds per minute for long periods, and may attain a short-period rate of 22 rounds per minute.

The gun has a radially expanded 2-ton steel monobloc barrel. The rifling has a uniform twist of 1 turn in 30 calibers. The bore is chromium plated from the forward portion of the powder chamber to the muzzle. The barrel is connected to the housing by a bayonet-type joint.

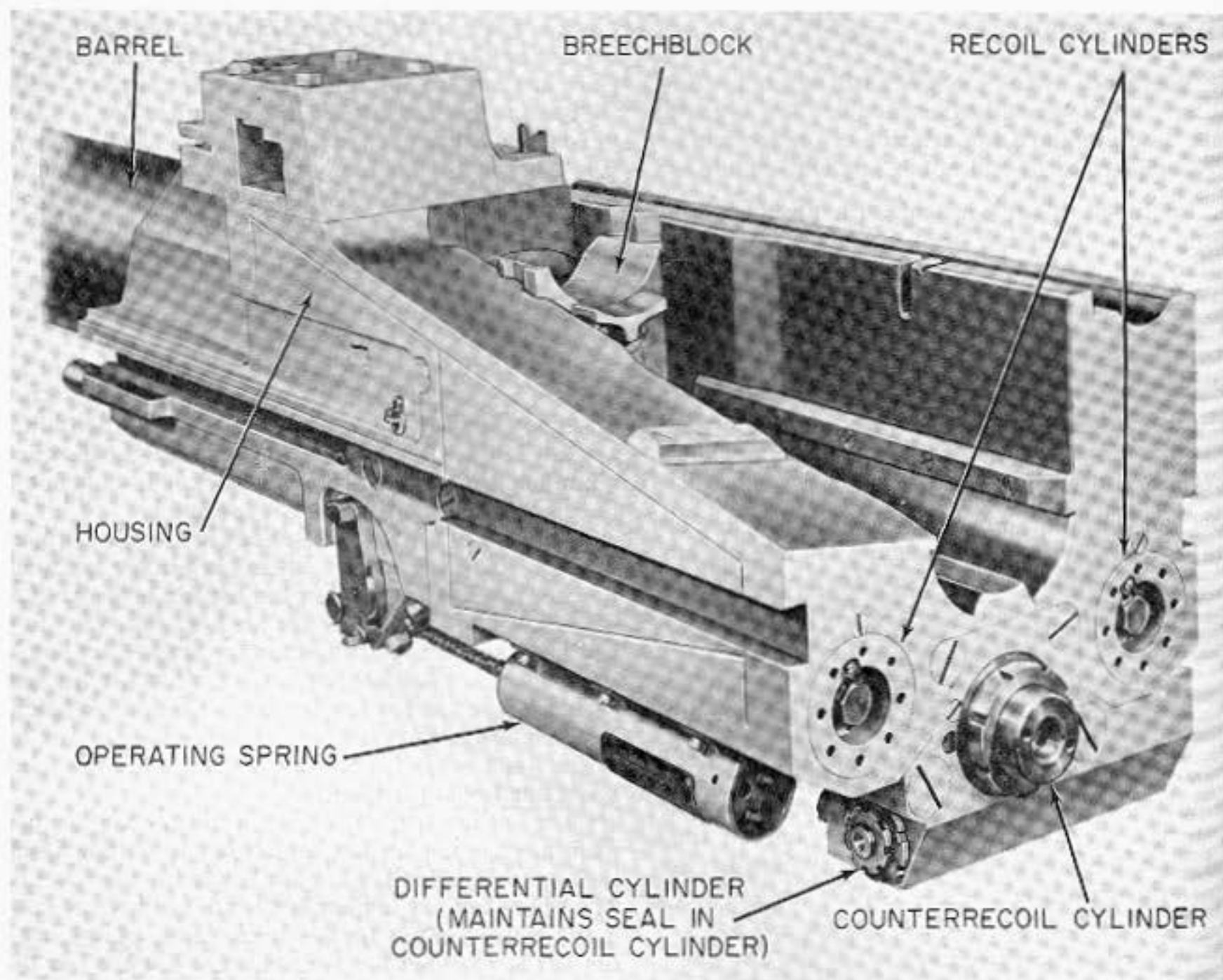
The housing (fig. 5-25) is a rectangular block-shaped forging, with forward portion machined to receive the barrel. In the center is a vertical well for the breechblock; and to its rear is a trough-like ammunition-loading tray. The housing contains twin interconnected recoil cylinders (groove type) and a single counterrecoil cylinder. The housing supports and locks the gun in the slide, and moves on the slide guides during recoil and counterrecoil.

The slide (fig. 5-26) is a large box-shaped weldment, open at top and bottom, within which the housing moves in recoil and counterrecoil. The housing is supported and guided by two guide rails bolted to the inner side plates. The elevating arc and the rammer are secured to the slide. Other mount structure details resemble those of conventional practice described earlier.

All enclosed mounts are housed in a shield of armor plate. The shield is a box-like structure that provides weather, blast, and splinter protection for the crew.

Through doors on both sides near the after end, the operating personnel enter or leave the mount. Other doors and access cover plates provide for inspection and repair. A roof hatch may be located near the after end of the gun mount. Where necessary, this hatch has a blast hood. Sight hoods on the side shield plates protect the three sight telescopes. A ventilation system supplies air to the mount and handling room.

Lights in the gun and handling room are energized by the ship's general illumination circuit, which also includes outlets for battle lanterns, window-wiper motors on each sight telescope, and the battle illumination system,



53.89

Figure 5-25. — 5-inch housing and gun (removed from slide).

which energizes small lamps at all instruments and controls.

Gun elevation, gun train, fuze setting, and sight setting synchro signals are supplied to the indicator-regulators and the sightsetter's indicator in the mount by fire control circuits from the computer.

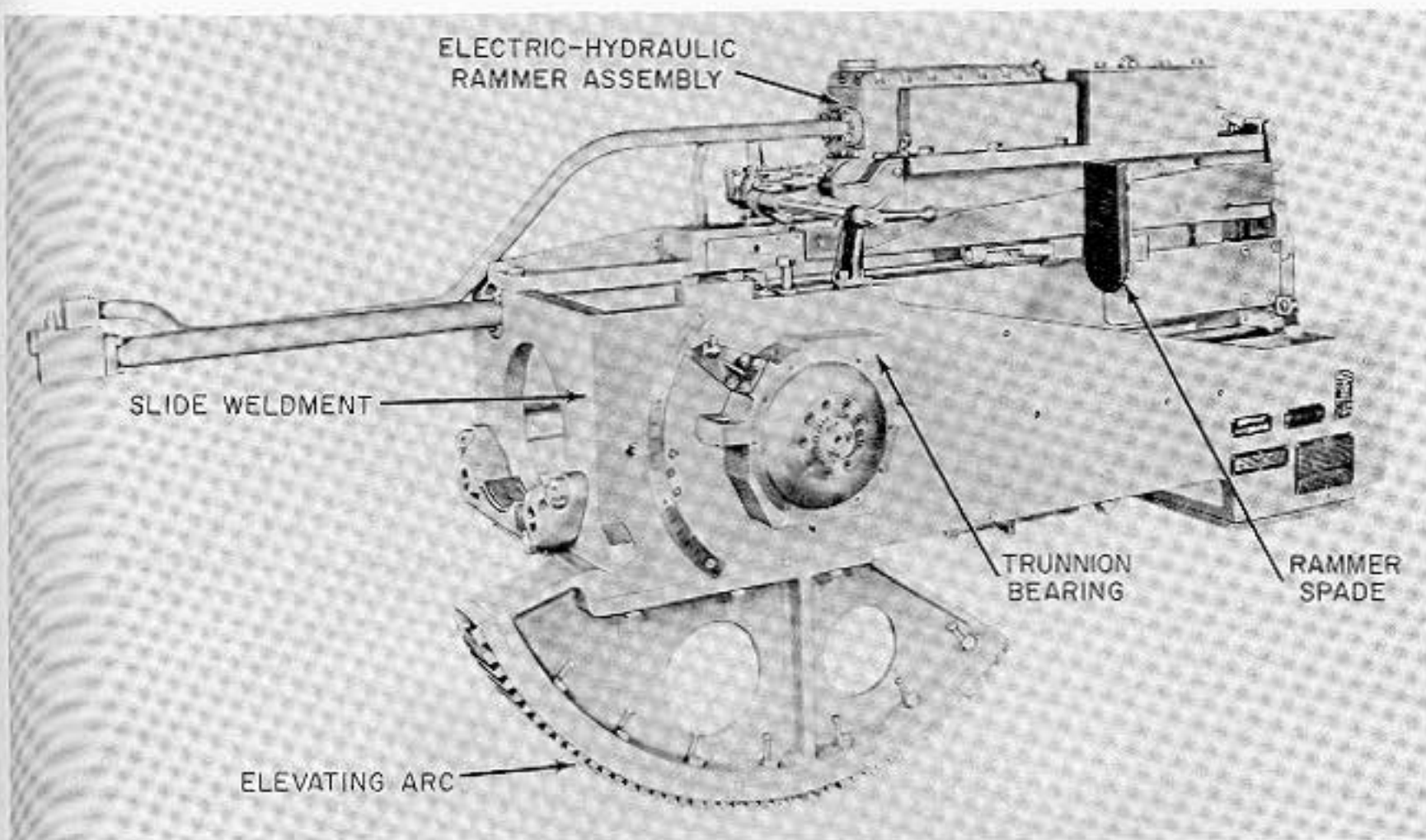
Communication facilities in 5"/38 mounts may include (1) a voice tube between gun room and upper handling room, (2) an automatic telephone in the ship's general communications system, (3) a sound-powered battle phone circuit between mount and fire control stations, (4) an auxiliary sound-powered phone circuit with call

bell between mount and lower ammunition-handling room, and (5) a loudspeaker connected to the director and plotting room.

BREECH MECHANISM

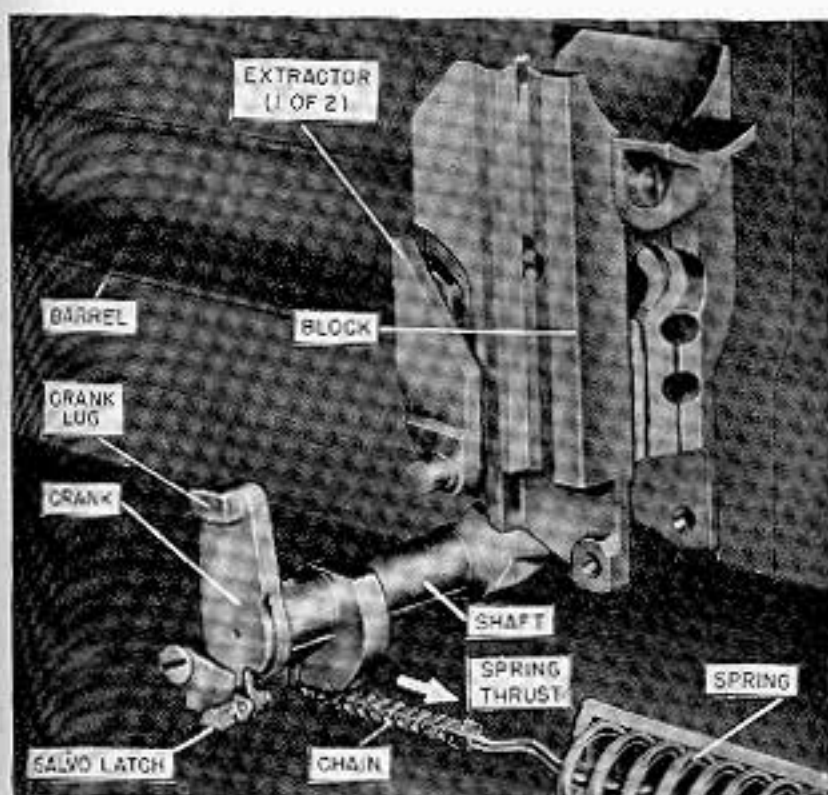
The important parts and the operating cycle of the 5"/38 breech mechanism are shown in figures 5-27 and 5-28. In operating principles and general construction the mechanism is similar to that of the 3"/50, and in lesser degree though still to a significant extent it resembles the breech mechanisms of the rapid-fire 5"/54 Mk 42.

The breechblock is a steel block which can slide up and down on guides in a breechway in the



84.119

Figure 5-26.—5-inch slide removed from mount and minus gun and housing.



84.159

Figure 5-27.—5-inch breech mechanism parts, breech closed.

housing. It is positioned by an operating shaft in the housing. The thrust of a coil spring as exerted through a chain on the shaft tends to drive the block upward to closed position. The salvo latch on one end of the crank locks the mechanism in breech-closed (breechblock-up) position; it is unlocked either by a cam on the slide or manually (if necessary). The block is forced down to breech-open position during counterrecoil by another cam on the slide which engages the lug on the crank during counterrecoil. The block is locked down by a pair of extractors, one on each side of the block. A hand-operating mechanism (not illustrated) provides for manual operation of the breech mechanism. The breech must always be opened by hand to start firing; hand operation is also required in maintenance operations, and when mechanical failure makes semiautomatic operation impossible.

Now follow the breech mechanism operating cycle. (Some details are omitted for the sake of clarity.)

1. (Figure 5-28A.) We start with breech open. Rammer (only the spade, which actually

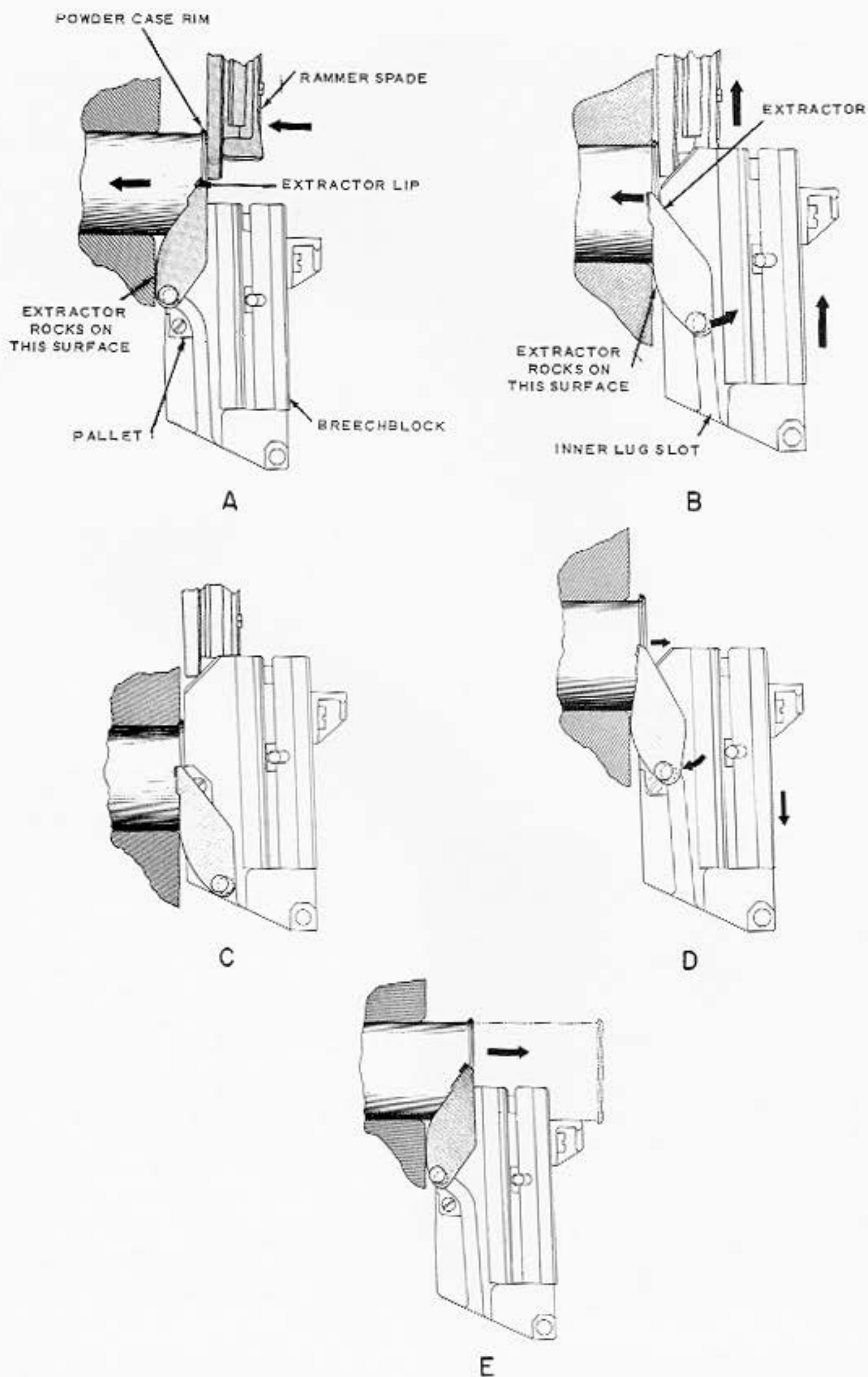


Figure 5-28. — 5-inch breech mechanism operating cycle.

pushes the round, is shown in the figure) thrusts round into chamber. Rim of case engages extractor lips and pushes them forward, unlocking block.

2. (Figure 5-28B.) Driven by breech-operating spring, block rises, wedging cartridge case into chamber. When breech is fully closed, salvo latch locks it closed. (Figure 5-27 shows salvo latch locking mechanism in closed position.)

3. (Figure 5-28C.) Gun ready to fire. It fires and recoils, but this diagram requires no change. However, salvo latch is cammed (not shown) to unlock breech (not to open it) during recoil.

4. (Figure 5-28D.) The gun counterrecoils. Cam (not illustrated) on slide engages crank lug on operating shaft and rotates shaft, causing it to lower breechblock. As breechblock drops, extractors begin to rock rearward. Extractor lips still engage cartridge case rim, hence case is forced out of chamber.

5. (Figure 5-28E.) Breechblock drops further, causing extractors to flip case out to the rear. When block is fully down, extractors remain in rearmost position and lock block down.

FIRING SYSTEM

The firing system of a 5"/38 mount closely follows conventional practice as described earlier. There is a firing mechanism in the breechblock; its insulated firing pin is in contact with the cartridge primer only when the gun is loaded, the breechblock is closed, and the gun is in battery. A foot-firing mechanism permits firing the primer by percussion, but this is rarely done. The standard method is to use the firing circuit. The pointer has a key which closes the secondary circuit of the firing transformer; the mount captain has a switch to permit selection of local or remote firing. In remote-control firing, the pointer's key is closed, and firing is controlled from either the director or plot.

The firing stop mechanism keeps the firing circuit open and the percussion firing linkage disconnected unless the gun is on an elevation and bearing at which the projectile will not hit the ship's structure.

GAS EJECTOR SYSTEM

Gas ejectors prevent entry of powder gases into gun mounts, safeguard against the danger of flarebacks, and assist in maintaining a rapid rate of fire by clearing the bore of gases. Air

under pressure of approximately 75 pounds per square inch is piped from the ship's supply to nozzles in the breechblock guideways pointed toward the gun bore. During counterrecoil, a gas ejector valve in the housing is cammed open and gas ejection begins. The valve is closed by the rammer as the next round is rammed. A hand lever permits manual opening and closing of the valve.

RAMMER AND AMMUNITION HANDLING CYCLE

The rammer is a semiautomatic electric-hydraulic unit on the upper rear part of the slide. A 7 1/2-hp electric motor drives a pump whose output is controlled by valves to operate the ram cylinder. The piston of the cylinder is mechanically linked to a rubber-faced rammer spade which moves forward along the loading tray, and to the rear in an elevated path along the slide. The cycle of operation is as follows:

1. Two crewmen (the projectileman and powderman) take the projectile and powder case out of their hoists and deposit them in the loading tray in the slide.

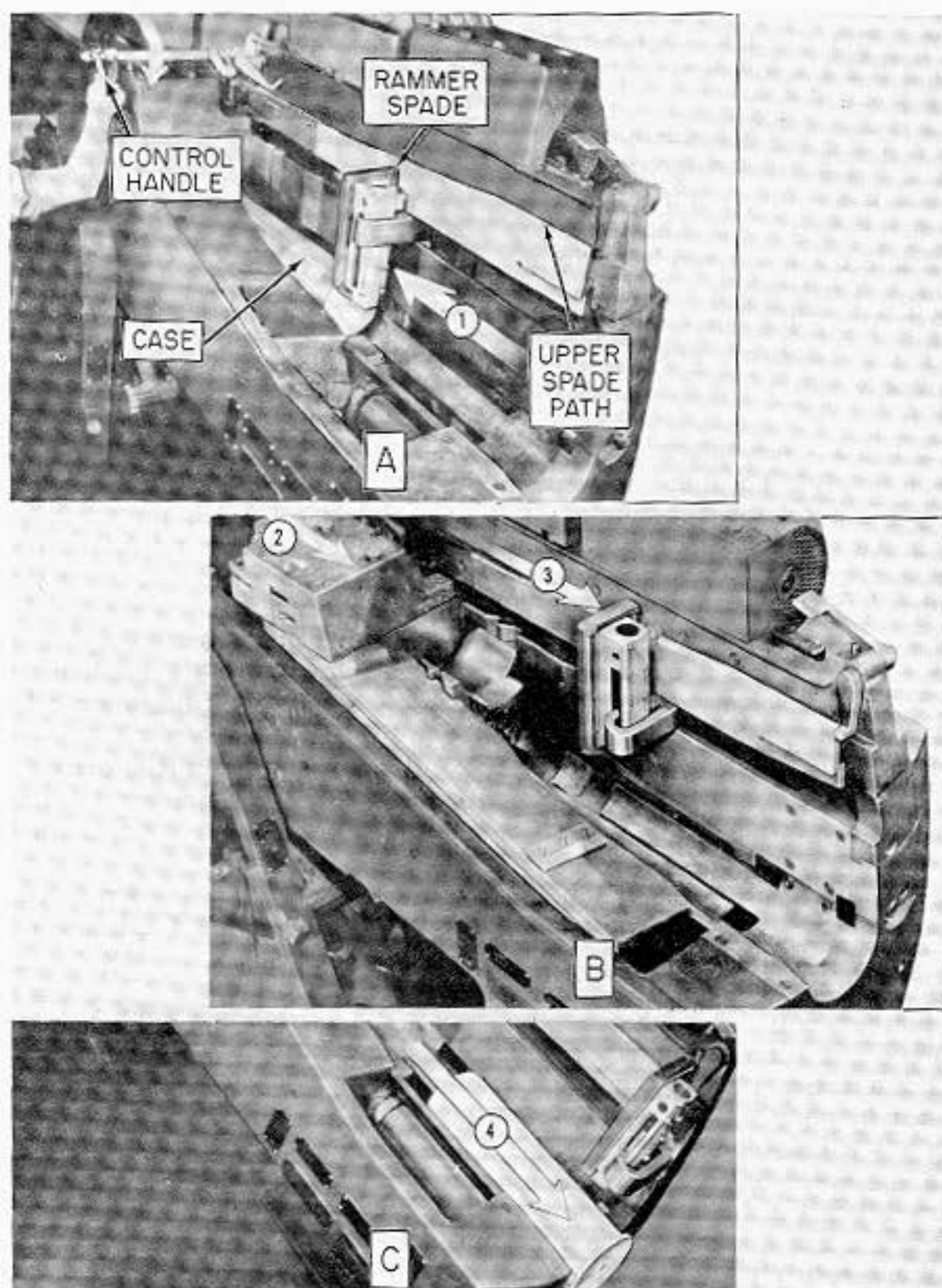
2. The rammerman depresses a control handle (fig. 5-29A). The ram cylinder forces the rammer spade forward (arrow (1)) to ram the round into the chamber.

3. When the breechblock closes and the gun fires and recoils (arrow (2) in fig. 5-29, part B), the rammer spade is automatically retracted (arrow (3)) along an upper path in the slide. This lifts the spade so that it will not obstruct the extracted cartridge case's path (arrow (4), fig. 5-29C) to the rear. A crewman throws the fired case out of the mount in single mounts. In twin mounts, except when gun elevation exceeds about 30°, case ejection is automatic.

4. The gun captain prepares for the next round by lowering the rammer spade to ram position.

TRAINING AND ELEVATING GEAR AND POWER DRIVES

The general principles of training and elevating gear were explained earlier in this chapter, and those of power drives in chapter 3. Those of 5"/38 mounts exemplify these principles in conventional applications, and will not be described in further detail here.



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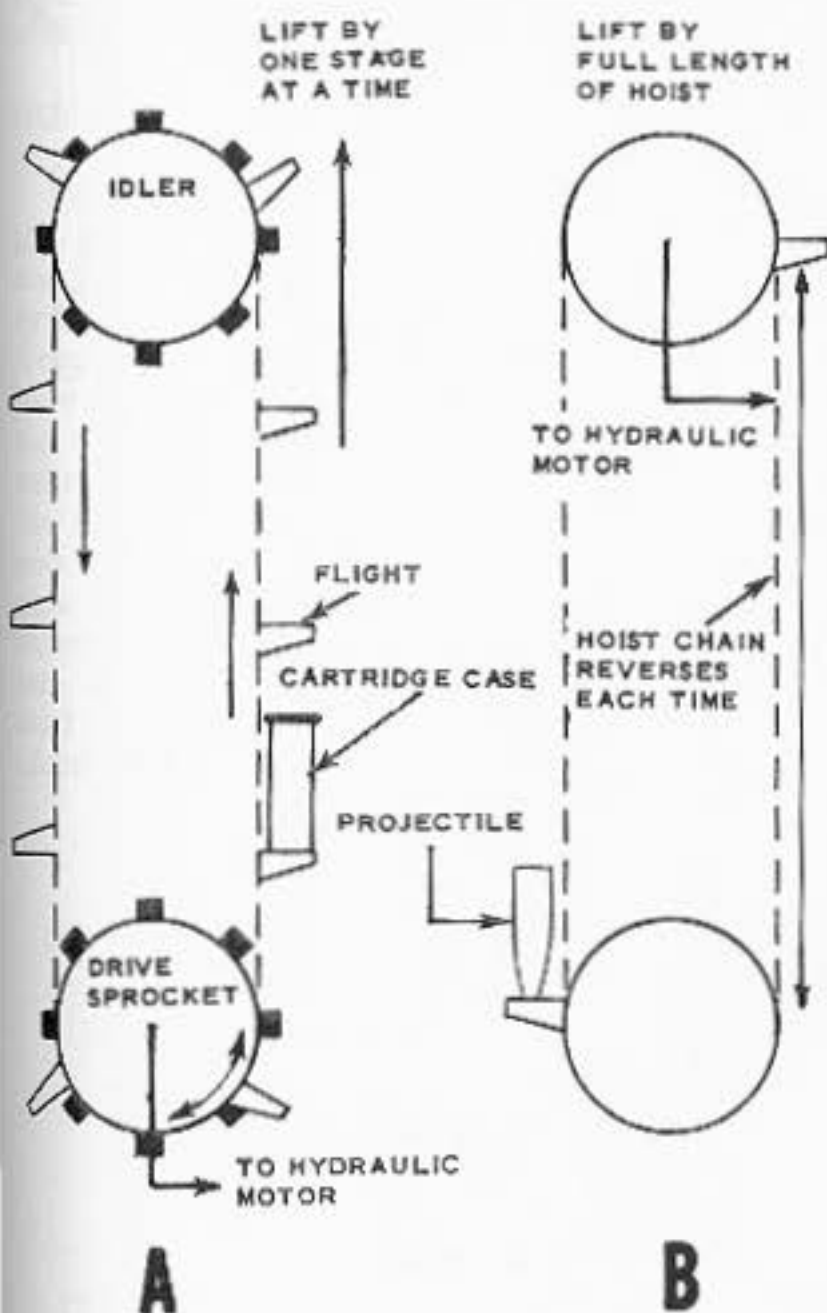
Figure 5-29.—5"/38 mount. Loading and extraction operations.

HOISTS

In the ammunition transport installation for a twin 5"/38 mount, powder cartridges are manually loaded into dredger hoists, which lift them to the upper handling room. Here they are manually removed from their tanks and transferred to a powder hoist which lifts them to the gun house. In the gun house a crewman manually transfers them from powder hoist to gun slide.

Projectiles typically are handled similarly, except that they are not stowed in tanks.

The powder and projectile hoists between the upper handling room and the gun house are quite different in functioning. The powder hoist (and dredger hoists are similar in principle) consists fundamentally of an articulated endless chain with supports or flights secured to it at regular intervals (fig. 5-30A). Powder cases are loaded by pushing them into the hoist in the path of



84.150

Figure 5-30.—Principles of 5"/38 hoists. A. Powder hoist. B. Projectile hoist. (Fuze setter not shown.)

the flights; when the hoist starts, the chain is driven upward until the next vacant flight is in loading position. When the next unit is loaded, the hoist goes up one more flight, and so on. The hoist starts automatically when loaded, except instances when a round is at the top of the hoist. The hoist is driven by a rotary hydraulic motor whose functioning is controlled by valves.

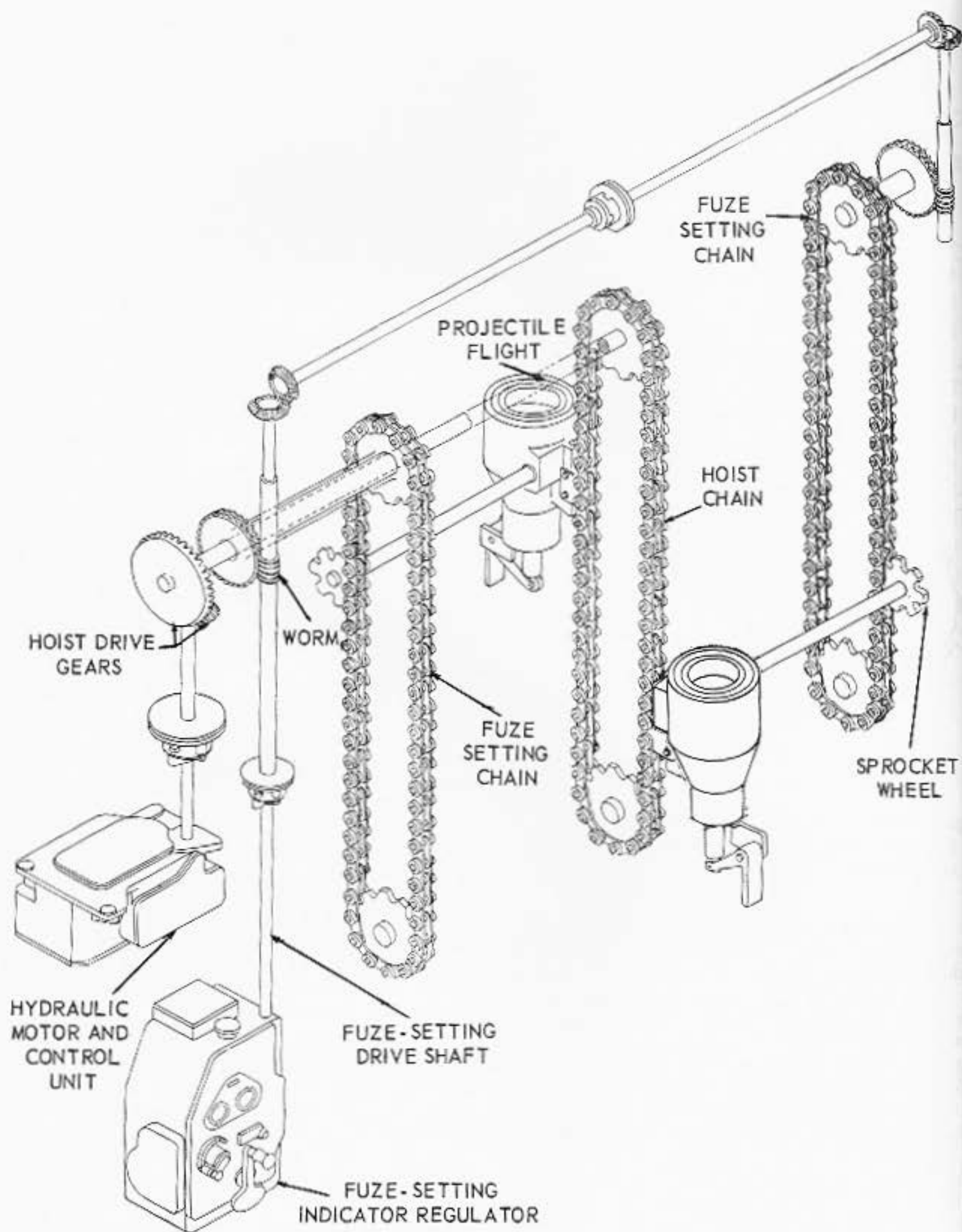
Endless-chain hoists generally can be operated in reverse to lower ammunition units, as is required in taking ammunition aboard. In either mode of operation, the hoist moves one flight at a time, intermittently in the same direction. Only one side of the chain is used.

The projectile hoist, in contrast, has an endless chain in which both sides of the chain are

used (fig. 5-30B). There are 2 flights, arranged so that when one is at the top of the hoist on one side, the other is at the bottom of the hoist on the other. The chain runs first in one direction, then the other, and the flights always move from all the way at the top to all the way at the bottom (or vice versa), as in the old-time well with 2 oaken buckets, one of which descended while the other went up. The projectile is loaded into one side, and automatically the hoist starts if the top is empty. As the loaded flight ascends, the empty comes down. The cycle reverses for the next projectile.

In addition to hoisting projectiles (it is never used for lowering them), the 5-inch projectile hoist also sets the projectile fuze (when a projectile with time fuze is loaded). As you can see in figure 5-31, the projectile hoist has three chains. The center one is the hoist chain. It is driven by a hydraulic motor through shafting that rotates a sprocket at the top of the chain. Each of the other two chains is part of the fuze setting linkage. They are positioned by the fuze setter indicator-regulator, a servomechanism controlled by the fire control computer. Each projectile flight has a small sprocket wheel which engages one of the chains. As the projectile flight is hoisted by the hoist chain, its wheel "walks" up the fuze setting chain. This rotates a ring (not shown) inside the flight. The projectile is manually loaded nose down into the flight. If it is a time-fuzed projectile, it is loaded so that a lug on the fuze engages the ring in the flight. As the projectile is hoisted, the fuze's lug is rotated by the ring. This adjusts the fuze to the desired time setting. So long as the projectile remains in the hoist, the time fuze setting is continuously adjusted by the fuze setting indicator-regulator through the fuze setting chain and ring. The time lapse from the instant the projectile is removed from the hoist (after which its fuze adjustment ceases) until it is fired is called dead time, which is estimated and included in the fire control computation.

This discussion of ammunition supply equipment has concentrated on twin mounts, which are the most elaborately equipped. Some single 5-inch mounts (for example, the single 5"/54 Mk 39 mount) are equipped with one powder hoist and one projectile hoist per mount. Other single 5"/38 mounts may have only a projectile hoist, plus (instead of a powder hoist) a deck scuttle through which powder cases are pushed by hand. Some auxiliaries are still equipped with open mounts with similar arrangements, or with no



110.63
Figure 5-31. — 5-inch projectile hoist. (Schematic.)

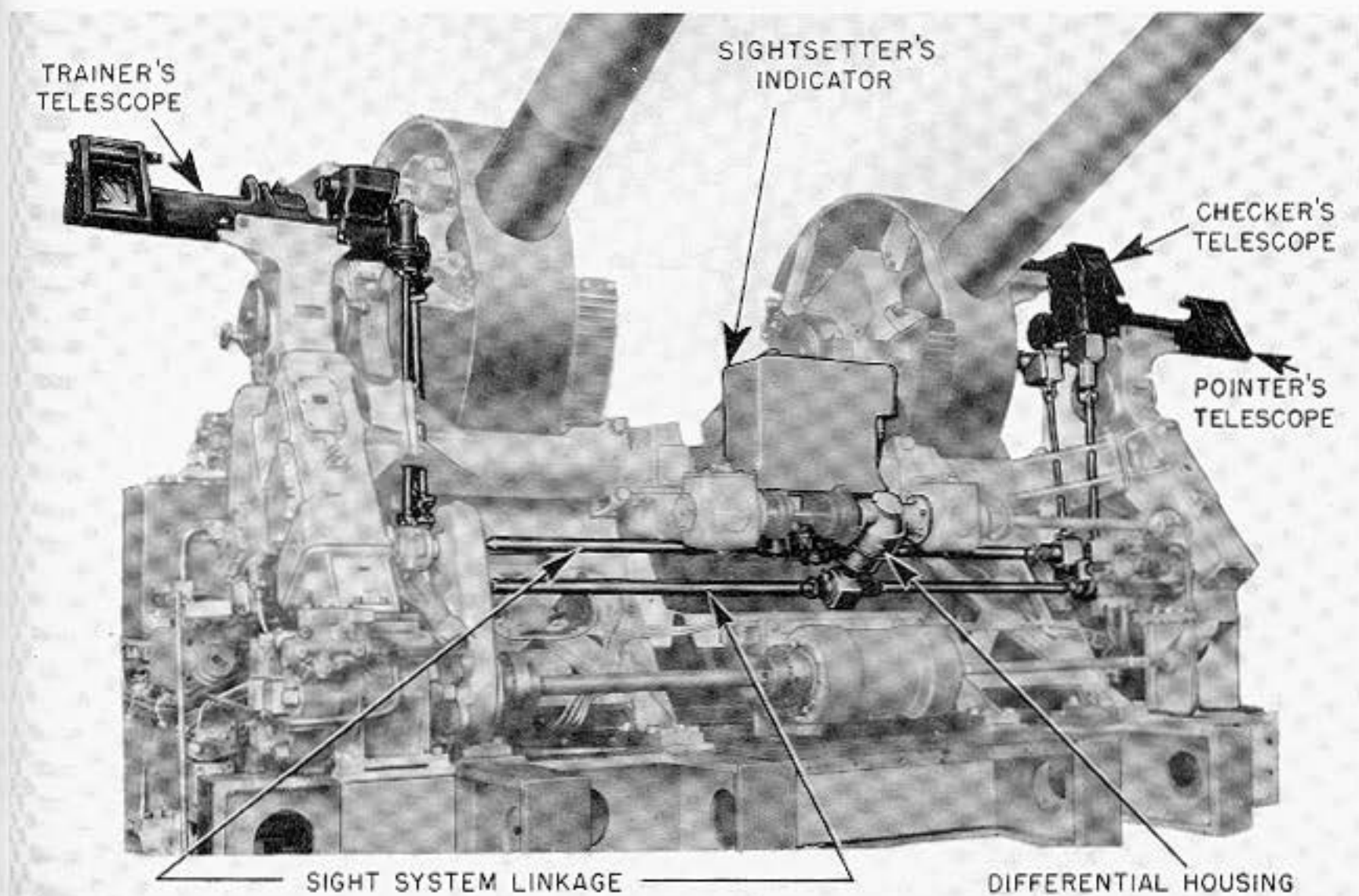
hoists at all, but this is not the normal condition aboard combat vessels in the active fleet.

SIGHTS

All enclosed 5-inch mounts, both twin and single, are fitted with carriage-mounted telescopic sights in which movable prisms in the optical system provide for offsetting the gun bore axis from the line of sight (LOS). All twin mounts have three sights—one for the pointer, one for the trainer, and one for a sight checker. However, there are but two optical systems—one for the trainer, and one that is shared by the pointer and checker. Each optical system has two movable prisms—one to introduce deflection, the other to introduce sight angle. The sighting system also includes a sightsetter's indicator operated by the sightsetter. These units and the mechanical linkages between them are shown in

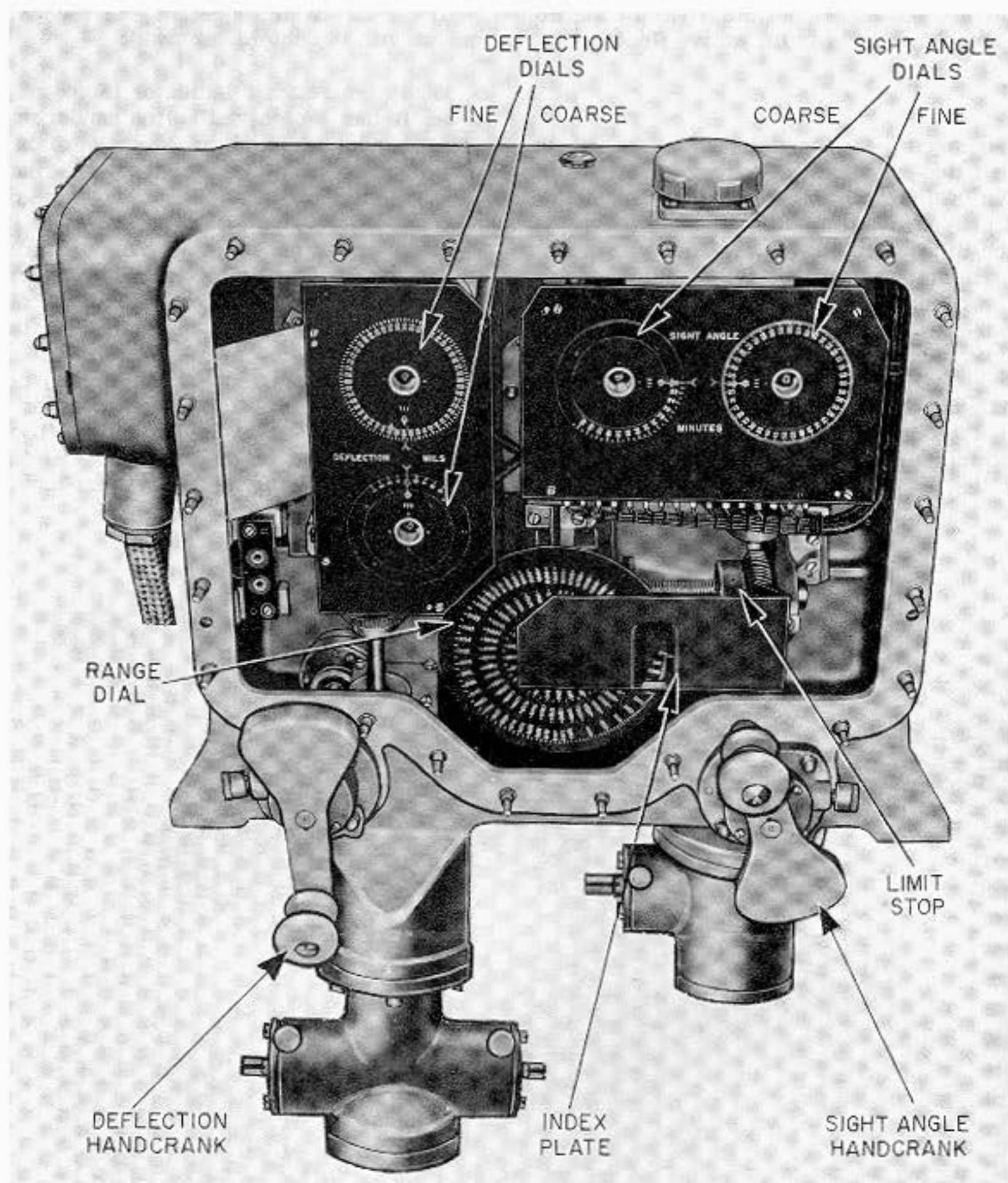
figure 5-32, which depicts the front of a twin mount with the shield removed.

The sightsetter's indicator is shown in figure 5-33. It has a sight deflection handcrank, a sight angle handcrank, and three sets of dials—a pair of deflection dials (one coarse, one fine), a pair of sight angle dials (one coarse, one fine), and a range dial. The indicator receives sight deflection and sight angle synchro signals from the computer. The deflection dials are calibrated in mils (6400 to the circle), with the zero point arbitrarily chosen as 500 mils on the dials. Sight angle dials are calibrated in minutes (21,600 to the circle) with the zero point (gun bore axis parallel to LOS in a horizontal plane) arbitrarily chosen at 2000 minutes. (Using these arbitrary values instead of zero eliminates the need for using signs to indicate the direction of offset.)



84.209

Figure 5-32.—5"/38 twin mount. Shield removed to show sight components as viewed from front of mount.

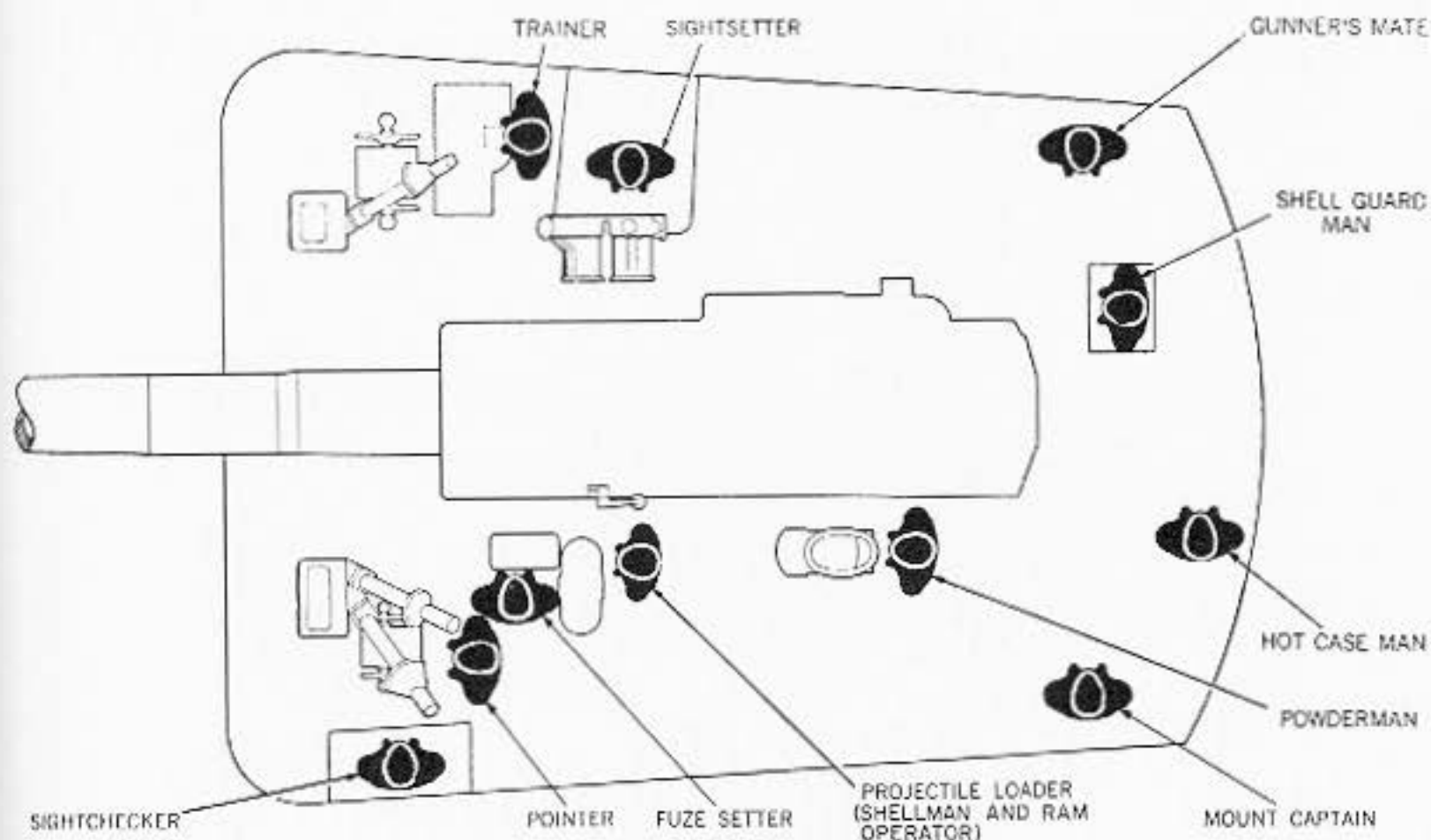


4.192
Figure 5-33.— 5"/38 twin mount. Sightsetter's indicator.

The range dial, which is geared to the sight angle handcrank, is calibrated in yards, and is used in emergencies against surface targets when no sight angle data are available from fire control plot.

MOUNT CREW

Figure 5-34 shows the crew stations of a single 5"/38 mount. The duties of the mount crew are described below.



80,217

Figure 5-34.—5''/38 single mount, crew stations (gunhouse).

The mount captain is the command leader. If available a gunner's mate is his principal assistant and supervisor of gun operation. He serves as troubleshooter and chief maintenance man. The pointer is responsible for checking and operating his sight and when not in automatic the elevating gear; he also, in most cases, fires the gun. The trainer does similarly for his part of the mount except for firing the gun. The sightsetter receives and sets sight deflection and sight angle. The fuze setter tests the fuze-setting mechanism, and operates it when the fuze setter is not in automatic. The projectile-and-rammerman operates the rammer and loads projectiles. The gun captain lowers the rammer spade and checks the loading operation. The powderman takes the cases out of hoist and passes them to the loader-hot-case man, who puts the cases in the slide.

In addition to these ten men in the gun house, there are six in the upper handling room (not diagrammed). Two powdermen keep the powder hoist supplied, two projectilemen do the same for the projectile hoists, and two others operate scuttles through which ammunition is passed from the magazines.

In a twin mount many of these crew stations are duplicated because there are two guns and two sets of hoists. The crew totals 27.

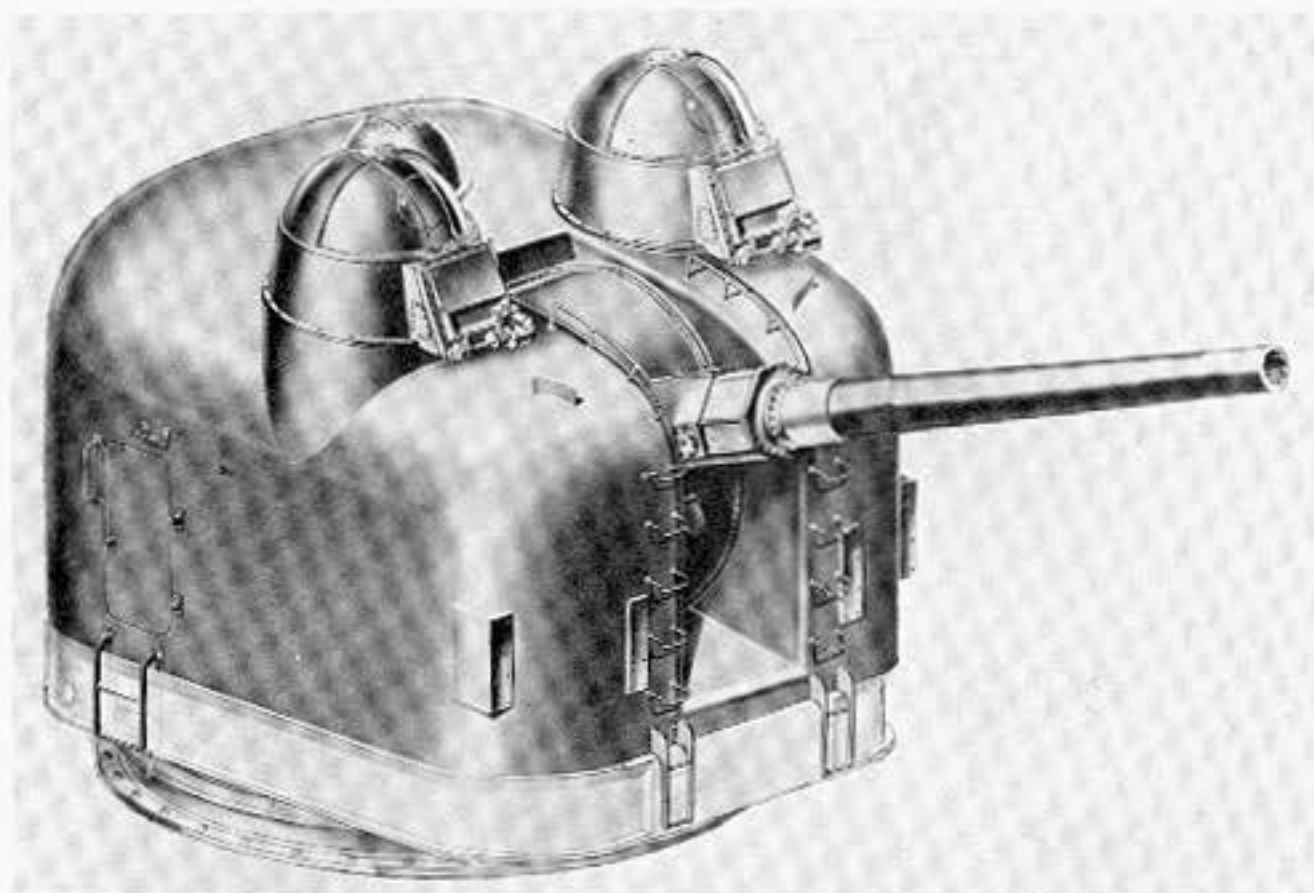
5''/54 GUN MOUNT

With the coming jet aircraft, it has been necessary to develop a reliable antiaircraft gun with increased range, tracking rate, and firing rate. The rapid-fire 5''/54 gun mount not only satisfies these requirements, but it is quite effective against surface and shore targets as well.

The following discussion is concerned with the 5''/54 Mk 42 and, briefly, the Mk 45 gun mounts.

5''/54 Mk 42

The 5-inch mount Mk 42 (fig. 5-35) is a shielded, dual-purpose, single-gun mount with an automatic firing rate of approximately 40 rounds of ammunition per minute. The gun is trained and elevated (laid) by using separate power drives that are electrically controlled and hydraulically operated. Ammunition is served



3,123

Figure 5-35.—5"/54 Mount Mk 42. Exterior.

by an automatic, dual-hoist gun loading system that is hydraulically operated and electrically controlled.

The gun mount consists of the following main components:

1. Gun assembly
2. Slide assembly
3. Gun loading system
4. Gun laying system

The gun mount also contains the following auxiliary systems:

1. Sprinkling systems
2. Electrical systems
3. Heating, lighting, communication, and ventilation systems.

Basically, the gun and slide assemblies are standard, except that the breechblock and extractors are operated hydraulically. The 5"/54 gun is unique, in that it has roller bearings supporting the gun housing. The bearings prevent gun and mount lateral movement during recoil and counterrecoil.

Recoil and Counterrecoil

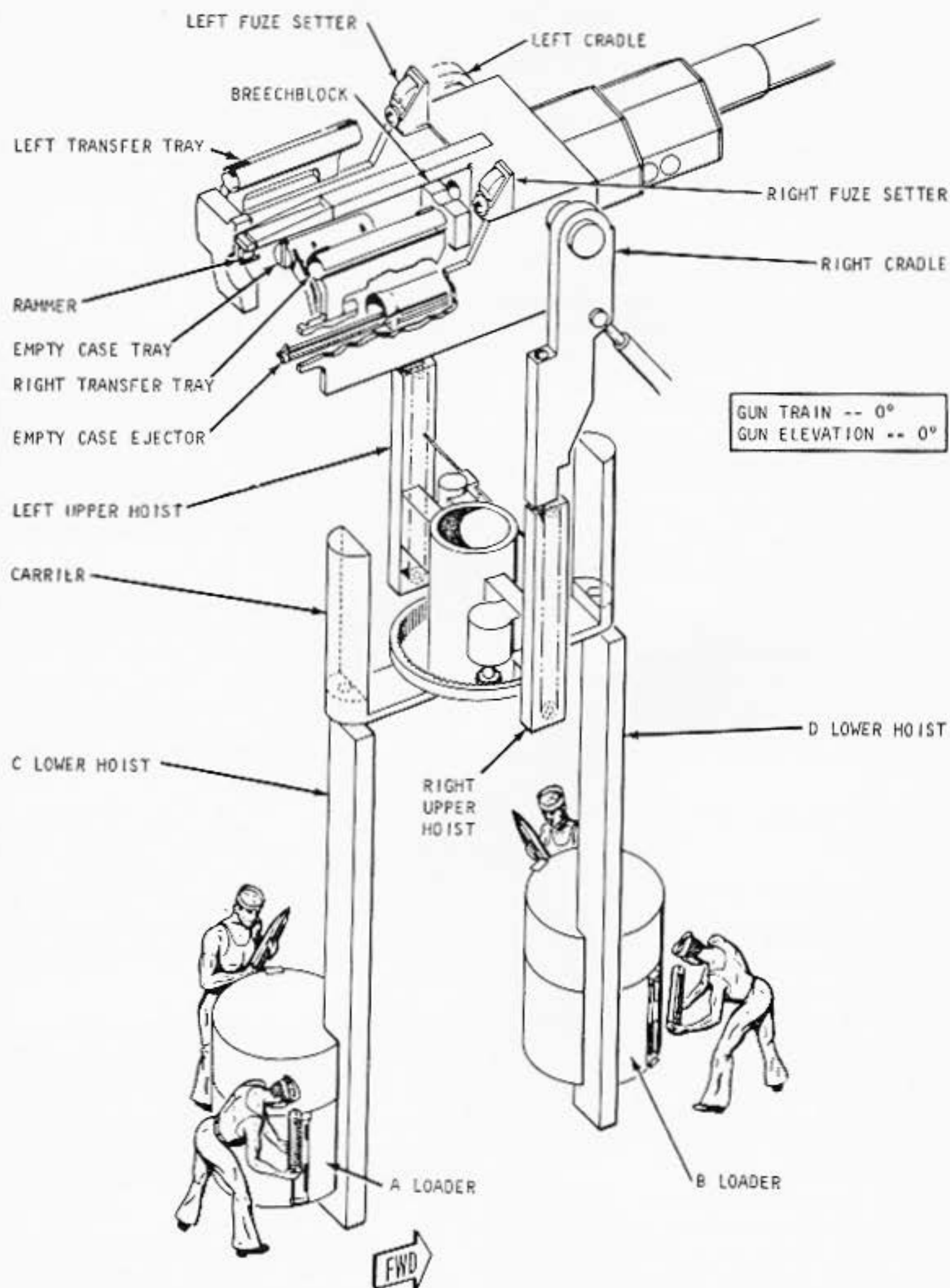
The gun recoil and counterrecoil systems are conventional, except that the location of the recoil pistons is changed, and the counterrecoil system differs in that two air chambers are used. The counterrecoil system is also arranged so that the differential and air chamber cylinder are mounted to the slide, and the piston rods bear against the after edge of the gun's main housing.

Gun Loading System

The gun loading system (fig. 5-36) extends from the ammunition handling room upward through the ship to the mount gun room. This loading system consists of a dual set of units which automatically serve rounds of semifixed ammunition to the gun from both sides of the slide.

Following is a brief description of ammunition movement from the handling room up through the loading system (fig. 5-36).

1. Rounds of semifixed ammunition are manually loaded onto the loaders (drums that automatically feed the lower hoist).



84.72

Figure 5-36.—5"/54 mount Mk 42 ammunition handlers load A and B loaders.

2. The rounds of ammunition are fed from the loaders to the lower hoists, which raise each round to the carriers (on Mods 1 through 6) or to the transfer station (on Mods 7 and 8) which positions the round into the carrier.

3. The rounds are then transferred from the stationary lower hoists to the rotatable upper hoists (located on the structure of the gun mount) by the carriers.

4. The rounds are alternately raised from the carriers to the cradle by the upper hoists.

5. The rounds are transferred from the upper hoists to the transfer trays, located on each side of the slide, by the cradle which alternately swing upward.

6. The rounds are held in the transfer trays while the projectile fuzes are set (on mechanical time-fuzed projectiles only). The transfer trays then lower the rounds to the ramming position, in line with the gun chamber.

7. The rounds are rammed into the gun chamber by the rammers, which extend through the transfer trays.

After the gun fires and the breech is opened, the extractor catapults the empty powder case rearward into the empty case tray. This tray then lowers the expended case into the empty case ejector, which ejects the case from the mount.

Gun loading systems are divided into three groups as follows:

1. Lower gun loading system.
2. Upper gun loading system.
3. Intermediate section (ammunition carrier).

The lower gun loading system includes the loader drums and lower hoists (refer to figure 5-36), their hydraulic power units, and the central equipment necessary for their operation. This portion of the gun mount assembly is also referred to as the stationary, or nonrotating gun mount components (fig. 5-37).

The upper gun loading system consists of upper ammunition hoists, transfer trays, rammer, empty case tray, empty case ejector, and fuze setters (fig. 5-36). All upper gun loading system components are part of the rotating gun mount assembly and move with the mount when the gun trains (fig. 5-37).

The intermediate section (carrier) transfers rounds of ammunition from the fixed lower hoist to the rotatable upper hoist. In so doing, the carrier acts as an independent transferring mechanism between the stationary gun mount assemblies (lower gun loading system) and the rotatable gun mount assemblies (upper gun loading system). Physically the carrier is part of the carriage and receives its hydraulic power from the upper gun loading system supply.

Design Differences for Different Mods

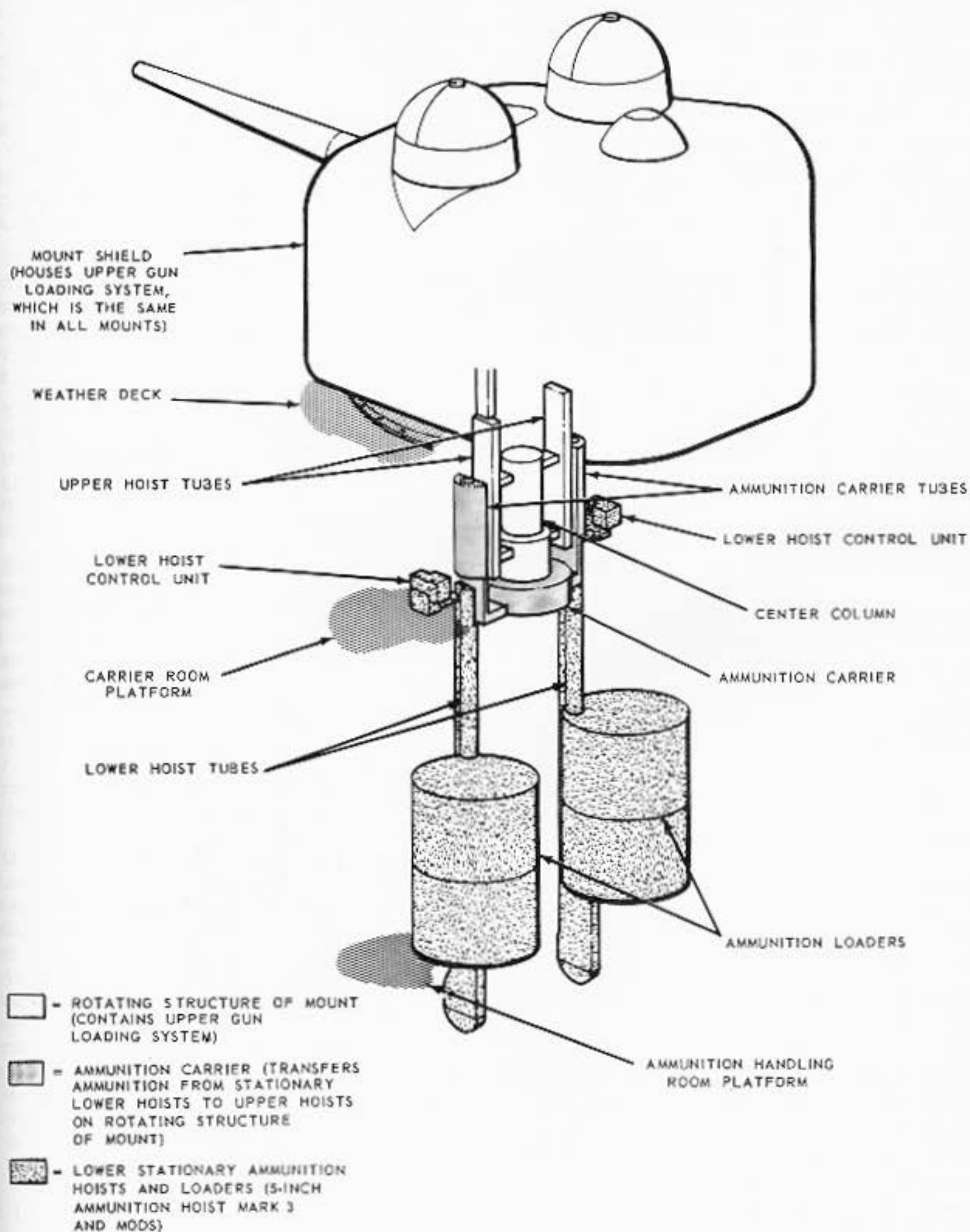
All mods of the mount have the same basic design. The only major difference in the mount installations (except in the mod 9 and higher) is the design of the lower ammunition hoists and ammunition carrier. In the mods 1-6 mounts, the lower hoists and carrier are completely different from those installed in the Mods 7-8 mounts. The difference is clearly illustrated in figures 5-37 and 5-38.

LOWER HOISTS AND CARRIER.—In some mods (fig. 5-37), the lower hoists are straight and terminate directly under the tubes of the ammunition carrier. These hoists are cycled by control units that are operated by hydraulic pressure from an accumulator system. The hoist cycles are initiated by relay actuators in the control units.

In this hoist design, the rounds contained by the hoists move directly upward from the tops of the hoist tubes into the carrier tubes. When the carrier is loaded, it rotates to the upper hoists where the carrier ejectors transfer the rounds from the carrier tubes to the lower hoist tubes.

In other mods (fig. 5-38), some of the lower hoists are curved and some are straight, but each hoist has two ammunition handling tubes (one for hoisting, one for strikedown) and is operated by an electrically driven hydraulic power transmission which is stroked by a hydraulic servomechanism installed in a solenoid-operated control unit.

In this design, the hoist tubes are capped by transfer tubes located alongside the carrier tubes. The transfer tubes are units of the lower hoists and are operated by hydraulic pressure from an accumulator system.



84.73

Figure 5-37.—Lower hoists and carrier in 5''/54 Mk 42 mounts mods 1-6.

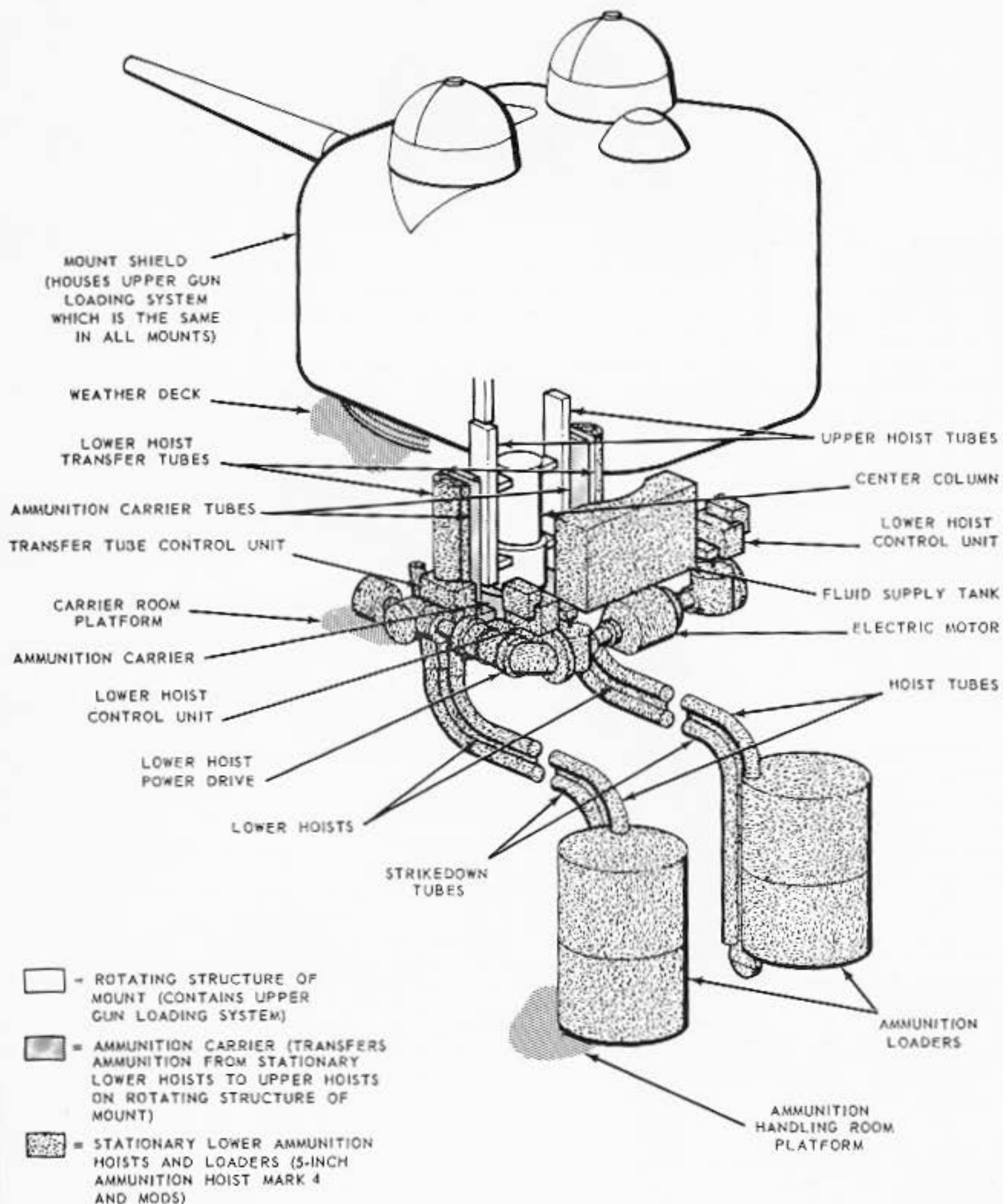


Figure 5-38.— Lower hoists and carrier in 5"/54 Mk 42 mounts mods 7-8.

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When the hoists are cycled, the rounds in the hoist tubes are elevated into the transfer tubes. From there they are ejected laterally into the opposite carrier tubes. The transfer tube ejectors then retract so that they will be in position to receive another pair of rounds from the lower hoists, and the carrier tube ejectors close over the rounds in the carrier tubes. The carrier then rotates to the upper hoists where the carrier ejectors transfer the rounds from the carrier tubes to the upper hoist tubes.

The strikedown tubes of the lower hoists are used for striking ammunition below to the handling room. When this is being done, the hoists are placed in local control so that they can be operated under power by means of hand-operated control cranks installed in the carrier room.

The cranks are arranged so that they can be used to stroke the hydraulic transmissions of their associated hoists. When either crank is turned, its hoist will cycle at a speed proportional to the rotational speed of the crank. When the crank is stopped, the hoist will stop.

The curved lower hoists are installed in mounts where the handling rooms are not located directly below the carrier rooms. This condition exists in all of the mounts in the CVA-class vessels and in the mounts in the DLG-class vessels.

The curve in the hoists of the forward DLG mount is very slight. In the CVA mounts, however, all of the hoists curve through two 90-degree angles and consist of vertical, curved, and horizontal tube sections.

MINOR DIFFERENCES IN MOUNT DESIGN.—Because of the variation in the vertical distance between the handling room and carrier room in different mount installations, the height of the lower hoists differs from mount to mount.

All mods of the mount have maximum gun elevation angles of 85 degrees and, with the exception of the CVA mounts, have 720 degrees of training freedom (360 degrees in either direction from the stowed position of the mount).

Maximum angles of gun depression vary in different mounts from 7.5 degrees to 15 degrees, as determined by structural characteristics of the vessel.

Gun Laying System

The mount itself can be operated in either remote or local control. No provision is made

for hand-powered operation. Handling drives are connected to the training and elevating gears, however, for stowing purposes and for use in connection with certain mount and gun alignment procedures involved in the installation of the train and elevation receiver-regulators.

The training and elevating gear assemblies are electrically controlled, hydraulically operated power drives that accurately position the mount and gun in response to electrical gun train and gun elevation orders. These orders can be applied to the train and elevation receiver-regulators from remote fire control or Gunar control stations (on certain mounts only), or from the one-man control units operated by the local control men in the mount.

The training gear assembly consists of a training gear, a power drive, and a receiver-regulator. The receiver-regulator converts the electrical gun train order signals into hydraulic control inputs to the power drive, which is an electrically driven, hydraulic power transmission. The output shaft of the power drive turns the training pinion, which drives the mount in train.

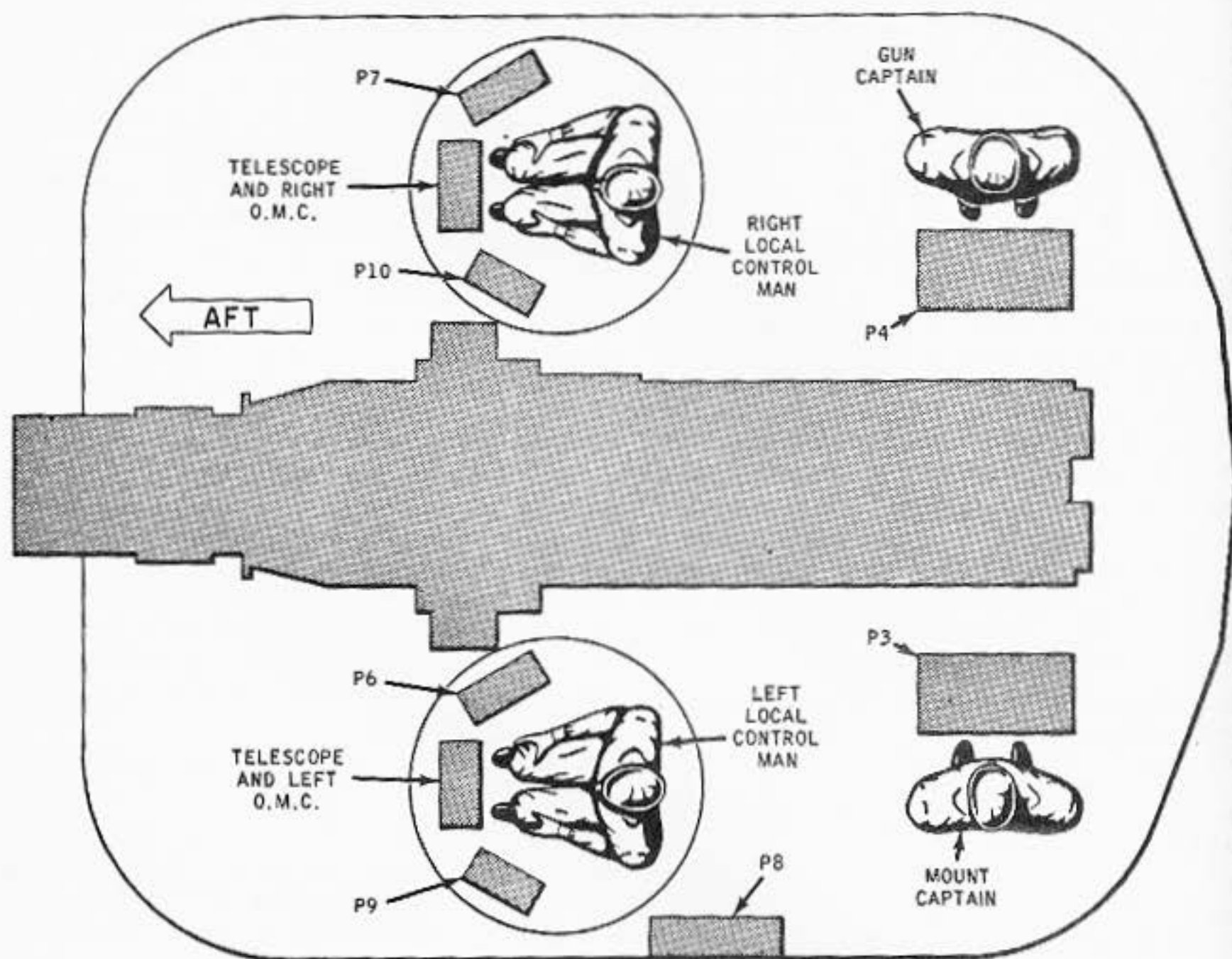
The elevating gear assembly consists of an elevating gear, a power drive, a receiver-regulator, and a firing cutout. The receiver-regulator converts the electrical gun elevation order signals into hydraulic control signals and applies them to the power drive, the drive turns the elevating pinion, and the pinion elevates or depresses the gun.

Both the training and the elevating gear assemblies are equipped with limit stop mechanisms. In the train receiver-regulator, the stop mechanism decelerates and stops the train drive as the mount approaches and reaches its limits of operation in either direction of train. The limit stop mechanism in the elevation receiver-regulator brakes the gun to a stop as it reaches its limits of travel in elevation or depression.

The firing cutout is connected by response gearing to the training and elevating pinion drive shafts, and operates switches in the firing circuit to prevent firing when the gun is pointed into danger sectors.

Personnel

The gun loading system and gun laying systems are separately controlled, and either system can



84.75

Figure 5-39.—5''/54 Mk 42 (mods 1-8) gun room stations and control panels.

be independently operated. Responsibility for control of the gun loading system is primarily delegated to the gun captain and the loader control man, whereas control of the gun laying system is the responsibility of the mount captain and the two local control men. Duties of the carrier control man are divided between the two systems. The duties of the gun crew (less ammunition handlers) for the 5''/54 are described below. Figure 5-39 illustrates the positions of the gun room crew and the control panels under their control.

MOUNT CAPTAIN.—The mount captain is in charge of the entire gun mount and receives all gun mount operation orders from weapons control via JP telephone circuits. He directs gun

loading, gun firing and gun laying operations of the mount from the P-3 panel, using either telephone, lights, or a combination of these as a means of communication. The P-3 panel, located in the aft left-hand part of the gun room, is used primarily to select the station to control the gun train and elevation power drives.

GUN CAPTAIN.—The gun captain is in charge of gun loading equipment and gun loading crew and is directly responsible to the mount captain. He controls gun loading by means of switches on the P-4 panel. The P-4 panel is located in the after end of the gun mount, on the side of the gun opposite the P-3 panel. This panel contains switches and lights that enable the gun captain

to control and monitor gun loading systems operation.

LOCAL CONTROL MEN.—The two local control men (one on the left and the other on the right side of the mount) operate the mount in local by means of telescopes, one-man control units, and the P-6, P-7, P-9, and P-10 control panels in the local control stations. The P-6 and P-7 panels contain the knobs, dials, switches, and lights necessary for sight setting and local control operations.

An auxiliary local control panel is also located at each local control station—P-9 in the left station and P-10 in the right. These panels are used to control the telescope window wipers, telescope shutter heater, and windshield defroster system of each local control station.

A one-man control (OMC) unit is located in each local control station. Either OMC unit can provide the gun train and elevation orders necessary for local control operation. The left OMC has control only when it is relinquished by the right local control man or when the mount captain selects the left station by means of a switch on the P-3 panel.

CARRIER ROOM CONTROL MAN.—He controls the mount's electrical power supply system from the P-1 and P-2 panels located in the carrier control room. The P-1 panel contains the 440-volt electrical circuits that carry power to the various units of the entire gun mount system. Lights located on the face of this panel indicate when power is available to the system and when motors are running on the gun mount. The P-2 panel houses amplifiers for the fuze setters, parallax systems, and train and elevation power drives. On the face of this panel are switches and light arrangements that function as a means of communication between the gun captain and the carrier control man.

LOADER CONTROL MAN.—The loader control man is in charge of the handling room crew and ammunition handling equipment. He controls the loader drums by means of switches on the P-5 panel when the loaders are being operated in the manual power mode. The P-5 control panel, located between the A and B loader drums, enables the loader control man (with permission from the gun captain) to operate the loader drums in manual power operation. Normally, manual power operation is used during loading,

unloading, exercising, or testing of the loader drums.

One Side Operation

The gun captain can select one-side, automatic power operation of the loading system when a casualty occurs to some units of the loading system. The procedures necessary for one-side operation vary according to the unit of the loading system that is inoperative. Depending upon the nature of the casualty, the gun captain can deactivate one side of the gun loading system or instruct the carrier room control man to mechanically deactivate the malfunctioning unit. One-side operation (using one hoist) will reduce the gun rate of fire to about 20 rounds per minute.

One advantage of the gun loading system used with the 5"/54 gun mount is that once the drums are loaded the ammunition handling crew need not be on station for automatic gun firing operation. This enables a ship's weapon system to function during a condition of readiness with a minimum number of personnel. The ammunition handling crew, which consists of four powder men and four projectile men, can be utilized for other duties in the event of personnel casualties. The handling crew is needed only to replenish the 40 rounds of ammunition (in the loader drums) after a firing mission, or the men can be left at their station if more than 40 rounds are to be used.

5"/54 MK 42 MOD 9

The Mk 42 Mod 9 was designed for the main gun battery of DE 1053 class ships and is similar in many respects to the previous mods. However, three major differences exist between them. The big differences are in the train and elevation receiver-regulators, the fuze setters, and the electrical control system. These changes greatly reduced the weight of the mount. As an example, the weight of the fuze setter and its associated amplifiers alone was reduced from 432 pounds to 53 pounds (a reduction of 379 pounds).

The electrical control system was completely redesigned. The mount captain's P-3 panel and the gun captain's P-4 panel (part of earlier mods) have been eliminated. A new control panel (EP2), operated by the mount captain and located in the carrier room (fig. 5-40), now contain all controls previously embodied in the P-3 and P-4 panels. The local

5"/54 MK 45

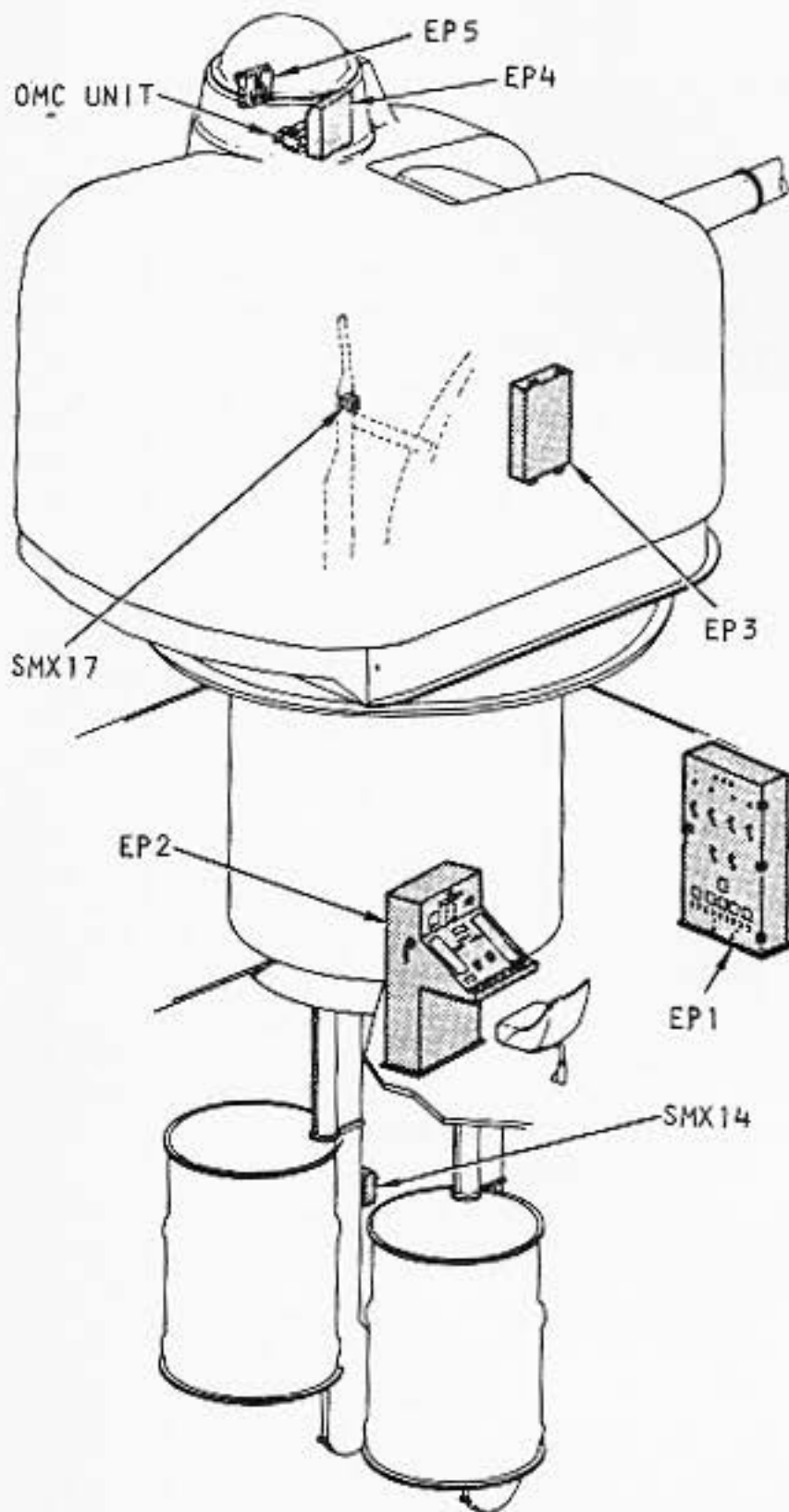


Figure 5-40.—5"/54 Mk 42 gun mount control panels.

control station on the right side of the mount was eliminated. As a result, the number of on mount personnel was reduced from four to two (the gun captain and the OMC operator).

The design changes, in addition to weight reduction, greatly improved the reliability and maintainability of the receiver-regulators and increased the accuracy of the fuze setter.

5"/54 Mk 45 light weight gun mount (fig. 5-41) offers outstanding reliability and maintainability and is served by a minimum complement of personnel. The mount is operated, monitored, and exercised remotely; personnel do not enter the gun house except for maintenance. A safety key located on the EP2 panel disables all circuits before the crew enters the gun house. One mount operator performs mount switching functions (as directed) for complete gun mount operation. The ammunition handlers load projectiles and powder cases into the automatic loading station. The mount loader drum holds 20 rounds in ready service. The loading station permits replenishing the loader drum during sustained firing without interrupting the fire mission. The load and fire cycle can be interrupted if a special-purpose type of ammunition, such as star shell, is to be used, or if a misfire-clearing charge is needed.

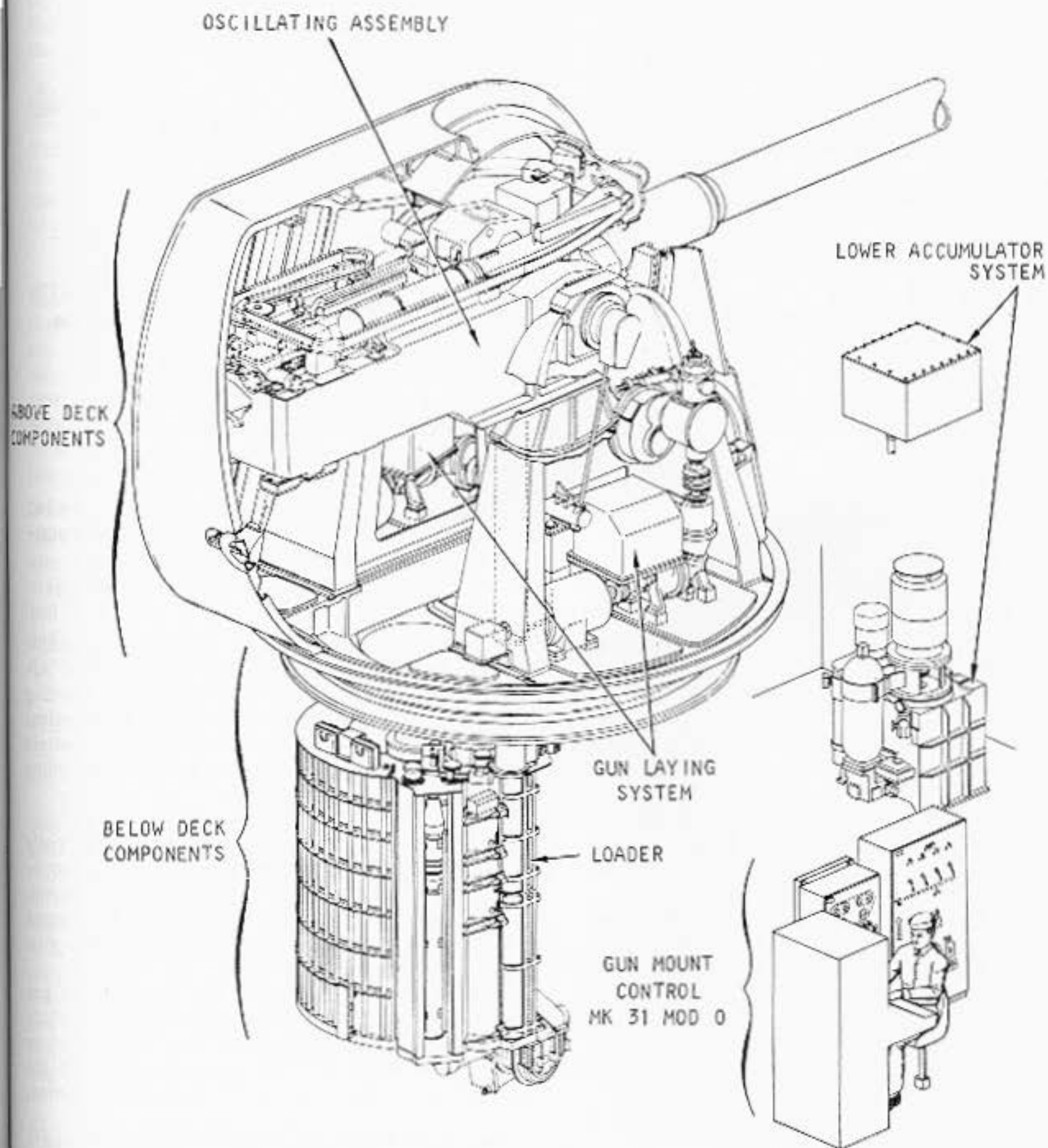
The mount design emphasizes safety. The crew needs not enter the gunhouse to extract misfires. Misfires can be extracted automatically and rapidly. By loading a clearing charge, the gun can be cleared and returned to service without personnel entering the gunhouse. Unloading is also accomplished automatically. The rounds not fired are returned to the hoist unload doors in the loader drum.

Gun Mount Components

The mount has two physical component groups: the lower structure (below deck) and the upper structure (above deck). The lower structure delivers an uninterrupted flow of ammunition to the upper structure. It includes the mount control system, loader drum, fuze setter, hoist, and lower accumulator system. The upper structure includes the stand, carriage, cradle, slide, gun barrel, upper accumulator system, gun laying system, and shield.

CONTROL SYSTEM

The mount control system consists of two control panels—the EP1 power panel and the EP2 control panel. The power panel (EP1) receives power from the ship's supply and distributes it within the mount and other panels. The control panel (EP2) permits selecting the



84.83

Figure 5-41. — 5"/54 Mk 45 gun mount (general arrangement).

various modes of mount operation and serves as the test board and local control for the gun laying system and the fuze setter.

The gun laying system has separate train and elevation power drive assemblies, which position the gun in train and elevation respectively. These assemblies are controlled electrically and operated hydraulically in response to orders from either a remote fire control system or the on-mount local control system. A firing cutout system opens the firing circuit whenever the gun is positioned to a nonfiring zone.

The mount local control system permits total system exercise and test. One man can activate and exercise the mount and verify mount operation ability in less than 5 minutes. A troubleshooting status board located within the EP2 panel is used in conjunction with indicating lights and dials to pinpoint the cause of mount stoppage. Standardized parts are used widely, and many of the amplifiers and logic printed circuit cards are physically and functionally interchangeable.

TURRETS

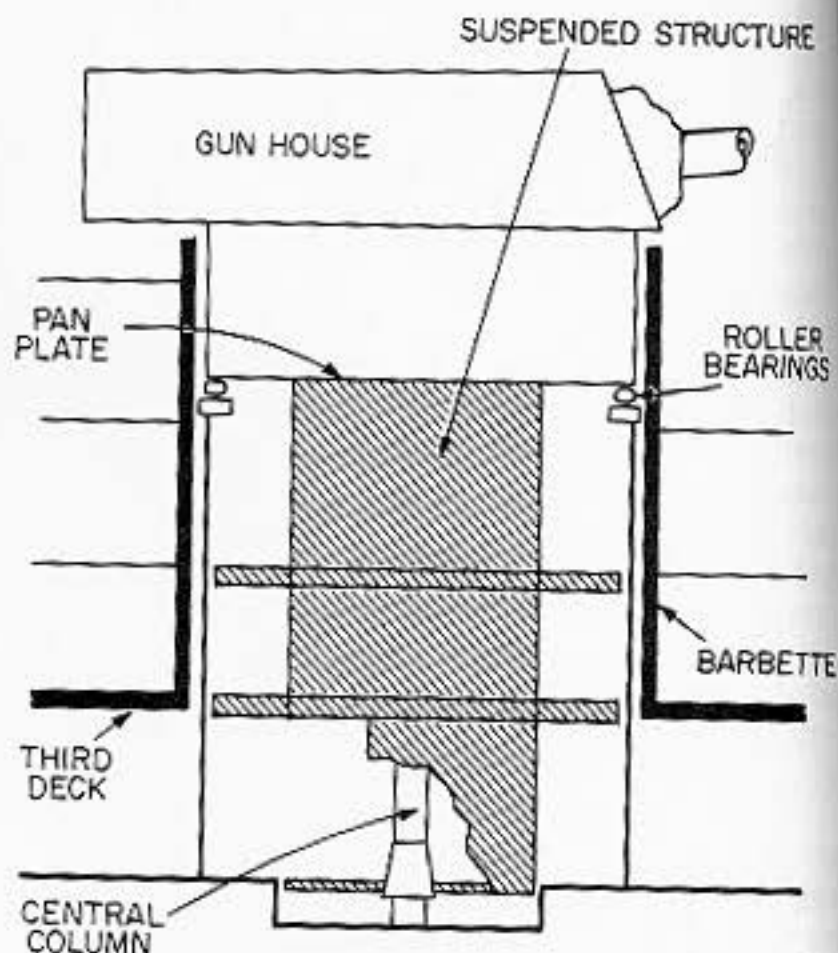
Turrets are heavy armored gun structures of at least 6-inch caliber and usually equipped with 3 guns. They are the primary offensive armament of conventional cruisers and battleships (most of which are in the reserve fleet). They are located on the centerline so that they can fire to either beam. Each gun of a multiple gun turret has a separate slide mounted in trunnion bearings and is arranged for either independent or joint elevation movement.

Some similarities exist between gun mounts and turrets. The major difference between them is that the turret's structure is protected by armor plate.

The gunhouse, or turret proper (part that shows above deck), is mounted on roller bearings within the armored structure (barbette); it is rotated by an electric-hydraulic power drive that can be controlled automatically or manually. The barbette surrounds the turret's rotating structure below the gunhouse and extends to the ship's armored decks.

TURRET STRUCTURAL ARRANGEMENT

The major parts of a typical turret are illustrated in figure 5-42. Each part is made



84.141

Figure 5-42.—Turret structure fixed and rotating elements.

up of separate levels that contain the major assemblies and subassemblies of a turret. Although a turret's construction will vary according to its function and differ in many mechanical details, generally its installations will contain all or some of the levels shown in the preceding figure and discussed below.

The first level (gunhouse) contains the turret's fire control and communication equipment necessary for turret control. Each gun compartment, or gun room, contains the power equipment necessary to operate and service each gun.

The second level, called the pan floor or pan plate, contains the pockets (gun pits) into which the breech end of the guns are depressed as the gun elevates. It also contains some of the machinery for the train and elevation systems.

The third level is the machinery floor where most of the power equipment for turret operation is located. In some turret systems the stations for gun laying, both in train and elevation, are also located on this level. In most

turrets, however, these stations are located within the gunhouse.

The next three levels are the upper and lower projectile flats, and the powder handling platform. The projectiles stowed on the projectile flats are loaded into hoists and lifted up into the gunhouse. The powder handling platform is surrounded by powder magazines which stow either bag or case type propelling charges. These charges are passed from the magazines, through flameproof openings called powder scuttles into the handling platform (room). The charges are loaded into elevator type hoists which deliver them to the gunroom.

The center column (fig. 5-42) and the bulkhead which surrounds it are fastened to the pan floor (plate). They extend through, and support the three levels of the suspended structure. The suspended structure contains the last three levels mentioned above and is part of the rotating structure of the turret. The combined weight of the rotating structure is supported by the roller bearings located on the pan plate.

The general principles of a gun mount's major components discussed early in this chapter, also apply to the turret's components with one major difference. In a turret, the slide, housing, and gun barrel are supported by girders (fig. 5-43). They serve the same purpose as a gun mount's carriage cheeks shown in figure 5-3.

CLASSIFICATION AND TYPES OF TURRETS

Turrets can be classified by the type of guns they employ, either case or bag type guns. Case guns are those in which the propelling charge is encased within a metal cartridge case; a bag gun is one in which the propelling charge is encased within a fabric container called a powder bag.

Four different types of turret installations are on present Navy ships, active and reserve fleet. Two of these turrets (6"/47 and 8"/55 rapidfire) are equipped with case guns and two (8"/55 bag gun and 16"/50 bag gun) are equipped with bag guns.

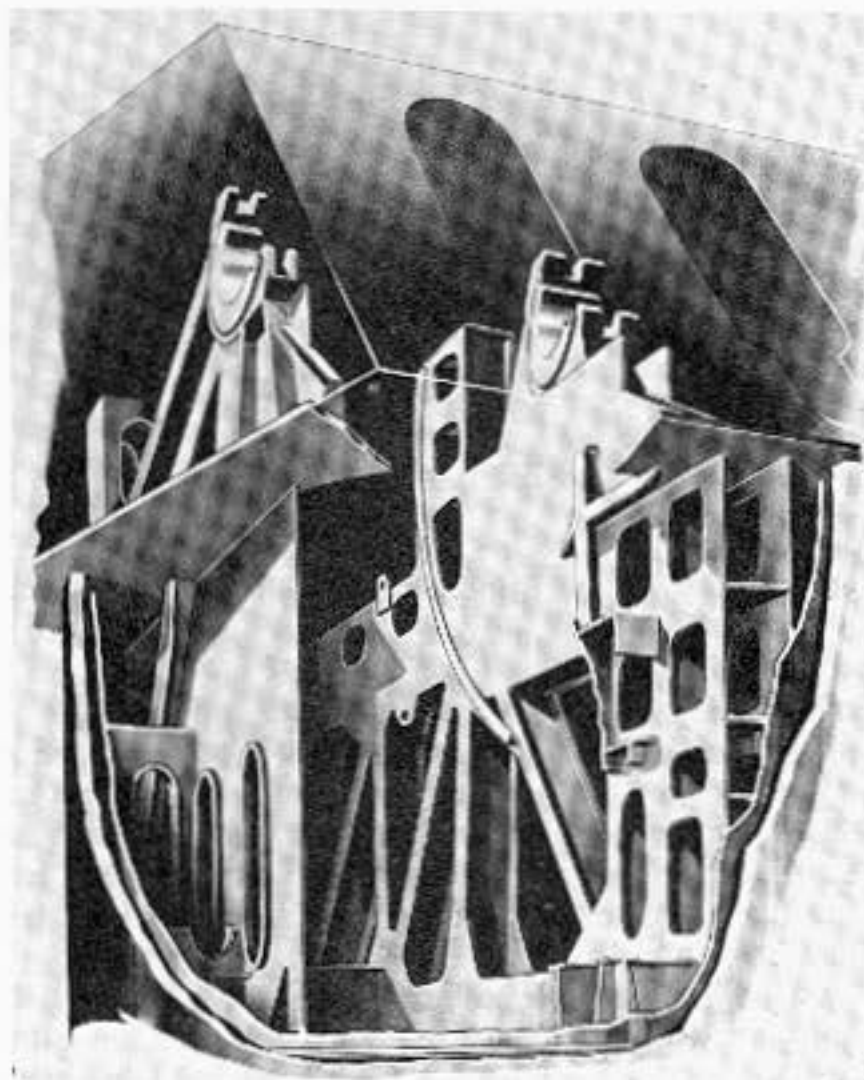
REPRESENTATIVE TURRETS

Most ships having turrets are in the reserve fleet. Therefore, turrets will be discussed only briefly.

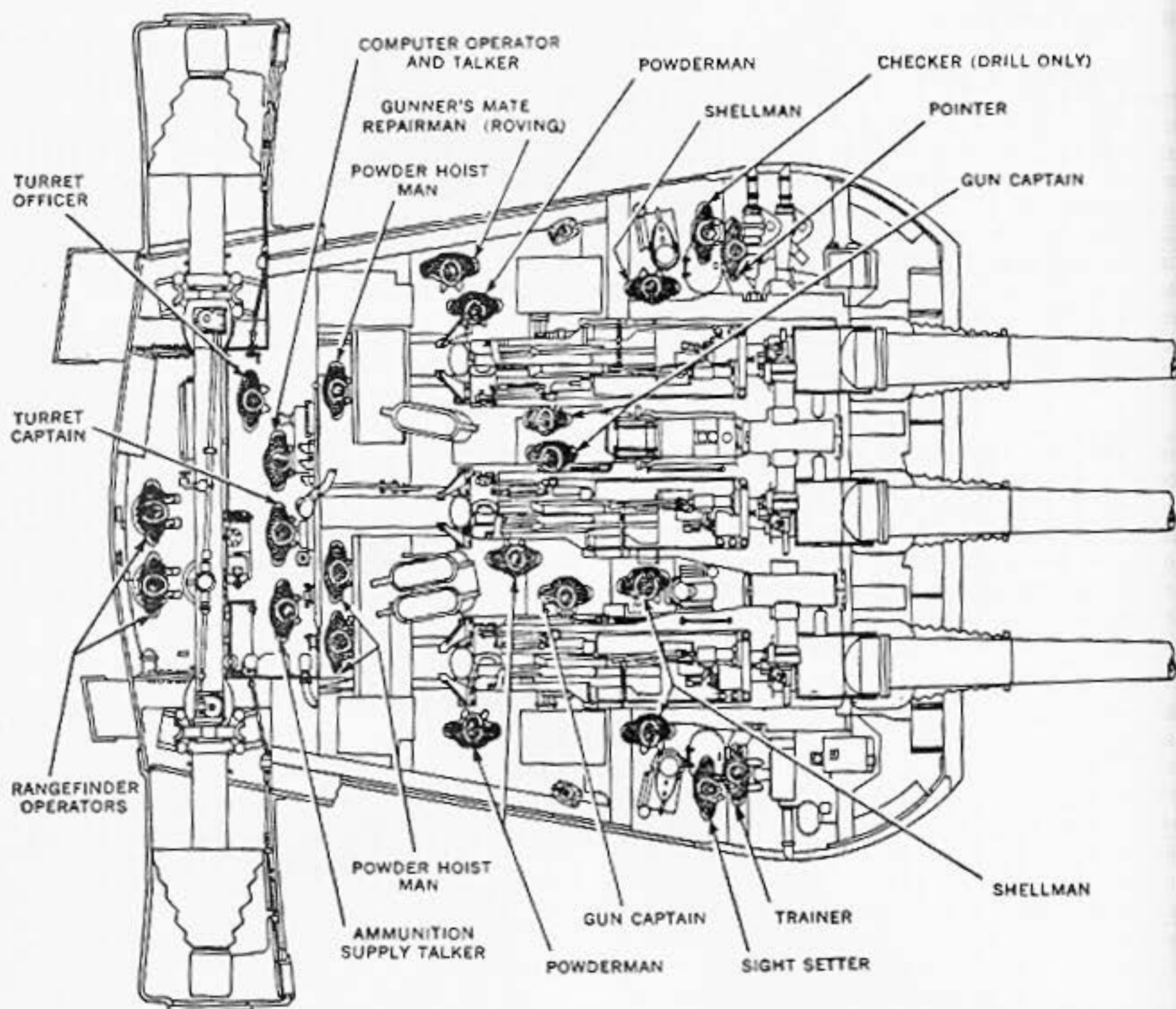
Case-Gun Turret

A 6-inch caliber three-gun turret is divided into four manned spaces and requires forty men to man the various battle stations for normal turret operation. Twenty-two crew members are stationed within the gunhouse (fig. 5-44) — sixteen in the turret's gun compartment and six in the turret officer's booth. The men stationed in the gun compartment are: (1) two gun-laying operators, (2) a sightsetter, (3) three gun operators (gun captains), (4) three powder hoist men, (5) three powdermen, (6) three shellmen, and (7) a gunner's mate repairman. Stationed in the turret officer's booth are four turret controlmen—the turret officer, turret captain, computer operator and ammunition supply talker—and two rangefinder operators. (Rangefinder operators are not required for turrets without rangefinders.)

The duties of the turret's crew (except for the computer operator, ammunition supply talker, and rangefinder operators) are very similar to



84.142
Figure 5-43. — Gun girders.



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Figure 5-44. — Turret personnel arrangement. Gun house stations.

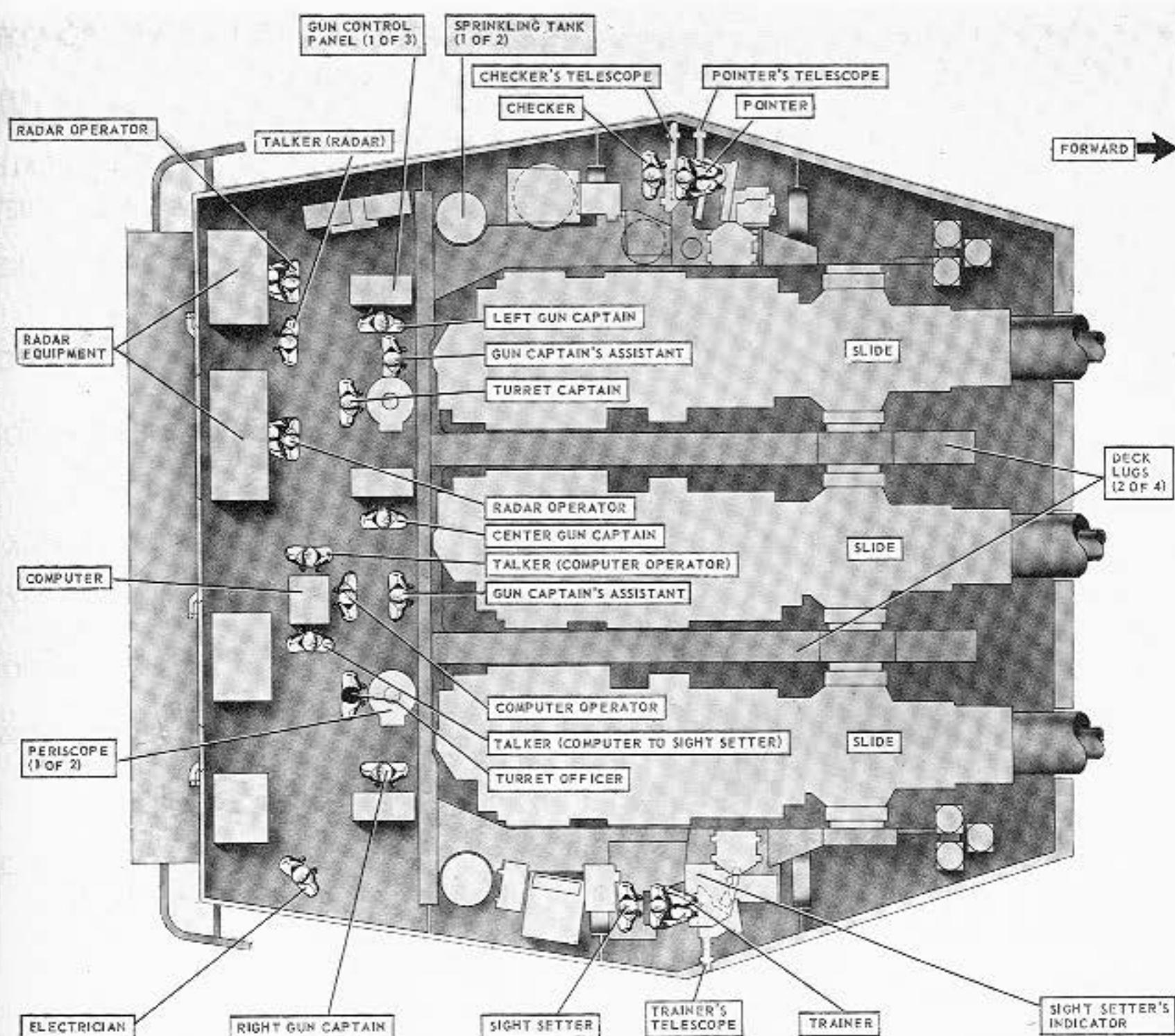
the duties of a mount's crew. The duties of turret officer and turret captain correspond to those of the mount captain and his assistant. Other stations compare accordingly. The turret's ammunition supply talker transmits orders from the turret officer or turret captain to ammunition handlers and loaders.

The computer operator is responsible for the computation of the fire control problem when the turret is in local or hand control. He introduces certain inputs into the auxiliary computer to produce sight angle and sight deflection, which are transmitted to the sightsetter by phone.

The rangefinder operators are both in standby duty when the turret is in automatic control. In local or hand control, they provide ranges to designated targets. They are also called on to spot in range and make initial target angle and speed estimates.

Seven men are stationed on the projectile handling level and ten are in the powder handling room.

The 8" caliber three-gun turret is installed in Salem class heavy cruisers. Although the



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Figure 5-45.—8"/55 rapid-fire turret. Gunhouse crew stations.

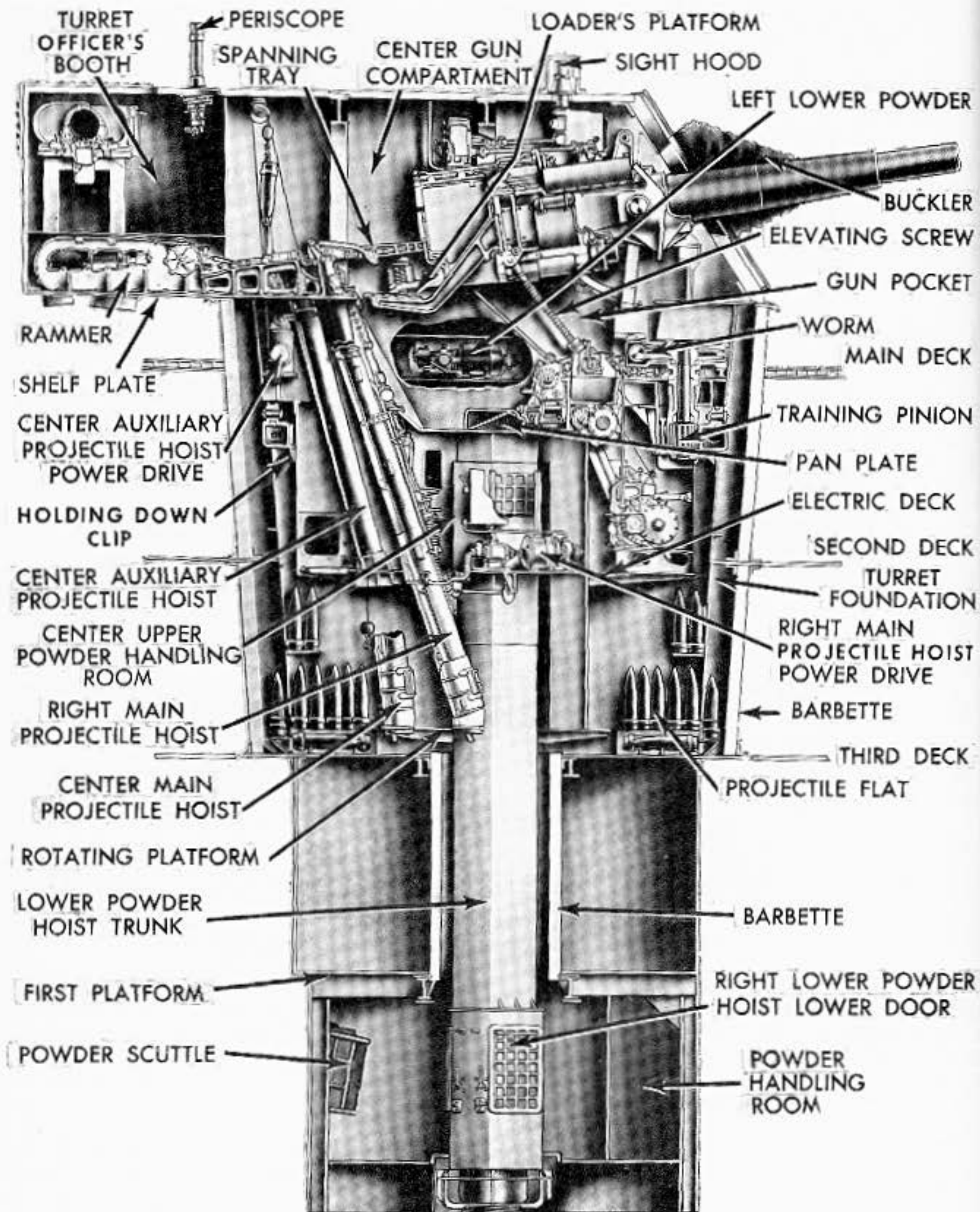
foundation structure, barbette, and magazine are of a standard turret design, the ammunition loading system is an entirely new design. The guns operate automatically and require no shellmen or powdermen within the gun compartment. The turret has automatic fuze setting and radar equipment instead of optical rangefinders.

Forty-four men are required to man the battle stations of this turret installation, seventeen in the gunhouse and twenty seven in the levels below the gunhouse. The gunhouse crew

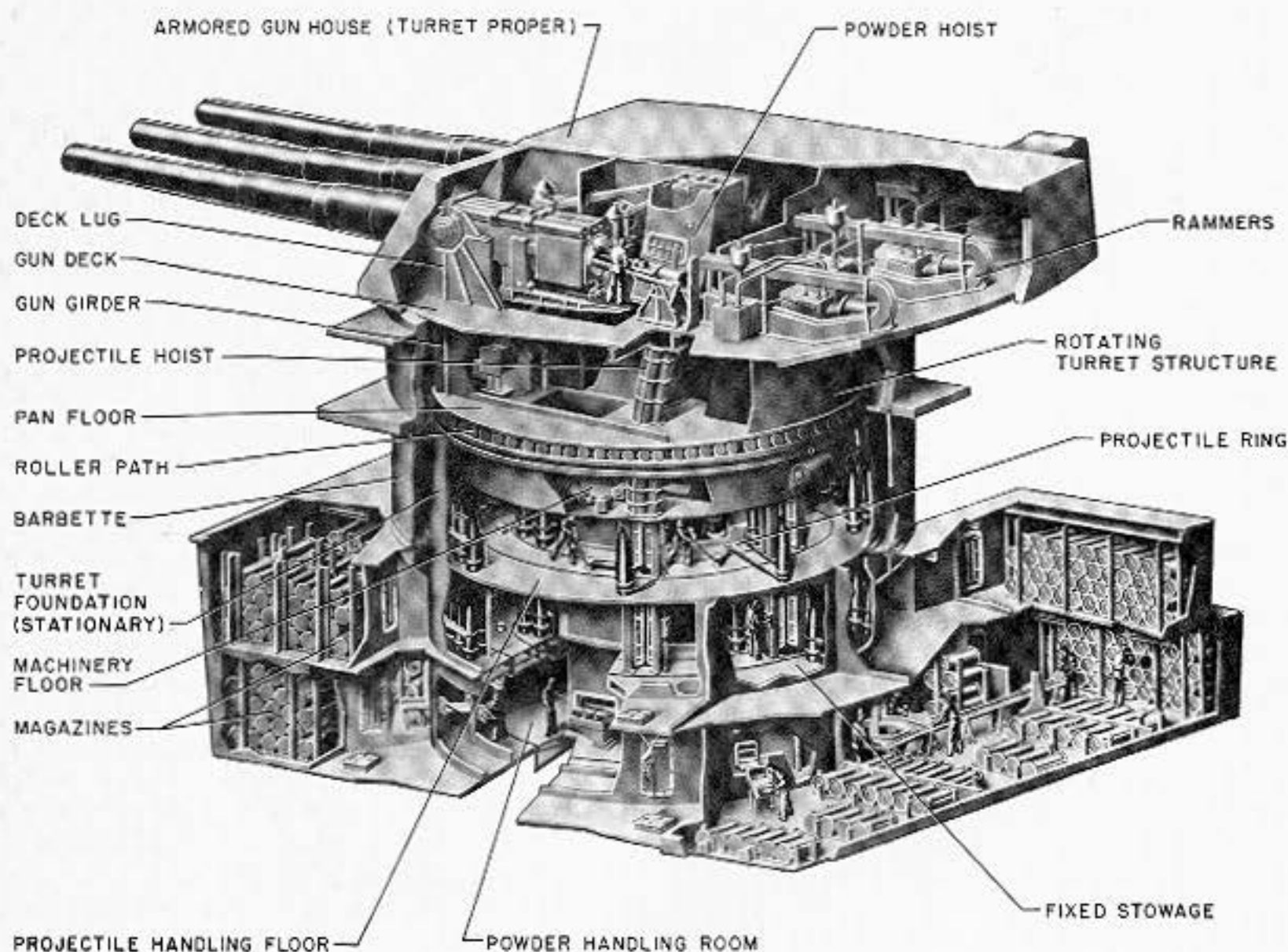
members are shown in figure 5-45. (The checker is a member of the crew in training operations only; his station is not manned in battle action.)

Bag-Gun Turret

Bag-guns differ from case-guns in their methods of handling, transferring, and loading ammunition. Since bag type ammunition needs greater safety in handling, each gun within the gunhouse and the powder hoist which services each gun are arranged in separate flameproof



84.91
Figure 5-46. — 8"/55 bag-gun turret.



110.53.2

Figure 5-47.—Cutaway view of 16-inch turret.

compartments and structures. A flame seal located at the upper end of each powder hoist isolates the lower powder handling rooms from each gun compartment.

Turrets equipped with bag guns are essentially similar. The 8-inch and 16-inch turrets

differ in many mechanical details, but in general their installations and equipment perform the same basic function.

Cutaway views of the 8-inch and the 16-inch turrets are shown in figures 5-46 and 5-47 respectively.

CHAPTER 6

GUN WEAPON SYSTEMS

You already know, from reading earlier chapters in this text, that guns were in use hundreds of years before the weapon system concept was dreamed of. Guns were, with only minor exceptions, THE weapons (in various shapes and sizes) for all naval warfare until almost the beginning of the 20th century. As guns improved in accuracy, rate of fire, and range, the rough-and-ready methods that had hitherto sufficed for placing gun projectiles with maximum effect were refined until modern techniques and equipment for fire control were developed. As submarines and aircraft added more weapons to the naval arsenal, as well as new varieties of targets for the weapons to engage, the gun lost its primacy as the principal naval weapon and became what it is today—one of the several major classes of weapons, each with its characteristic range of applications and types.

The weapon system concept as applied to guns and their associated equipment differs somewhat from its application to such newer weapon systems as guided missiles and their associated equipment. Missile systems are characteristically integrated—they are conceived, engineered, and designed as systems. Although gun weapon systems function effectively as systems, they are more flexible and less integrated. Thus, a given fire control system may function equally well with any of several types of gun mount, or a gun mount may continue to function with an alternate fire control system or even with only the sights in the gun mount if its primary fire control system is knocked out.

ELEMENTS OF A GUN WEAPON SYSTEM

Functionally a gun weapon system includes the following elements:

1. A fire control system.

2. One or more gun mounts organized as a BATTERY.
3. Ammunition supply arrangements.

Since it is inherently flexible both in function and in the equipment that goes to make it up, a gun weapon system is not invariably composed of the same elements—in fact, a combination of the elements that make up a system may vary during a single exercise or battle action. However, a given combination is generally recognized as best—that is the PRIMARY arrangement—and others (SECONDARY arrangements) may be substituted if required by battle casualties or for training purposes. This chapter will concentrate on the preferred combinations that make up the primary systems.

Today all but a few gun weapon systems are either primarily designed for action against air targets (these are antiaircraft or AA systems), or are equally well adapted for engaging air or surface targets (these are dual purpose or DP systems). A few systems designed primarily to engage surface targets can be adapted for certain antiaircraft applications, but these will not be the focus of attention in this text. This chapter is mainly concerned with a typical dual-purpose and a typical antiaircraft gun weapon system.

GUN BATTERIES

The guns on any naval vessel are organized into groups or batteries, each consisting of several gun mounts of similar size and ballistic characteristics. This simplifies the control of gunfire, the supply of ammunition, and maintenance. The size and number of guns in a battery depends on the type of ship.

There are several ways to classify gun batteries aboard ship. The simplest is to use the bore diameter (caliber) and the number of calibers as we have done in chapter 5. It

practice, the number of calibers is very often omitted in the ship's battery designations, at least when referred to by members of the crew. Thus, a battery of 6"/47 caliber turrets is a 6" battery, and so on. The length of bore in a 5" battery is also dropped from the designation because a ship will have either a 5"/38 or a 5"/54 battery, but not both. Keep in mind that these shortened terms are valid only within your ship or for ships with the same armament. The batteries must be accurately identified in other circumstances. The 5"/54 Mk 42 and the 3"/50 rapid fire, described in chapter 5, must be further identified within their caliber because of the operating differences between these mounts and the older 5"/54 and 3"/50 mounts. A few cruisers (most, if not all, of which are in the reserve fleet) have rapid fire 6-inch or 8-inch turrets that require more identification since they differ from their slow-fire prototypes. The 40-mm and 20-mm guns are not described in terms of their number of calibers; they are designated by bore diameter only, as are other guns smaller than 3-inch.

Batteries also are classified as main, secondary, and machinegun batteries, depending on the type of ship in which they are mounted. Traditionally, the largest caliber of guns on board is the main battery; the next largest, the secondary battery; and the remaining installed guns are either heavy or light machinegun batteries. Thus, a 5" battery is the main battery of a destroyer, but only the secondary battery of a cruiser. This method of classifying becomes further complicated when ships sometimes extend the term "main battery" to mean the weapon of greatest potential effect; for example, the planes of an aircraft carrier, or the torpedoes of a submarine. The terms "main armament" and "secondary armament" are used extensively in call-for-fire gunfire support missions.

The last (and probably the best) method classifies batteries according to their service application as follows:

1. **SURFACE BATTERY**—a battery that is designed primarily to combat surface targets (including shore-bombardment or gunfire support). This battery, sometimes called single purpose, is comprised of 6" or 8" turrets mounted on cruisers. (Turrets can be used against air targets, but this is not their primary application.)

2. **DUAL PURPOSE BATTERY**—a battery that is designed to combat both air and surface targets (including gunfire support). Dual purpose

batteries are 5" guns only. Dual purpose relates not so much to the 5" gun's versatility, as it does to the dual-computing devices and methods in the fire control system.

3. **AA BATTERY**—a battery that is designed primarily to combat air targets. This battery normally has 3" guns. The 3" gun can also be used against surface targets, and for "direct fire" missions in gunfire support.

FIRE CONTROL IN GUN WEAPON SYSTEMS

In any weapon system the fire control problem is essentially that of getting the weapon or projectile to hit the target and explode, or at least to explode when the target and weapon or projectile approach close enough for maximum damaging effect. In gun weapon systems the problem is to lay (aim) the gun in such a way that the projectile will hit or approach close to the target. In some other types of weapon systems the weapon is self-propelled and contains guidance equipment so that it is capable of homing on the target (i.e., it can detect the target and follow it, ultimately catching up with it), or other guidance methods may be available. This is not true of gun weapon systems. Once the projectile has left the gun muzzle, nothing further can be done to affect its course. The gun's fire control problem must be solved before the gun fires.

In this section we shall discuss basic interior ballistics, variables in the fire control problem, the elements of fire control systems, and finally the process by which these elements are used in solving the fire control problem.

BASIC INTERIOR BALLISTICS

First of all, what is ballistics? Ballistics is the science of the motion of projectiles. It is divided into two branches, interior and exterior ballistics. Interior ballistics is that branch of the science which deals with the motion of the projectile while it is in the gun. The initial velocity (I.V.) of the projectile is a result of the forces involved in the general term, interior ballistics. Exterior ballistics pertains to the projectile after it leaves the gun. Obviously I.V. is the one value common to both interior and exterior ballistics.

Gun design is essentially a compromise. The gunner wants maximum I.V. for great range and flat trajectory; the designer must consider

the strength of his gun and desires minimum wear and erosion. Interior ballistics includes the study of (1) the combustion of the powder, (2) the pressure developed within the gun, (3) the variations in pressures and velocities with changes in any of the "conditions of loading," and (4) erosion of the bore.

Propellants and Burning Rate

Propelling charges are designed to burn in the chamber of the gun in such a way that they will develop maximum projectile velocity without excessive heat, pressure, or erosion. Ideally, the most efficient propellant for a gun would be so balanced that the charge is entirely consumed immediately before the projectile leaves the muzzle.

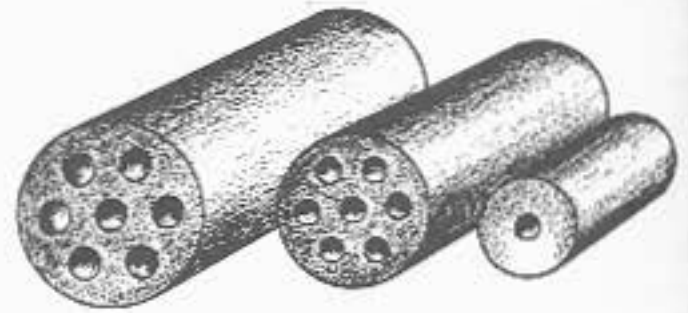
To approach this ideal, propellant burning rate must be controlled, so that the propellant will be suited to the specific gun in which it is to be used. The dominant factor in determining burning rate of a given propellant composition is the surface area per unit weight of propellant. The greater the area per unit weight, the faster the burning rate. (Other but less significant factors include the percentage of nitration, moisture content, content of volatiles, and the stabilizer used.)

As you know, gun propellant compositions are manufactured as homogeneous cylindrical grains of uniform diameter, length, and number of perforations (fig. 6-1), with larger grains for larger caliber guns. For a given muzzle velocity, larger caliber guns require a slower burning propellant than smaller caliber guns, since the distance the projectile must travel to the muzzle is proportionately longer and the powder must burn for a longer time. Other things being equal, larger grains have smaller area per unit weight, hence slower burning rate.

Propellant powder grains for guns 40-mm and larger have 7 perforations. Since burning rate climbs rapidly in smaller size powder grains, there is only one perforation, or none at all, in grains for calibers smaller than 40-mm.

A propellant's potential is the total work that the gases of combustion could perform while expanding from the solid state to the space they would occupy when fully expanded to atmospheric pressure and when cooled to a specified temperature.

In the average conventional gun, some 60 percent of the potential disappears in muzzle



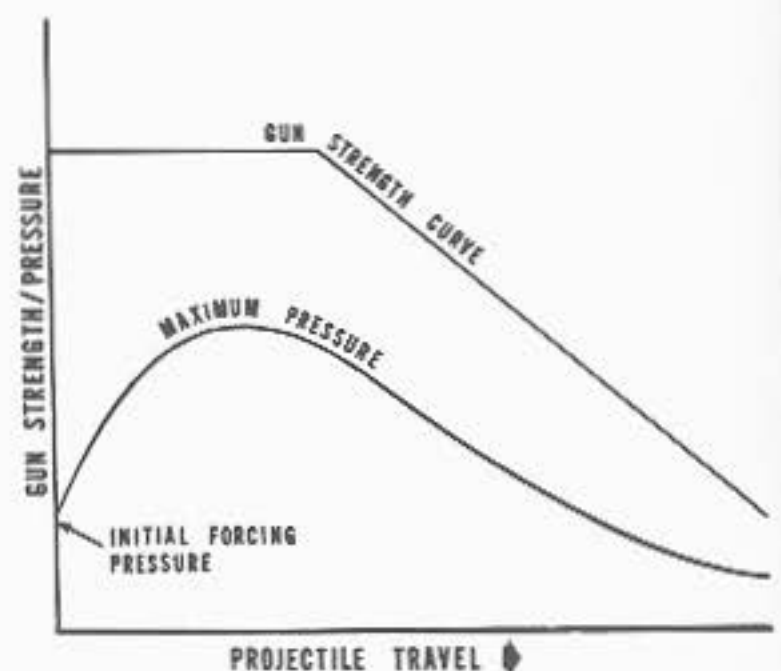
53.144

Figure 6-1.—Perforated propellant powder grains.

loss; 30 percent is transmitted to the projectile, and all other losses—such as heating the projectile and gun, causing the gun to recoil, and so forth—amount to about 10 percent.

Gun Strength Vs. Propellant Pressure Relationships

Figure 6-2 illustrates a basic principle of gun design. The figure may be taken as typical of the strength-pressure relationship in modern guns. Note that the high breech strength is carried well forward of the point of maximum pressure. The gun strength at every point must exceed the powder pressure at that point by an amount that will provide a suitable margin of safety.



110.57

Figure 6-2.—Typical gun strength and pressure curves.

The curve as it appears in figure 6-2 shows pressure beginning at a value well above zero. This indicates the pressure build-up that occurs after the propelling charge begins to burn but before the projectile begins to move. (The x-axis in the figure represents projectile movement in the bore, not time or bore length.) The projectile begins to move only after the propellant gas reaches the initial forcing pressure required to initiate movement of the projectile in spite of projectile inertia and the engagement of the rotating band in the rifling.

Note that the gun strength curve is represented as a straight horizontal line above the area between the point of initial forcing pressure and the point of maximum pressure. It does not vary in parallel with pressure curve. The reason is that the same pressure that the expanding gases exert against the base of the projectile is exerted equally against all interior surfaces of the gun behind the projectile. Hence the breech part of the barrel must be designed for the maximum stress to be imposed.

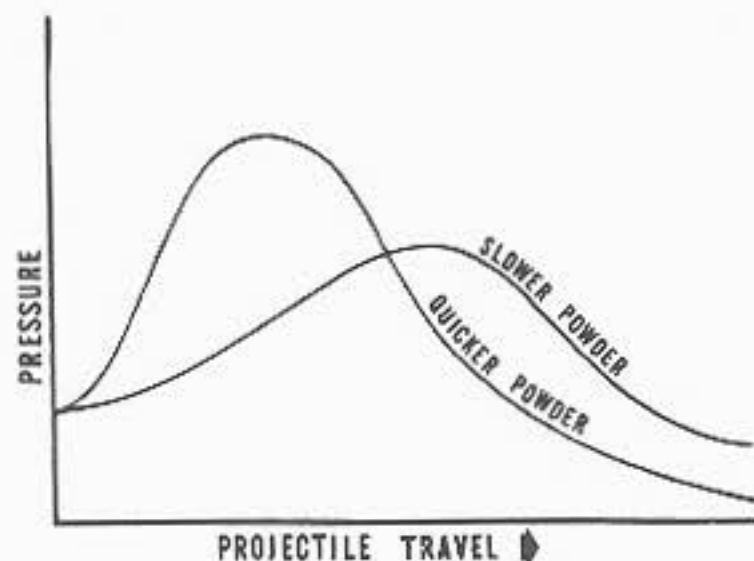
After the projectile passes the point of maximum pressure, it continues to be accelerated by gas pressure until it leaves the muzzle. The total area under the curve, up to the point where the projectile leaves the gun, is a rough measure of initial velocity, and the pressure remaining at the muzzle is an indication of the muzzle loss. A high muzzle pressure increases muzzle flash.

Changes In "Conditions of Loading"

By "conditions of loading" are meant the powder used, the weight of charge, the density of loading, the volume and form of the powder chamber, and the weight of the projectile.

POWDER USED AND WEIGHT OF CHARGE.—

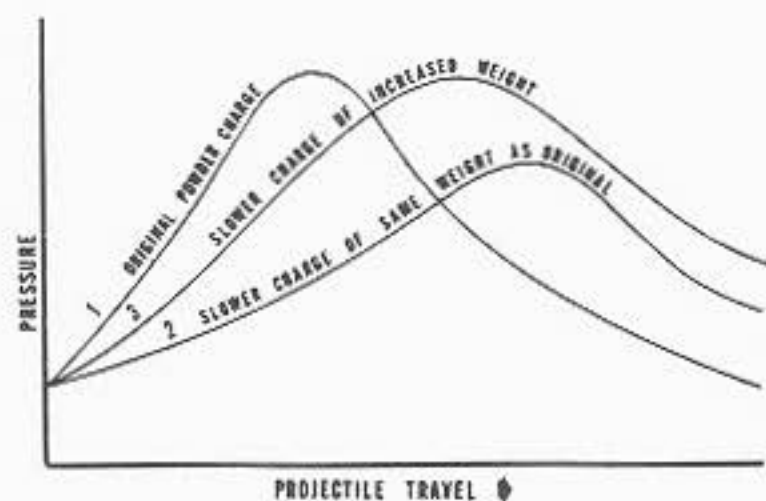
Powders are termed quick and slow in reference to their rate of combustion in a particular gun. For instance, a small-grain powder is quicker than a larger grain of the same shape, since all the grains would be consumed in a shorter time. Not only will the larger grain increase the time required for burning the charge, but it will also cause maximum pressure to be lower and to be reached later in the travel of the projectile. The gun pressure curves shown in figure 6-3 compare slow powders and quick powders where the same weight of charge was used.



110.58
Figure 6-3.—Typical gun pressure curves showing variations due to quickness of powder, same weight of charge.

Within limits, the muzzle velocity for a particular gun may be increased without causing excessive pressure by increasing the size of the charge and at the same time using a powder that burns more slowly. See figure 6-4.

DENSITY OF LOADING.—Density of loading is the ratio of the weight of the charge of powder to that of the volume of water which, at standard temperature, would fill the powder chamber. It is a measure of the amount of space in which the gases of combustion may expand before the projectile begins to move.



110.59
Figure 6-4.—Typical gun pressure curves showing methods of obtaining increased muzzle velocity in a gun without increasing maximum pressure.

A high density of loading leaves but little space for initial expansion; consequently pressure builds up rapidly. The maximum pressure behind the projectile is reached early in the projectile's movement through the bore. With lower density of loading, more expansion of the gases may take place before the projectile starts to move. The maximum pressure is achieved later, and this maximum is lower than that with high density of loading. (Compare the curves in figure 6-5.) Other factors remaining equal, increased density of loading increases maximum pressure, muzzle velocity, and muzzle loss.

The densities of loading at present vary between 0.4 and 0.7, depending on the caliber of the gun and on whether the charge is case, stacked bag, or unstacked bag. Since the specific gravity of smokeless powder is about 1.6, the following relationship holds:

$$\text{Density of loading} = 1.6 v,$$

where

v = the proportion of the total chamber volume which is filled by the charge.

Hence it is apparent that a loading density of 0.4 would require a charge filling 25 percent of the chamber volume, and a loading density of 0.7 would require a charge filling 45 percent of the chamber volume.

When the density of loading drops markedly below the above figures, irregularities of muzzle velocity may be expected. The pressure

builds up irregularly instead of smoothly, and the high point may be reached at the wrong time.

A practical example of the importance of loading density would be a projectile lodged part-way down the bore of a gun, greatly increasing the effective chamber volume. Besides greatly lowering density, and causing pressure waves which may build up beyond a safe limit, it extends the area of maximum pressure beyond the area of maximum barrel thickness. A normal powder charge used to dislodge a projectile so positioned might cause the gun to burst, or at least bulge, immediately behind the projectile.

Very high density of loading, on the other hand, may cause detonation of the propelling charge, again resulting in a burst gun.

VOLUME AND FORM OF POWDER CHAMBER.—The designers of the gun, having established first the desired muzzle velocity, then the limiting maximum pressure allowable in the gun (determined from study of gun construction), can proceed to determine the volume and form of the powder chamber and the weight of the charge. In a particular gun, the volume and form of the powder chamber change only because of erosion at the origin of rifling and improper seating of the projectile, causing irregular muzzle velocity.

Projectiles differing in weight—for example, high-capacity and armor-piercing types—can be fired from a given gun. High-capacity projectiles, being lighter, will have a slightly higher muzzle velocity.

Summary of Interior Ballistics

There is much more to interior ballistics than has been taken up in this section, but you have read enough here to grasp the general nature of this branch of gunnery. Here are repeated the main points of the discussion, by way of summary:

1. Using the same weight of charge, a slow powder produces a smaller maximum pressure than a fast powder, and attains this maximum pressure later in the travel of the projectile.

2. Increasing the weight of a charge of powder of a given grain size increases the maximum pressure attained and causes this maximum to occur earlier in the travel of the projectile.

3. Because of muzzle loss and irregularity of muzzle velocity, slow powders are less efficient than fast powders.

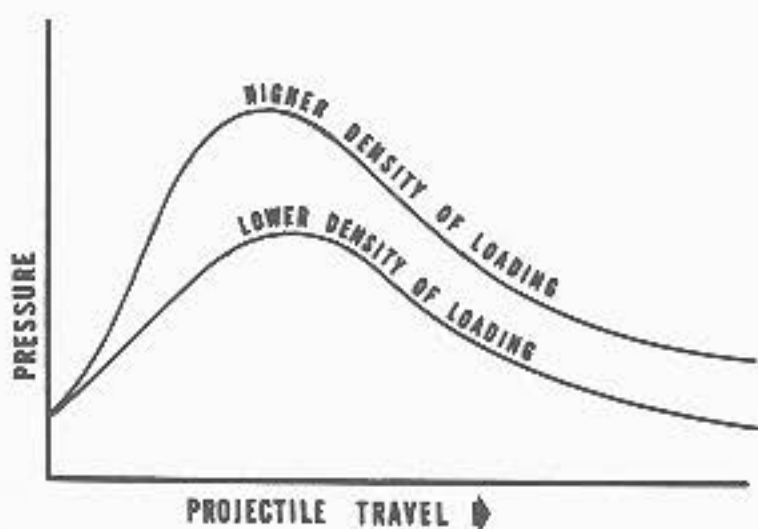


Figure 6-5.—Typical gun pressure curves showing variations due to density of loading.

4. The muzzle velocity of a given gun may be increased within limits by using larger charges of slower propellants.

VARIABLES IN THE GUN FIRE CONTROL PROBLEM

To solve the fire control problem, it is necessary to consider three main types of variables—

1. Exterior ballistics.
2. Target position and relative motion of the target and own ship.
3. Inherent corrections necessitated by the physical characteristics of the weapon system.

Each of these is discussed separately below.

Exterior Ballistics

From the instant it leaves the gun muzzle until it ends its flight by impact or explosion, the gun projectile's path or trajectory is affected by the following factors:

1. **MOMENTUM.** As you remember from Newton's laws of motion, any material object has inertia, and, if moving, tends to continue its motion at constant velocity (i.e., at constant speed in a straight line). The important values in determining the momentum of a projectile are its I.V. (initial velocity) and its mass. I.V. is measured in feet per second (usually abbreviated fs) as the projectile leaves the gun muzzle. Mass is conventionally measured in pounds (a convenient measure, if not strictly correct scientifically). If no other factors affected its motion, any gun projectile would have a straight-line trajectory. Note also that all naval guns (except a few special purpose devices) are designed to make the projectile spin at high speed on its long axis. This makes the long axis of the projectile tend to maintain a fixed attitude in space while in flight.

2. **GRAVITY.** On the earth's surface all material objects are subject to the earth's gravitational attraction, which pulls them toward the earth's center. Any unsupported object therefore tends to fall at a constant acceleration of about 32 feet per second per second. Gun projectiles are unsupported once they leave the muzzle; unlike aircraft, they are not airborne, and unlike rockets, they are not supported by propellant

thrust. They therefore fall with the same acceleration as if they had been dropped, not fired. The idea may be novel to the student, but the fact is that a projectile fired from a horizontally aimed gun will strike the surface of the sea at the same instant as a similar projectile that has merely been dropped from the same height above the water. It is, of course, true that the fired projectile will hit the water some distance away (fig. 6-6A).

Under the influence of momentum and gravity (but of no other factors) the trajectory of a projectile will be one of a family of symmetrical curves called parabolas. For a given I.V. and projectile mass, the projectile will then travel farthest from the gun if the gun barrel is elevated to make a 45° angle with the horizontal (fig. 6-6B).

3. **AIR RESISTANCE.** A projectile traveling at a speed of up to 3,000 feet per second creates a considerable disturbance in the air. At such speeds, air at sea-level density is far from insubstantial, and its resistance significantly slows the projectile throughout its flight. Air resistance affects the trajectories of all projectiles, but its effects, which depend on air density, are much greater on less massive ones.

The trajectory as affected by momentum, gravity, and air resistance is still more or less parabolic, but is not symmetrical; the projectile is traveling slower as it approaches the end of the trajectory, and (fig. 6-7) it falls at a larger angle with the horizontal (tending toward 90°).

4. **WIND.** Wind is air movement. Movement of the air with respect to the earth is called true wind. Air movement caused by the motion of a ship is called relative wind for that ship. Apparent wind is the vectorial sum of these two winds, and it is the quantity read from the ship's anemometer. Wind speed is measured in knots, and wind direction in degrees from the reference (true north, or ship's bow) clockwise to the direction FROM which the wind is blowing. By vectorial analysis, apparent wind can be resolved into relative wind and true wind. True wind is the wind input to fire control computers. True north is the reference for true wind, thus true wind is independent of ship's movement; however, both relative wind and apparent wind depend on own ship's course and speed.

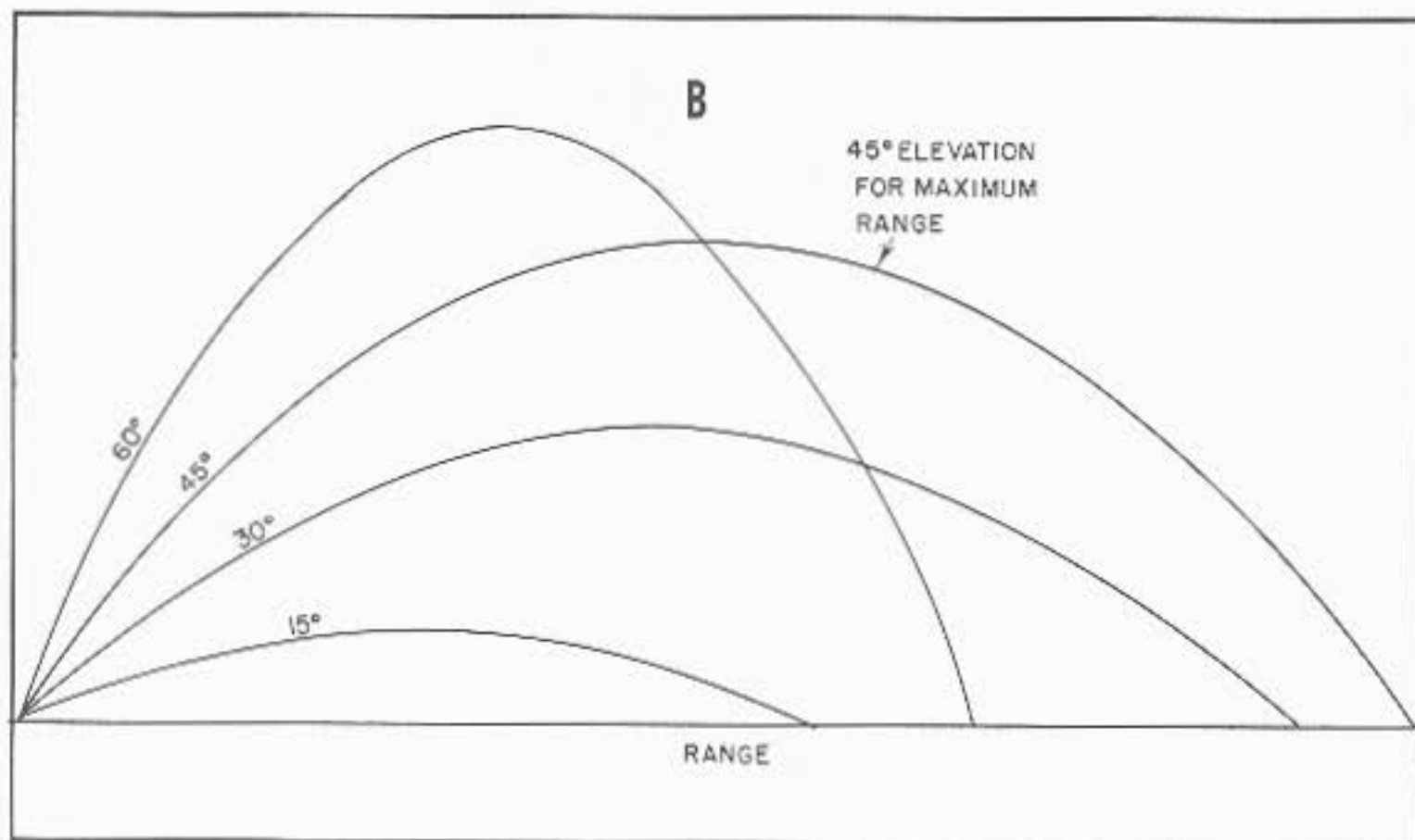
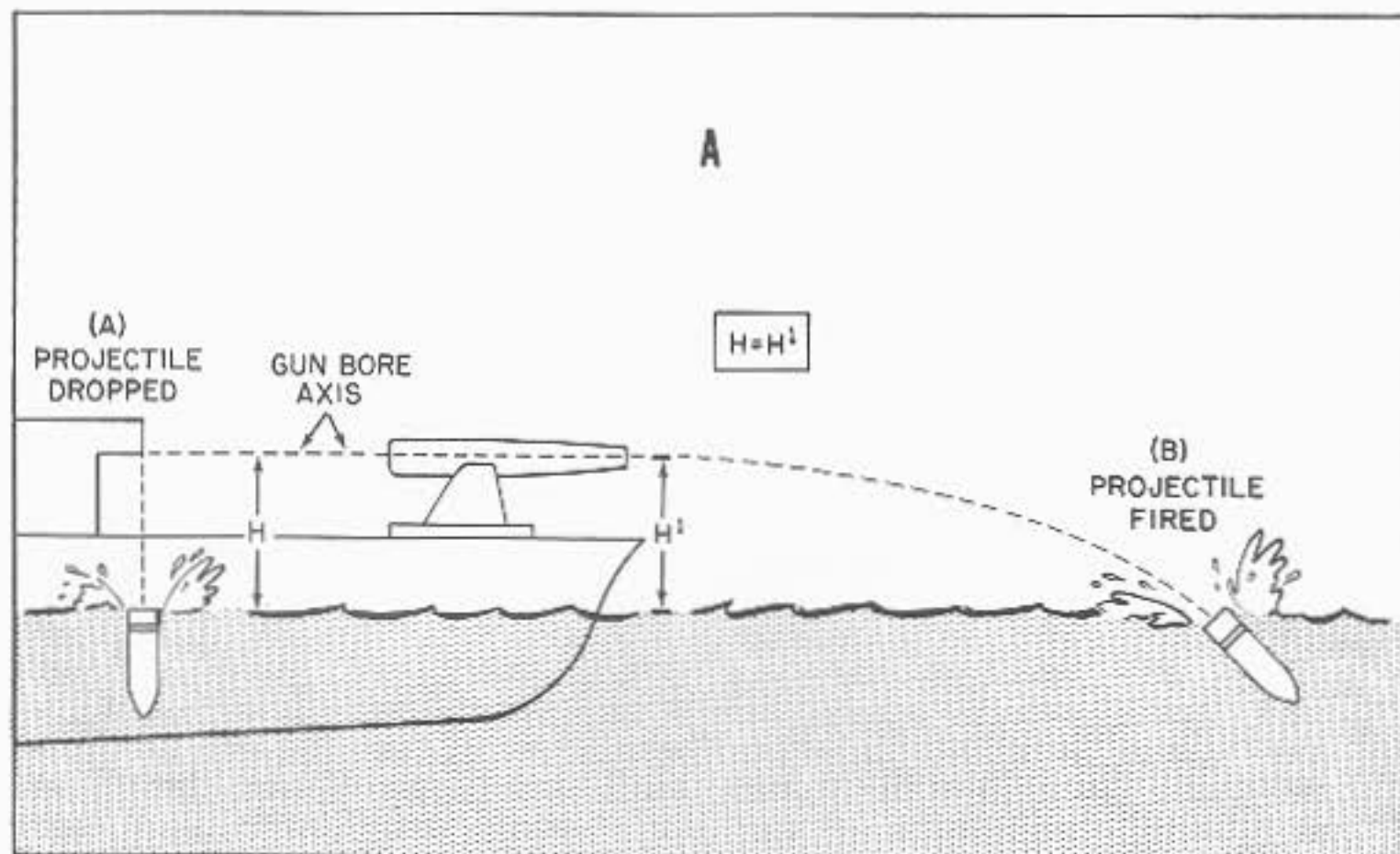


Figure 6-6. — Projectile trajectory as affected by gravity. A, Projectile (B) fired from horizontally aimed gun strikes water surface at same instant as projectile (A) dropped from same height. (Height $H =$ height H' .) B, Theoretical parabolic trajectories in vacuum at various gun elevations.



12.4

Figure 6-7.—Comparison of vacuum and air trajectories.

In fire control computers, true wind is resolved into two components with respect to the line of fire. One, called range wind, lies in the line of fire and may either accelerate or decelerate a projectile. Cross wind is the other component; it blows at right angles to the line of fire moving the projectile to the left or right of its planned trajectory. These components and their effects are automatically computed, and automatic corrections are made to the gun's position in train and elevation.

A ship's anemometer measures surface wind, but a projectile's trajectory passes through various altitudes. These altitudes, primarily because of air density and temperature, have different wind velocities than those on the earth's surface. A ship's meteorologist can track the flight of a balloon and measure the velocities and directions of tropospheric winds. Or, periodic wind reports are often received by radio from a shore station which has better wind measuring facilities. Most ships do not have a meteorologist on board; they depend on reports from other ships or stations. Ballistic wind, which is determined by aerological observations, is the resultant wind vector from zero altitude to about 20,000 feet. But if the projectile's maximum ordinate is less than 20,000 feet, only the wind affecting the projectile is considered in the ballistic wind computation. Wind velocities and directions are measured in 2500-foot increments (layers) from the surface horizontal to 20,000 feet. Weighted factors are provided in the manual so that any number of increments can be used easily and quickly. The number, of course, depends on the projectile's maximum ordinate. All necessary data for air and surface targets, including various altitudes and ranges, and various guns used, are provided in the manual. The final ballistic wind calculation for a particular type of engagement, at a specified

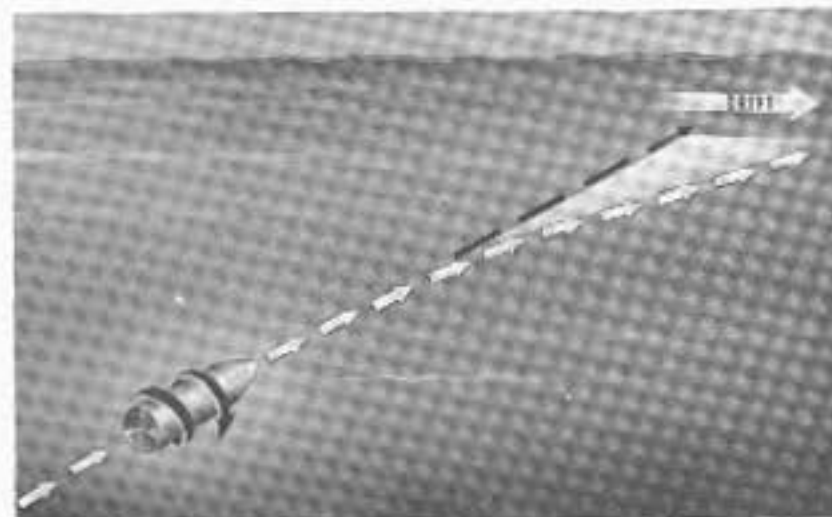
altitude and range, is substituted for true surface wind in the fire control computer. In the absence of ballistic wind data, true wind (surface) is the computer input.

5. DRIFT. Drift (fig. 6-8) is a deflection of the trajectory to the right, and is caused by the interaction of gravity, air resistance, and the projectile's clockwise spin. (Counterclockwise spin would deflect the trajectory to the left, but all naval guns except the .45 caliber have clockwise rifling.) Drift is directly proportional to range. It is independent of wind.

6. EARTH'S ROTATION AND CURVATURE. The discussion so far has implicitly assumed that the earth is flat and does not rotate. For ranges up to 20,000 yards or so, such an assumption does not cause any serious errors in fire control. At extreme gun ranges (30,000 yards and more) these two factors become important enough to be taken into account, particularly in firing at surface targets. Since such ranges are characteristic of the surface batteries of heavy cruisers (of which there are only a few in the active fleet) and those of battleships (none of which are in the active fleet), we can neglect these effects in this text.

Target Position and Relative Motion of Target and Own Ship

In the fire control problem, target position at any instant is measured in terms of target bearing (a horizontal angle measured from a vertical reference plane), target elevation (a



84.200

Figure 6-8.—Clockwise projectile spin causes drift to the right.

vertical angle measured from a horizontal reference plane), and range (a linear distance measured along the line of sight (LOS) to the target (fig. 6-9)).

As you noted at several points in connection with the discussion of exterior ballistics, the effect of the factors listed in the preceding article depends on, among other things, range. Another way of putting it is to say that they depend on time of flight—i.e., the time lapse between the projectile's departure from the gun muzzle and its impact or explosion. During this time the factors that determine the projectile's trajectory have their effect; obviously, the longer the time of flight, the greater their effect. Since, other things being equal, at any specified I.V. time of flight is proportional to range. This is one reason that it is important to know the range to target (generally measured in yards) as accurately as possible. Range to an air target, as measured along the LOS, is called slant range to distinguish it from range measured on the surface.

There are two kinds of target bearing. Relative target bearing is the angle, measured clockwise in degrees and minutes, between a vertical plane through the centerline of own-ship and the line of sight (LOS) to target. (This is illustrated in figure 6-9.) True target bearing is measured similarly, but from a vertical plane containing a line to true north. Figure 6-10 shows the distinction and relationship between true and relative bearing, and demonstrates that true

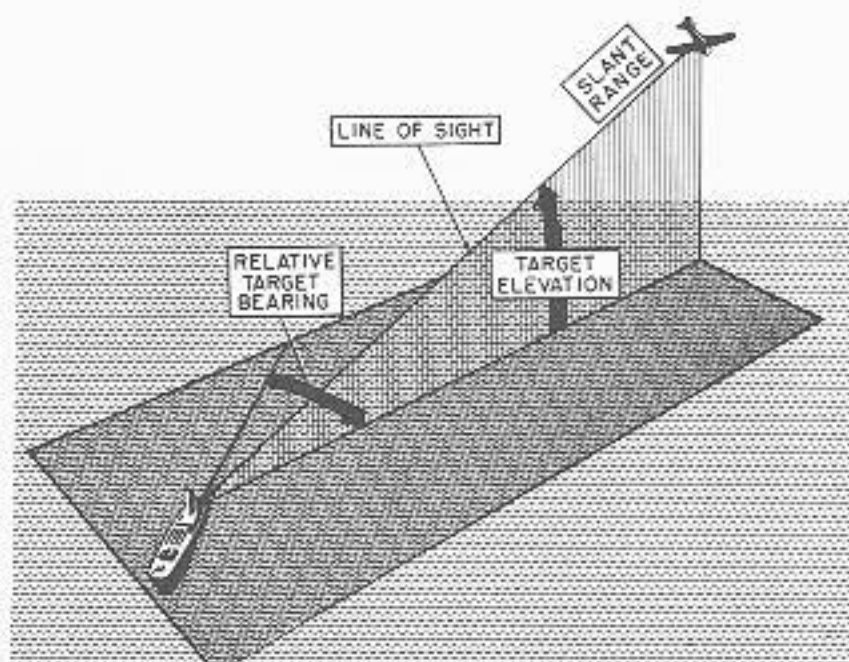


Figure 6-9.—Relative target bearing, slant range, and target elevation.

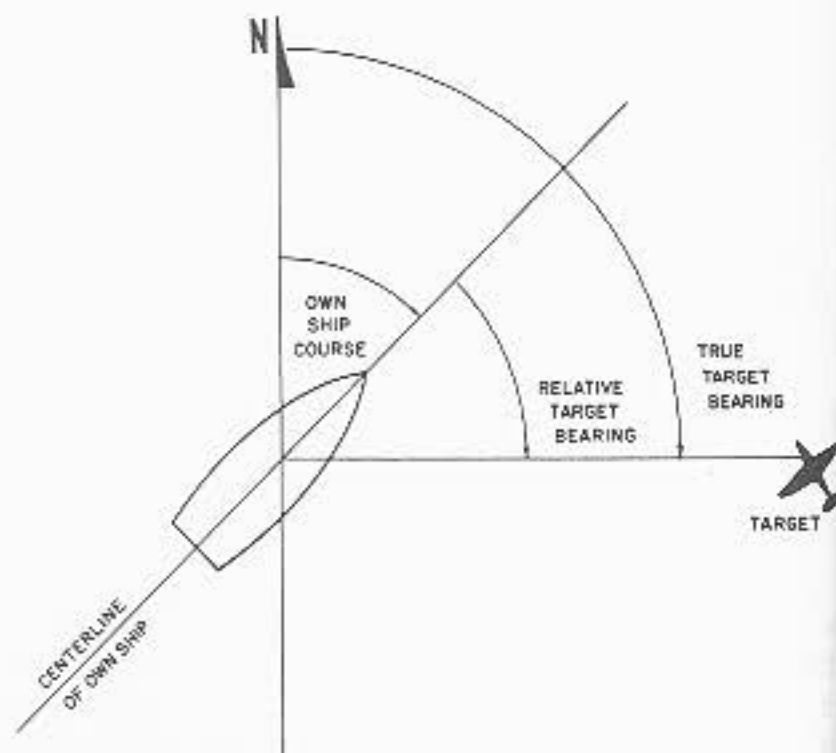


Figure 6-10.—Relationship between true bearing, relative bearing, and own ship course.

bearing is the algebraic sum of own ship course and relative bearing.

For the location of an air target with respect to own ship, one more value is needed—target elevation (generally measured in minutes of arc from the surface horizontal plane.)

If now we were to assume that the target and own ship were stationary with respect to each other, it would be necessary to correct only for exterior ballistic factors and the gun would be laid for a hit on the target. However, such a situation is rare. Target movement with respect to own ship is a part of every practical fire control problem, and it becomes increasingly important as ranges decrease and target velocities increase. (You can expect some air targets to be moving at over 600 knots.) In fact, at very close ranges (in the neighborhood of 2,000 yards or less) the ballistic factors are completely overshadowed in importance by corrections for target velocity, and many of the ballistic factors are not even considered in fire control systems designed for close-range work. This is true because at short ranges

- (a) time of flight is short
- (b) angular velocities (i.e., changes in target bearing and target elevation) increase as target range decreases, even when target speed as measured in knots remain the same.

(c) time available for arriving at solutions to the fire control problem is so short that there is time only for essential steps in solution.

Inherent Corrections to the Fire Control Problem

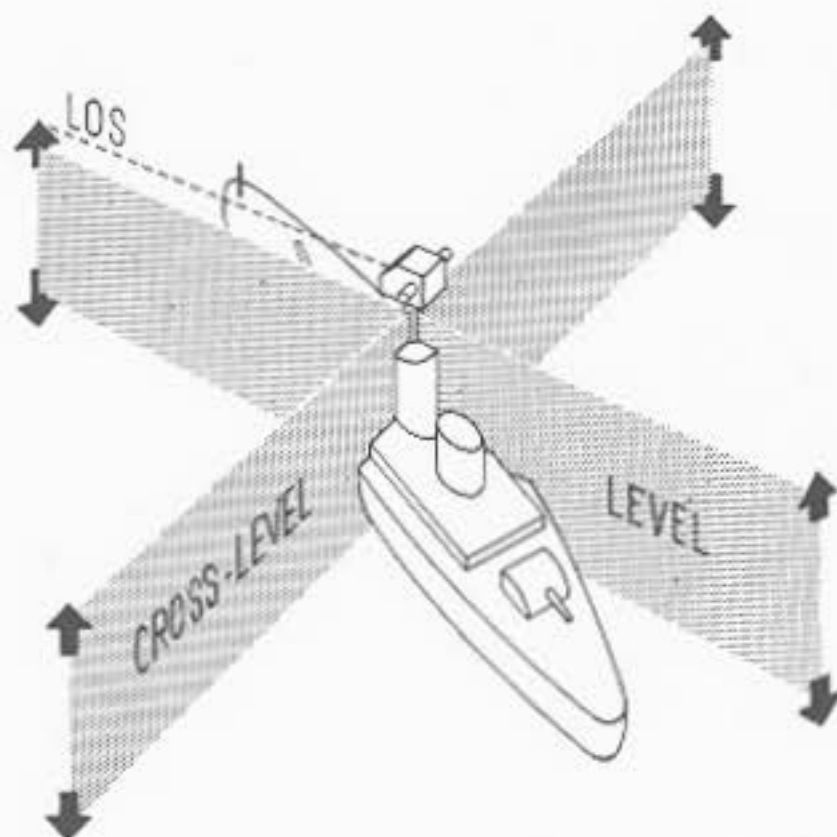
The miscellaneous factors that we lump under the label **INHERENT CORRECTIONS** include corrections for:

1. Motion of the gun platform (i.e., the ship's rolling and pitching motions as it floats on the water).
2. Parallax—i.e., distance between fire control system elements located at different points aboard ship.
3. Divergence of gun mount roller paths from the deck reference plane.

These factors are called "inherent" because they are unavoidable. All ships afloat have some rolling and pitching motion; parallax exist between the different elements of a gun fire control system aboard ship; and the roller paths of gun mounts cannot be machined perfectly parallel to the deck of the ship.

CORRECTIONS FOR GUN PLATFORM MOTION.—As you remember, the essence of fire control is to position the gun barrel so that the projectile's trajectory will culminate in its collision with the target. We may (as we did earlier in this chapter) assume for purposes of analysis that the deck on which the gun mount stands is stable, but in practice it is not generally possible to make this assumption. Nor is it practicable to stabilize the deck itself. Instead, either of two alternative correction methods is used. One requires that the gun be continuously repositioned by its power drive so that it maintains the desired attitude regardless of the ship's roll and pitch. The other (less frequently used) is to control the firing circuit so that as the ship rolls and pitches the firing circuit is energized only during those instants when the gun happens to be in the position required for hitting the target.

Corrections are required for the effects of ship's roll and pitch. They are level and cross-level (fig. 6-11) and trunnion tilt. Level is the angle that the deck plane, which rolls and pitches with the ship, makes with the horizontal, as measured in a vertical plane containing the line of sight (LOS). Crosslevel is measured at right angles to level.



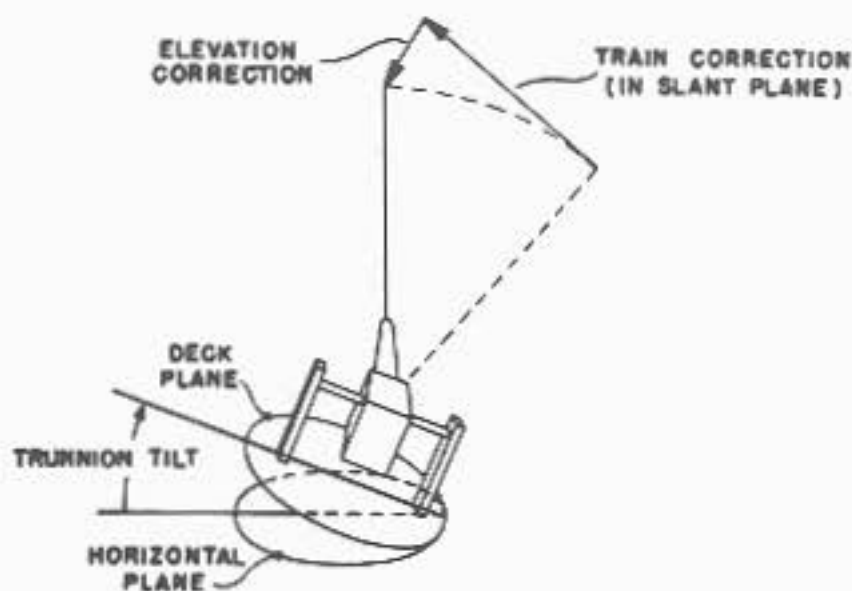
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Figure 6-11.—Level and cross-level.

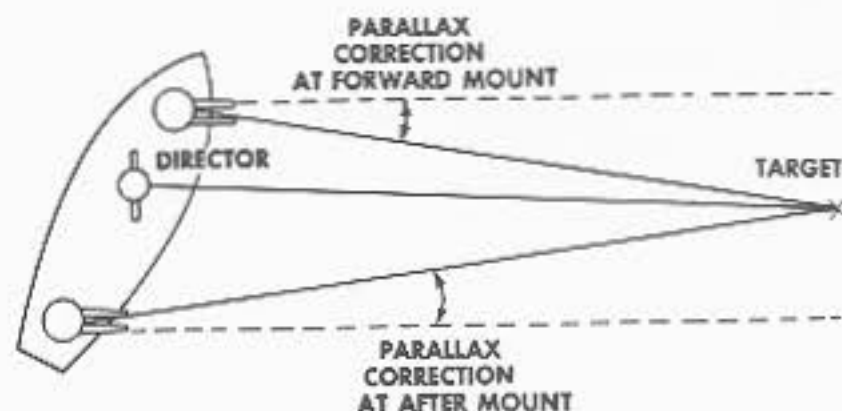
Inclination of the deck across the line of sight causes trunnion tilt. As the gun mount tilts with ship's motion, the gun no longer elevates in a plane perpendicular to the horizontal. This introduces errors, both because the gun does not elevate to the proper angle and because elevation in a plane not perpendicular the horizontal causes the gun to shift in train. Thus at a chosen instant, if the right trunnion is lower than the left, elevating the gun by X number of minutes with respect to the horizontal will require more than X minutes of elevation in the tilted plane. Additionally, the barrel, after elevation, will be displaced to the right of the plane it was in before elevation. Figure 6-12 shows the corrections required to compensate for trunnion tilt.

PARALLAX CORRECTIONS.—In general, parallax is the apparent displacement of an object (for example, a target) as seen from two different locations. The phenomenon occurs in several different contexts in fire control. We are now concerned with the effect diagrammed in figure 6-13. Relative target bearing is different at each gun mount and at the director. The parallax correction compensates for these differences.

CORRECTION FOR ROLLER PATH TILT.—Ideally, the roller path of each gun mount should



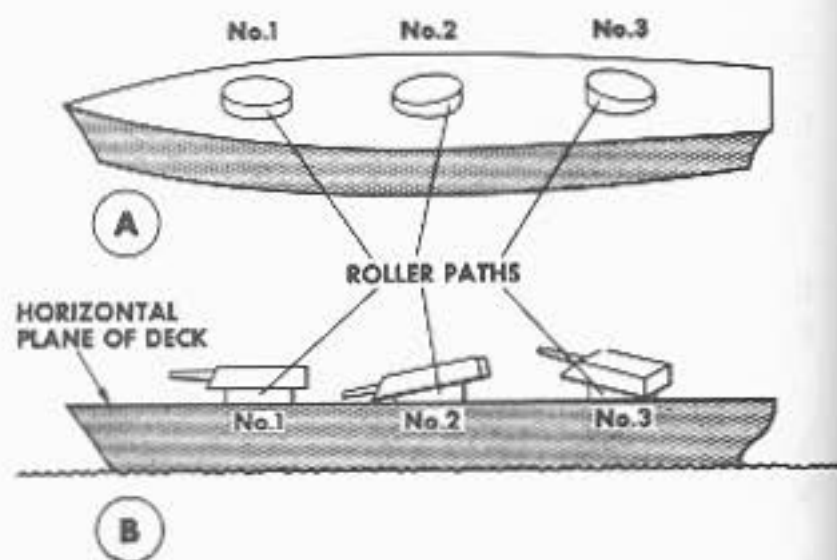
12.45
Figure 6-12.—Corrections for trunnion tilt.



12.48
Figure 6-13.—Horizontal parallax.

be parallel to that of the reference unit (director in most cases). Although the tilt of a gun mount with respect to the reference is, in modern naval construction, always small (rarely over a degree, and usually much less), it must be corrected. Some tilt is unavoidable because a ship's hull is supported much differently in the shipyard than it is when afloat. Individual corrections are required for each gun mount. The correction is made in elevation, but its magnitude depends on the angle to which the mount is trained. Figure 6-14 shows the effect of roller path tilt in exaggerated form.

Roller path tilt correction is performed mechanically by a device built into each gun mount. The computer in the fire control system has nothing to do with this correction, which is different for each mount. Chapter 8 illustrates one



12.47
Figure 6-14.—Effect of roller path inclination (much exaggerated).

type of roller path tilt corrector, and briefly describes how it is used.

ELEMENTS OF GUN FIRE CONTROL SYSTEMS

As you noted earlier, the complexity of the fire control problem, and hence of the fire control system necessary for its successful solution, increases with the maximum range of the guns associated with the system, since ballistic factors are relatively more important when the time of flight is longer. At the same time, at shorter ranges the position and motion of the target with respect to own ship become relatively more important than the ballistic factors. Moreover, at shorter ranges the time available for solution of the problem is much more limited than at longer ranges. Consequently, instead of a single "universal" fire control system or type of system used in all applications, you find that there are two main types, each best adapted to a particular kind of application. One of these is the relative-rate type, which efficiently deals with fast targets at short ranges. The other is the linear-rate type, which is particularly well adapted to deal with the more complex ballistic computations required for distant targets.

Examples of both types will be described in more detail later in this chapter, but so that you may understand better the description that follows of how the fire control system solves the fire control problem, consider briefly the elements of each type.

Linear-Rate Systems

Linear-rate systems are used for both surface and air targets at much longer ranges than those for which relative-rate systems are generally used. The system consists of (fig. 6-15) a director located high in the ship's structure, a computer and stable element closely linked to each other and located in a plotting room in the hull, a radar console located either in the plotting room or the director, and gun mounts (commonly the 5-inch battery, though the system can be connected to control other mounts also). All these elements are interconnected by electrical data transmission circuits, except that the stable element may be mechanically or electrically connected to the computer.

The director is equipped with telescopes, an optical rangefinder, radar equipment (in some installations), data transmitters and receivers, and power drives, so that it can:

- Determine target bearing, elevation, and range either optically or by radar.
- Be power driven by computer-generated signals enabling the director crew to verify that the computer is developing the proper fire control solution.
- "Lock on" the target for automatic radar tracking (i.e., automatically follow the target as its location changes with respect to own ship).

The computer (depending on the specific system) may be either an electromechanical or an electronic-electromechanical unit. It accepts all ballistic factors (including I.V.) as well as target data and data on own-ship course and

speed. It transmits gun position data to the gun mounts it controls. And it can send its fire control solution to the director as electrical signals that position the director optical and radar elements to indicate how accurately it is solving the fire control problem. The computer contains no gyroscopic elements.

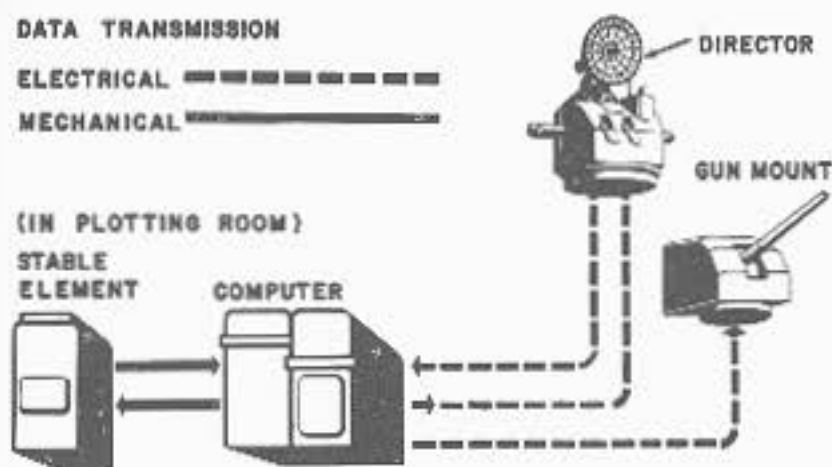
The stable element contains a gyroscope which, because it remains fixed in attitude, generates a stabilized reference plane to which all angular values received and computed can be related.

The data transmission receivers in the gun mounts control the gun power drives so that the guns will be positioned in accordance with the signals transmitted from the computer.

Relative-Rate Systems

The essential parts of a simple relative-rate fire control system are a director and a transmission system through which the gun position data required for accurate firing are transmitted to the gun mount. In simpler systems, there may be one director for one or two mounts, and the directors are located fairly close to the mounts they control. Range is either estimated optically and cranked in manually, or measured by radar. The director operator looks through the optical sight on the director (or he may use radar) and tracks the target (that is, as it moves in his field of vision he keeps it aligned with his LOS as indicated by a reticule in the sight, or in the center of his radar display). This movement affects a gyroscope and a pendulum device in the director case. Electrical pickup devices in the director sense the gyro and pendulum movements, and send electrical signals to the gun mounts. The signals correspond to the gun positions required for hitting the target, and they either control the mount power drive so that the guns assume the desired positions, or the gun crews may control gun position manually in accordance with the signals as displayed on dials. Simple relative-rate systems take into account only a few ballistic factors—generally gravity, drift, and air resistance.

In some types of relative-rate systems the director may be divorced from the gyro and pendulum devices. The gyro is then a component in a separate computer. The more complex relative-rate systems will accept additional ballistic data inputs and are more accurate, particularly at longer ranges, than the simpler systems.



53,114

Figure 6-15.—Elements of a linear-rate gun fire control system aboard a destroyer.

The most elaborate systems utilize power-driven directors rather than the manually operated directors of the simple system described above. Under radar control, these can track targets automatically once they are "locked on." The more complex systems also include an additional gyro for stabilization, like the one described earlier for linear-rate systems, and additional computers for wind data inputs and for generation of gun positioning signals for two gun batteries simultaneously.

On-mount fire control elements include data transmission receivers, the power drives, and the sights. (In some systems, radar elements may also be installed on the mount.) The first two of these have been discussed in chapter 3; we shall briefly concentrate on the sights. These are optical devices, either telescopic or non-telescopic, equipped with crosshairs intersecting at right angles in the center of the view field. Any target as seen through the sight at the center of the view field is on the line of sight (LOS). Sight dials on the mount indicate at all times precisely the angle that the LOS makes with the axis of the gun's bore. In most mounts, dials concentric with the sight dials and driven by data receivers controlled by the computer are automatically positioned to display the angles that the gun bore axis should make with the LOS if the gun is to be laid for hitting the target. A crewman can manually crank the desired angles into the sight-setting indicator (an indicator with gearing which positions the sights). These arrangements permit continuous aiming of the gun even if the gun power drives quit, if the data transmission from the computer is interrupted, or if the computer or other fire control system elements are knocked out.

SOLVING THE FIRE CONTROL PROBLEM

As you remember from the beginning of this section, the fire control problem consists essentially of three groups of variables. In a given fire control system, some individual variables may either be taken into account or neglected, depending chiefly on target velocity (with respect to own ship) and range, and on desired accuracy and speed of solution. The main steps in solving the fire control problem are:

1. MEASUREMENT of each of the variables to be taken into account.
2. COMPUTATION of what gun position must be in relation to an LOS from own ship to target

so that the projectile will hit the target, and transmission of this information to the gun mounts. (This computation and transmission may also include projectile fuze setting if required.)

3. POSITIONING THE GUNS in accordance with this information and energizing firing circuits as required.

4. OBSERVATION of effects of firing and correction of fire control information.

Now consider each of the steps in somewhat more detail.

Measuring or Establishing Values of Variables

Ideally, each variable in the fire control problem should be observed and accurately measured, then entered in the computing system. As a practical matter, some may be estimated and "cranked in" (i.e., put into the system manually), and some may be considered as having a fixed relationship to another variable (for example, the effect of gravity has such a relationship to time of flight), so that they don't have to be measured. (We have already noted that in all but the most refined systems some variables are omitted entirely because they are not considered essential to a solution of practical accuracy.)

1. Ballistic variables are measured and entered into the fire control system computer as I.V. Most of these variables were discussed earlier in this chapter. For a detailed discussion of how I.V. is determined, refer to appendix II.

2. Gravity has a fixed relationship to the time of flight, which in turn has a known relationship to range. Its effect is therefore "built into" the computer as a specially shaped cam (in electromechanical computers) or electrical network (in electronic computers).

3. Air resistance is in most medium- and long-range systems determined by fire control personnel who plot observed air temperature and barometric pressure on a nomogram and then determine the required correction. (Air density correction nomograms are printed in range tables. A specimen is reproduced in appendix II, which also contains details on how this and several other ballistic corrections are determined.) The correction is put into the computer as part of I.V.

4. Wind is a factor in medium- and long-range systems; it is generally neglected in simple relative-rate systems designed for use

at short ranges. In long- and medium-range systems ballistic wind is cranked into the computer.

5. Drift is treated like gravity.

6. Earth's rotation and curvature are figured from range tables and their effects are cranked into the system as direct increments to sight angle and deflection. The computer does not solve for these. In any case, these values are used only against surface targets at extreme ranges. See appendix II for details.

Target position and relative motion of target and own ship are important factors in all gun fire control systems, but for high-speed targets at shorter ranges they dominate the fire control problem.

Target position is fixed by three coordinates—bearing, elevation, and range. All three can be measured optically in a linear-rate system. The first two are established when the sight telescopes in the director are on target. Angular values of director train (an angle nearly equal to relative target bearing) and director elevation (an angle measured with respect to the deck plane, vertically to the LOS) are sent to the fire control system computer by data transmitters (synchros). A linear value of range is measured at the rangefinder and also sent by synchro to the computer.

Radar can be used to measure all three coordinates in a Mk 37 linear-rate system. Data transmission is generally the same when the director is tracking by radar, except that the range synchro information comes from the radar instead of the rangefinder. The Mk 37 (fig. 6-15) is the principal linear rate director used in the Navy. It can track targets optically in train and elevation while maintaining an automatic radar track in range; this is called partial-radar control. Or, either train or elevation can be shifted into automatic radar track without shifting the other, provided the director is radar-tracking in range.

When the director is in full-radar track, the system, including the computing devices, is fully automatic. Sometimes (particularly at long ranges) the target echo is too small for full radar tracking, but can still be seen on the radarscopes in the director. As long as it can be seen, it can be tracked by radar. The pointer and trainer move their power drive controls to keep the target video aligned (in elevation and train, respectively) to the line of sight references on the radarscopes. These references correspond to the actual position of the director

in elevation and train, and are aligned to the crosshairs in the optical sights. The radar range operator keeps the target video manually "gated" or aligned to the range measuring device on his radarscope, i.e., the notch, mark, or step as the case may be.

There are several types of relative-rate directors used in the Navy today. Some can track automatically by radar, others track manually by radar, and others use a combination of radar and optical. And then there are the optical relative-rate directors that were installed before radar was used in fire control; these use estimated ranges. One feature common to all relative-rate directors is the use of gyros to measure angular tracking rates. More will be said about this later.

In the simplest relative-rate systems the director operator tends to keep the director stabilized as he tracks the target; in any case stabilization errors in such systems are not important at close ranges with high-speed targets. In longer range relative-rate systems and in all linear-rate systems the system outputs compensate for ship's roll and pitch because they are developed with respect to a stabilized reference plane, which is kept horizontal by a gyroscope. In relative-rate systems the stabilization gyro is incorporated into one of the consoles or into the director of the system; in linear-rate systems the gyro is in a separate console called the stable element or stable vertical. An alternate manual stabilization arrangement used in emergency in some linear-rate systems requires that a crewman sight at the horizon continuously through a telescope coupled to the remainder of the system by a synchro whose output provides the stabilization signal.

Parallax correction is important only in systems where some of the gun mounts are located some distance from the director. A special section of the computer develops parallax correction for a base length (distance between director and gun mount) of 100 yards. This is called the unit parallax correction. For this or any other base length, the closer the target the greater the angular correction needed for parallax. However, the base length assumed for the unit parallax correction is not likely to be correct for any one gun mount, since obviously the parallax correction ought to be greater for mounts further from the director than 100 yards, and less for mounts that are closer. Consequently, there is in each gun mount a set of change gears which converts the unit correction to the correction

required, based on the ratio between the assumed base length and the actual base length. Parallax is also computed to compensate for vertical distance between mounts and director, but since all mounts are more or less equally far below the directors, the computed correction is fed equally to all.

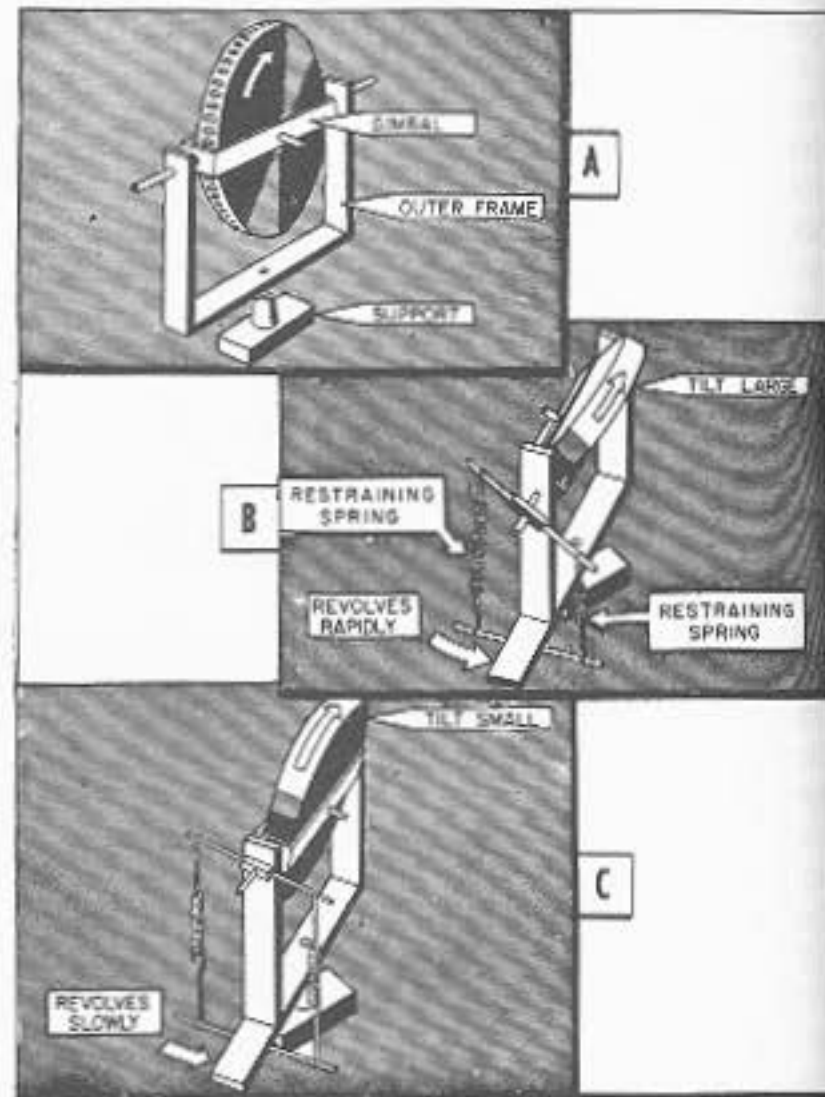
Computation and Data Transmission

This text does not go deeply into the mathematics of the fire control problem and its solution. The details of functioning of a fire control computer will therefore not be described. However, in chapter 3 you learned that such mechanisms as gears, cams, and differentials can be used to perform all the basic arithmetical operations as well as many trigonometric ones. Chapter 3 also described other mechanisms used in a typical fire control computer, such as the integrator, component solver, multiplier, etc. These enable the electromechanical computer, for example, to perform all the mathematical functions necessary in solving the fire control problem.

There are basically three different varieties of computer used in present day Navy gun fire control systems—the GYROSCOPIC, the ELECTROMECHANICAL, and the ELECTRONIC. The first two are what computer engineers call analog computers. The electronic computer may be either analog or digital depending on the system in which it is used. The GFCS (gun fire control system) Mk 68 uses an analog computer (generally) whereas the GFCS Mk 87 uses a digital computer. The difference between analog and digital computation is explained in chapter 3.

GYROSCOPIC COMPUTERS are used in relative-rate systems. They may be housed in gun-sight cases which are mounted on directors, or they may be in the director itself. Their function is to generate the correct lead angles, and lead angles (for bearing and elevation) depend on two variables in addition to ballistic corrections. The variables are: (1) the angular velocity of the director or gunsight in bearing and elevation, and (2) the time-of-flight (or range) to the target.

A gyroscopic computer uses a rate-of-turn gyro as shown in figure 6-16A. Assume that the gimbal frame in part A is attached to a gunsight case, and in part B is made to revolve rapidly (and in part C slower) by a motion of the gunsight case while tracking a target. Notice that gyro is restrained by two springs, and in part B the precession is greater than it is in part C.



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Figure 6-16.—Functioning of rate-of-turn gyro (simplified). A. Gyro elements. B. Action in tracking fast. C. Action in tracking slowly.

The tension of the two springs is set (either manually or by radar) to be proportional to the target's range. The amount of precession of the gyro, then, is proportional to the angular velocity of the case and the range to the target. As range increases, the tension on the springs decreases. By this action a larger lead angle is developed at longer ranges for a given angular velocity. The springs have another function in that they return the gyro to zero precession when tracking has ceased, and they supply the force to compensate for decreases in angular velocity while tracking.

There are two basic ways to use the rate-of-turn gyro's precession in the fire control system. Older systems use the gyro to control the optical train of the gunsight. The gunsight operator's line of sight is controlled by connecting gyro precession to prisms within the optical train. Since the guns are aligned to the sight case, offsetting the line of sight within the

case introduces the lead angle into the system. The other way to use these data starts with electrical sensors, called pickoff units. A pickoff unit senses the gyro displacement without perceptibly disturbing it, and produces a proportionate electrical signal. Electrical signals, proportional to lead angles, are sent to the fire control system computer where orders for the guns are computed in some systems. They may also be a direct input to the gun in other systems.

There are various rate-gyro devices in fire control which use one or more gyros. Some use electromagnetic damping devices instead of restraining springs. And some use ballistic gyro weights, while others use torque motors for the ballistic corrections. Discussing all of them in this text would obscure, rather than clarify, the basic theory.

ELECTROMECHANICAL COMPUTERS.—To solve the fire control problem for a moving target, the fire control system must have the rate of target movement with respect to own ship—specifically, the rate of change of target bearing, target elevation, and range. Since own ship is usually in motion also, its motion must be entered into the computer. Own ship's course is transmitted from the ship's gyrocompass, and own ship's speed is transmitted from the pitometer log. Both are synchro-transmitted inputs to the computer. Rates of change in bearing, elevation, and range go into the fire control computer as the director tracks the target. The computer solves the problem by performing a series of mathematical operations with the data put into it. The operations are performed almost entirely by mechanical units of the type described in chapter three. The input data are usually in the form of shaft rotations or other mechanical displacement. The mechanical displacement may be produced either by manually setting a knob or handcrank, or through a servomotor (which reproduces relatively weak electrical or mechanical servoinputs), or a synchro receiver (which reproduces an electrical input without amplification). The computer outputs are mechanical but are translated into electrical synchro signals (with one exception) that go to other system components. The signals are also displayed on dials and other indicators.

In some fire control electromechanical computation equipment, simple computation (addition and subtraction) may be performed by synchro units.

ELECTRONIC COMPUTERS.—Electronic analog fire control computers use specific circuits or electrical elements to perform specific mathematical functions. For example, two voltages can be added or subtracted in an electrical network similar to the one in figure 3-78; if a-c voltages are used, changing their phase relationship yields a voltage that represents the vectorial sum of the voltages. Transformers, both fixed and variable, can be used for multiplication or division—changing the transformer turns ratio changes the divisor. Rotary variable resistors called potentiometers can vary the amount of resistance in a circuit either in straight-line fashion or in accordance with a selected nonlinear function (for example, the effect of drift). Such functions can also be calculated by using special nonlinear amplifier circuits. Small rotary transformers called resolvers can either resolve an a-c voltage representing a vector quantity into its components (for example, yield north-south and east-west components of own-ship course and speed), or add the components to yield a solution expressed in an a-c voltage of specific amplitude and phase, or perform other functions with vectors. In such electronic computers, the shafts of rotary devices such as potentiometers and resolvers (as well as synchros) are usually driven by servomotors energized by servoamplifiers. An electronic analog computer can thus be functionally substituted for an electromechanical one.

By using flip-flops, storage registers, and other digital devices, digital fire control computers can perform the same operations as analog computers.

DATA TRANSMISSION.—Except for mechanical connections between computer and the stable element in some linear-rate systems, all data transmission between fire control system elements is through synchro systems. These were explained in principle in chapter 3. All inputs and outputs between systems are translated into synchro signals of transmission and retranslated into suitable electrical and mechanical outputs at the receiving end.

Thus, for example, the signal voltage developed by a pickoff unit on a train rate-of-turn gyro in a relative-rate director controls a servo whose motor drives a synchro transmitter. The transmitter's output goes through synchro wiring to the gun mounts.

The data transmitted electrically by synchro to the gun mounts from the fire control system

include at the minimum, gun train and elevation orders. In some relative-rate systems no other data are transmitted; in others, and in linear-rate systems, transmitted data may include sight angle, sight deflection, fuze-setting order, and parallax.

POSITIONING AND FIRING THE GUN

With the fire control problem's variables evaluated and the solution available, it is possible to lay the gun so that the projectile will hit the target. Other requirements may limit the solution in such a way that firing can successfully take place only at certain instants, in which case the solution must specify those instants.

The process of gunlaying is essentially that of offsetting the axis of the gun bore from the LOS by a specific angle. This compensates for the divergence of the trajectory from the straight line it ideally would be in interstellar space with stationary gun and target. No matter what any specific variable in the gun fire control problem may be or what its magnitude and direction are, the only possible ways of compensating for it are (a) variation in the propelling charge or projectile (which for all practical purposes is so infrequently done that we can neglect it here) or (b) algebraically adding an increment in the angular offset between gun bore axis and the line of sight (the only method we consider in this chapter). Since the gun is positioned in two perpendicular planes by its train and elevation mechanisms, the offset is always measured in two perpendicular planes.

Figure 6-17 shows the angular offsets for a surface target. The vertical offset in part A is called SIGHT ANGLE; the deflection offset in part B, SIGHT DEFLECTION. These two angles are equal to the total lead angles for elevation and bearing in both air and surface exercises. In a surface exercise, the elevation lead angle assumes the properties of a "range lead angle" since range is a function of the gun's angle of elevation. Smaller angular values make up sight angle and sight deflection. For example, drift is part of sight deflection and an angle called SUPERELEVATION is part of sight angle. Superelevation is the angle that the gun must be elevated above the line of sight to compensate for the downward pull of gravity. It is not affected by the relative motion of own ship and target; but it is affected by range and elevation, the variables which cause changes in trajectory.

Thus the required superelevation, at any given range, is determined by the uncorrected trajectory. If own ship and target in figure 6-17A are stationary, and if wind effects are discounted, then superelevation will equal sight angle.

Figure 6-18 shows the vertical offset for an incoming air target. Notice that the LOS to target is elevated above the horizontal by an angle labeled target elevation. The gun barrel is elevated above the LOS by sight angle. Sight angle here not only includes a correction for superelevation, but predictions based on relative motion as well.

The angles which ultimately position the gun are called GUN ELEVATION ORDER and GUN TRAIN ORDER. Essentially, each contains an angle equal to target position in elevation and bearing, respectively, plus the computed lead angle for each. Since a gun elevates and trains in the ship's deck plane, gun elevation order is the amount the gun is elevated above the deck plane, and gun train order is the amount the gun trains in the deck plane measured clockwise from the ship's bow. Gun train and elevation orders are outputs from the system computer, and their principle computed variables, respectively, are sight deflection and sight angle.

Now consider the effects of fire control variables on sight angle and sight deflection, and on elevation and train gun orders of which they are part.

Ballistic Variables

In the following list of ballistic variables, we indicate the effect that increasing the variable has on sight angle and sight deflection.

Variable	How compensated as variable increases
Projectile momentum	
(a) Mass (weight).....	Increase sight angle.
(b) I.V. ¹	Decrease sight angle.
Gravity (itself a constant, but its effect is a function of time of flight).	Increase sight angle with increased time of flight.
Air resistance	Increase sight angle.

¹ In practice, as the gun wears I.V. decreases, hence sight angle must be increased to compensate.

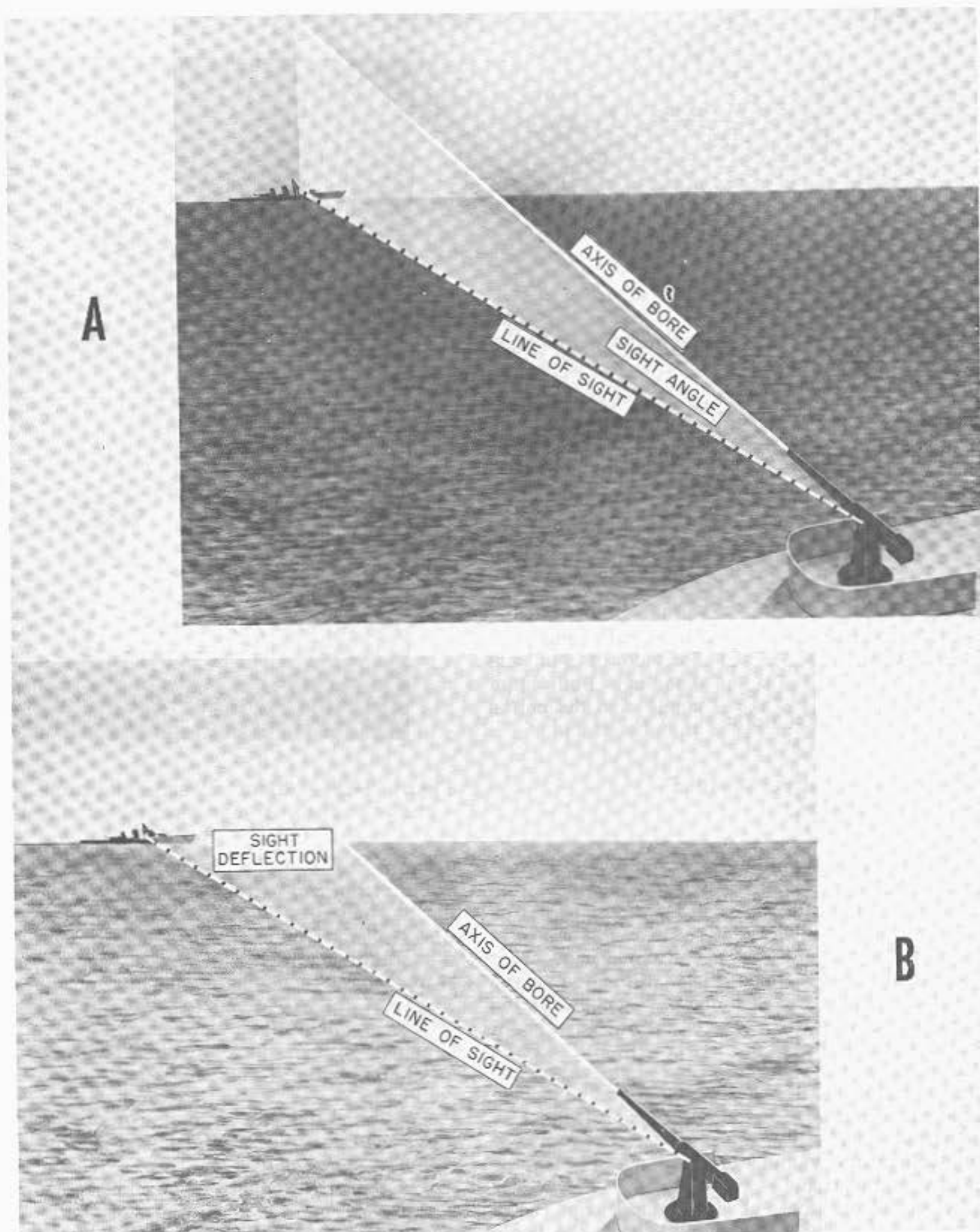
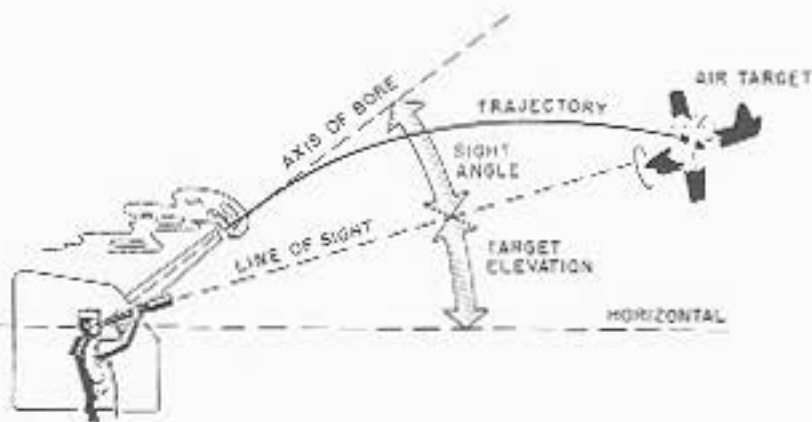


Figure 6-17.—Offsets from LOS. A. Sight angle. B. Sight deflection.

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Figure 6-18.—Target elevation and sight angle.

Wind..... Depends on wind direction. If wind tends to increase range, reduce sight angle (and vice versa); add deflection and sight angle as needed for cross winds.

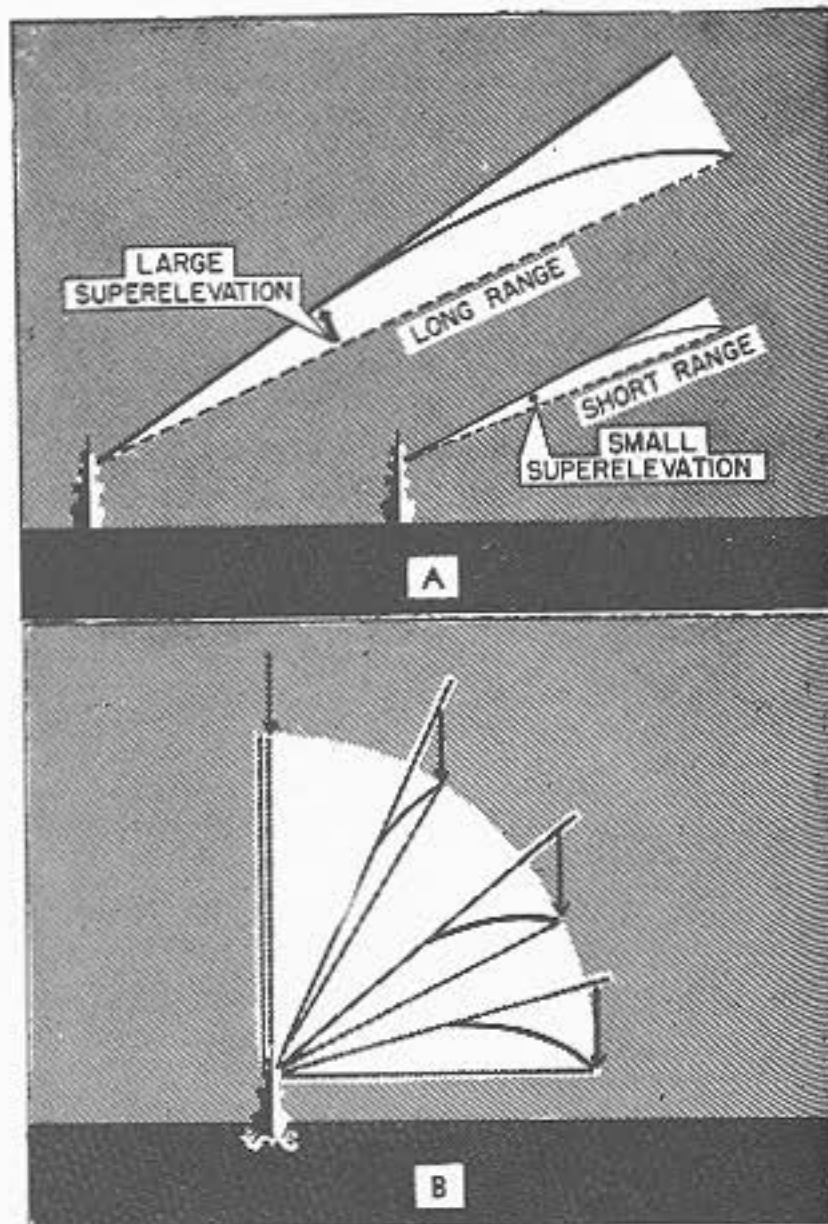
Drift..... Add left deflection.

Earth's rotation and curvature..... Varies with range, latitude of gun, gun bearing. Both sight angle and deflection may be affected.

Correction for Target Position and Target Motion

If you consider both your ship and the target to be stationary, once you know target position (bearing and range) you need lay the gun only for ballistic and wind corrections to put your projectiles on target. For a stationary air target you would have to add target elevation to the problem. Figure 6-19A shows super-elevation angle to be large for a given target elevation at long ranges. But notice what figure 6-19B shows. Assuming a constant slant range, super-elevation gets smaller as the target elevation increases. Super-elevation is zero when the target is directly overhead (090° elevation). To put it precisely, super-elevation varies directly as the cosine of target elevation.

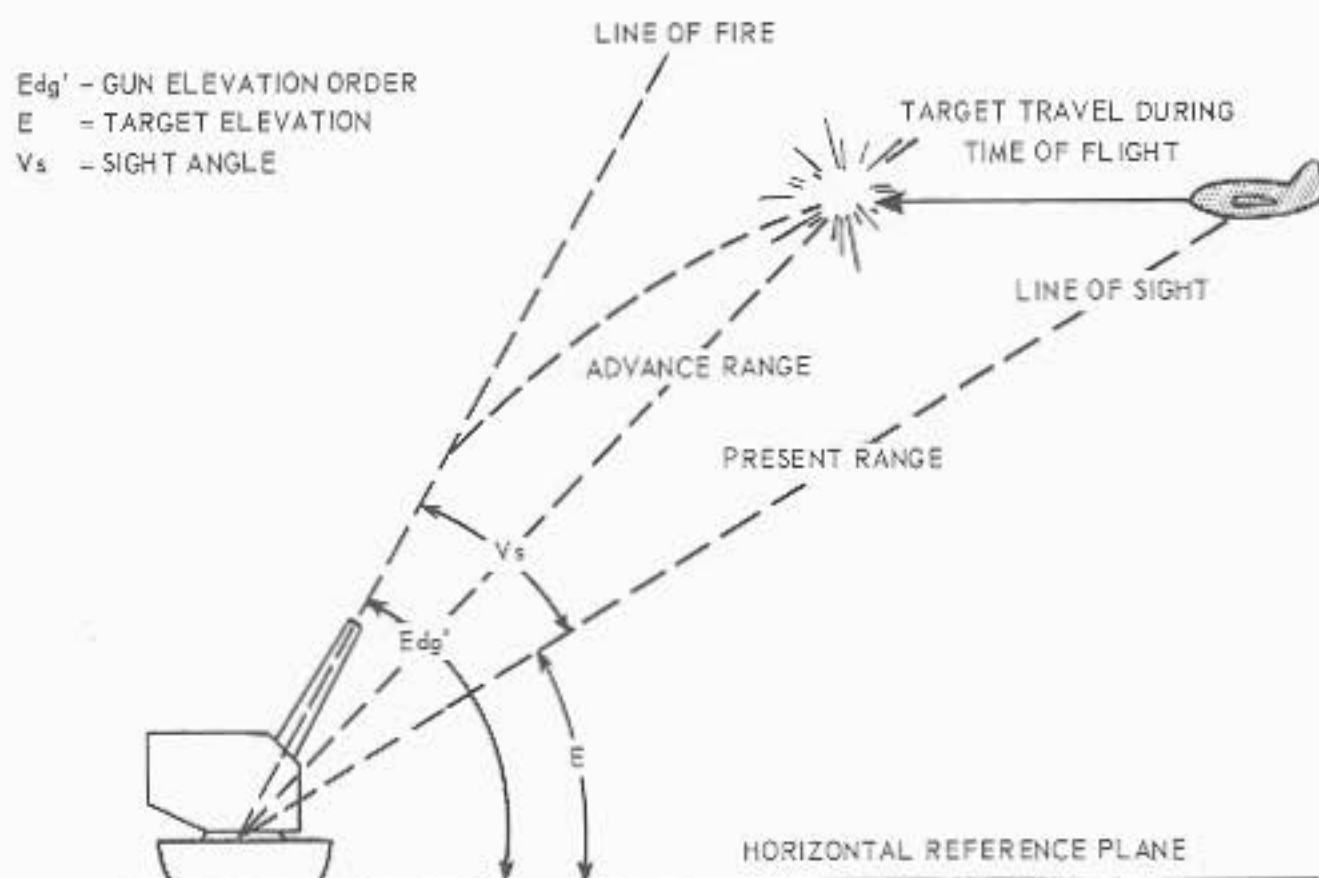
Now let us look at a moving target as in figure 6-20. This figure only shows the basic elements in gun elevation order. Notice that the ship's deck is assumed to be horizontal (rarely



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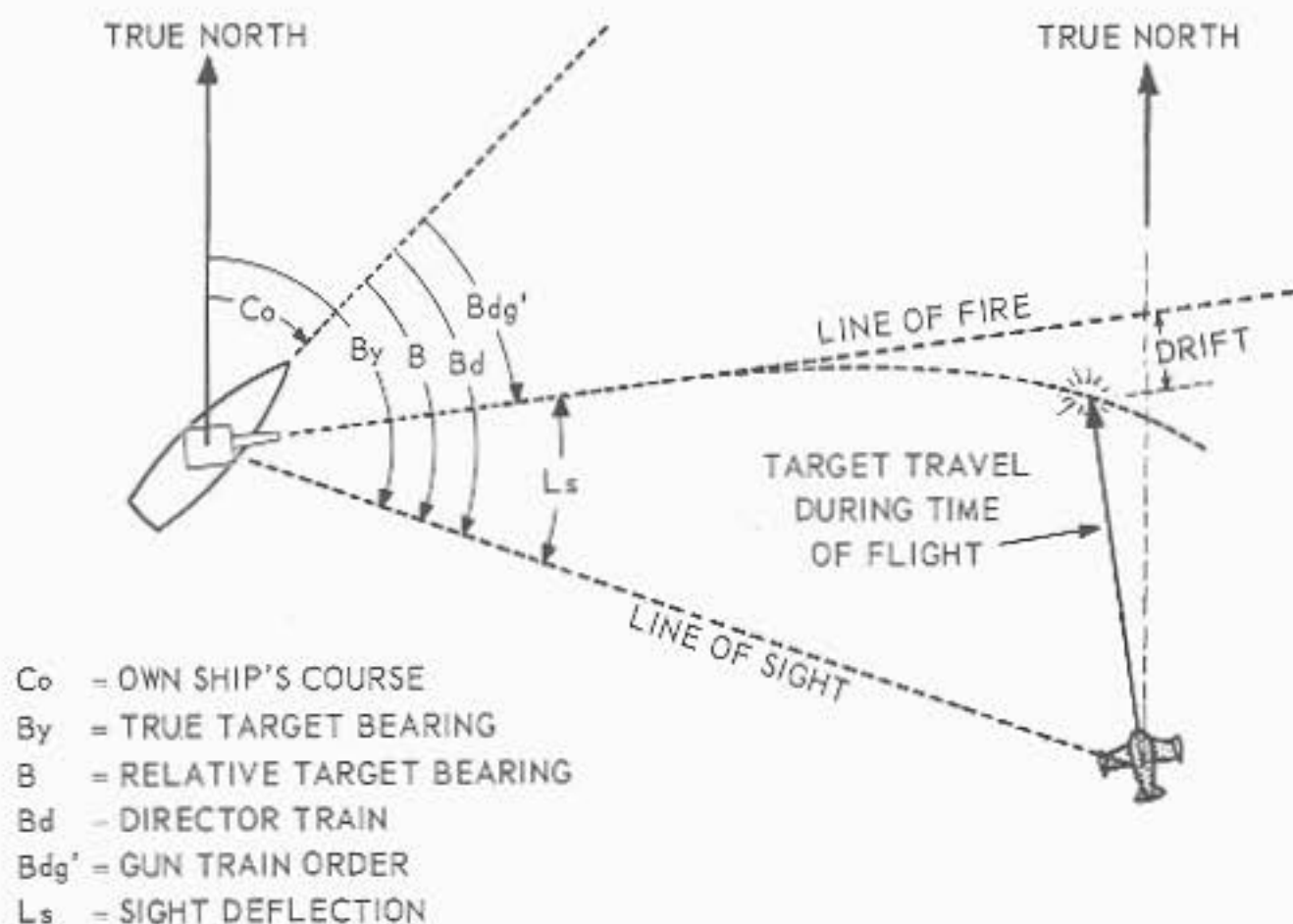
Figure 6-19.—Effect on super-elevation: A. Increased range. B. Increased target elevation.

is this true) and that super-elevation is not shown in the figure. You will recall that super-elevation is a part of sight angle. Figure 6-21 shows the relationship of the various angles in gun train order. These angles are easily understood. However, we will discuss two items which may be new to you. First, notice that relative target bearing (B) and director train (Bd) are shown as equal angles. This is true only when the ship's deck plane is in the true horizontal (when there is no roll or pitch). Director train is measured in the deck plane, and relative target bearing is measured in the horizontal plane. All of the other quantities, except for gun train order, are measured in the horizontal plane. The second item concerns sight deflection (Ls). Sight deflection corrects for projectile drift and for the target's travel during the projectile



55,228

Figure 6-20. — Basic angles in gun elevation order.



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Figure 6-21. — Basic angles in gun train order.

time of flight. The correction in our illustration is in the same direction for both factors. If the target were proceeding on an opposite course, sight deflection would be the algebraic sum of the corrections for drift and the target's travel during time of flight because the drift correction is always to the left. In the situation shown in figure 6-21, the gun train order angle (Bdg') is less than the director train angle by the amount of the sight deflection angle. (There are various other angles in fire control, which have been omitted for simplicity in figures 6-20 and 6-21.)

Inherent Corrections

As you remember from an earlier discussion, inherent corrections are (a) correction for motion of the gun platform, (b) parallax correction, and (c) roller path compensation.

We correct for motion of the gun platform (i.e., ship's pitch and roll) by relating it to a gyrostabilized horizontal reference. You may recall from chapter 3 that one of a gyroscope's characteristics is its tendency to maintain a stable attitude in space (the other, used in gyroscopic computers, is its tendency to precess when the direction of its shaft is changed). In different gun fire control systems the gyroscopic mechanism that does this is called a stable element, a stable vertical, or a vertical gyro, but the principle is the same. The gyro maintains a fixed vertical attitude; electrical pickoff units (which roll and pitch with the ship) continuously sense their angular displacement with respect to the stable gyro axis and produce a corresponding signal. The gyro unit receives director train angle as an input; its main outputs are level angle and crosslevel angle. Figure 6-11 shows level and crosslevel.

These quantities are combined in the computer along with the ballistic and target movement (lead) corrections to make up sight angle and deflection; these, in turn, become part of the gun orders to the mounts.

Horizontal parallax corrections, as pointed out earlier in this section, are computed on the basis of a standard unit correction which is then converted at each gun mount to the proper value for that mount. Horizontal parallax correction is usually transmitted independently of gun order to the gun mounts. Vertical parallax is considered equally applicable to all mounts, since their height variations are small, and is transmitted as part of sight angle.

Roller path correction is taken care of entirely by the mount compensator mechanisms mentioned earlier.

How the Guns are Positioned

In most mounts larger than 20-mm, the guns are positioned by electric or electric hydraulic power drives. They may be positioned by automatic control (i.e., by the power drives under the complete remote control of the computer or director), in local control (by the power drives under the control of the mount crew), in manual control (by the muscular effort of the mount crew), or in hand control (in some 5-inch electric-hydraulic mounts only; the hydraulic elements of the power drive are directly controlled by the crew). Automatic control is the primary mode of control; the other modes are used either in mount adjustment or for emergencies and in training for emergencies.

As they come from the synchro transmission wiring, the gun order signals are fed to an indicator-regulator or a receiver-regulator. These perform pretty much the same function; they are the control element of the power drive (which, as you recollect from chapter 3, is fundamentally a servomechanism). The distinction between indicator-regulators and receiver-regulators is not significant functionally. From here on we will refer to all of them as indicator-regulators. Naturally there is a separate indicator-regulator for the train power drive and for the elevation power drive in each mount.

The gun order synchro signal is usually dual-speed; that is, it consists of two separate signals, one low-speed (coarse) and one high-speed (fine). (These were explained in chapter 3.) The coarse signal is generally 1-speed (i.e., synchro rotation bears a 1:1 ratio to the value being transmitted), though in some systems a 2-speed coarse signal is used for elevation (i.e., synchro rotation bears a 2:1 ratio to the value being transmitted, so that, for example, synchro rotation of 200 minutes occurs when an elevation value of 100 minutes is transmitted). In today's standard practice, the high-speed signal is 36 times the low-speed signal (i.e., the fine synchro rotor turns 360° for each 10° rotation of the coarse synchro rotor). In most synchro dual-speed transmissions, the fine synchro signal is then a 36-speed signal; in those with a 2-speed coarse signal, the fine signal is 72-speed.

Indicator-regulators now in service in gun mounts (other than bag-type major-caliber turrets, which we do not take up here) can be classified in the following general types:

1. Those with a hydraulic amplifier controlling a hydraulic A-end.
2. Those with an electronic amplifier controlling a hydraulic A-end.
3. Those with an electronic amplifier controlling an electric drive.

Most 5"/38 mounts with power drives have the first type of indicator-regulator. The incoming gun order signal goes into synchro receivers; their rotors turn and actuate sensitive hydraulic pistons which control oil flow to more powerful pistons; these position the A-end tilt plate so that the B-end drives the mount in accordance with the signal. Mechanical feedback drives the synchro stators to null position.

The second type of indicator-regulator (or receiver-regulator) is used in some turrets, in late type automatically loaded 5"/54 mounts, and in 40-mm mounts. In this type the incoming synchro signal goes to synchro control transformers which convert it into an a-c voltage whose phase and magnitude are proportional to the angle of the synchro control transformer rotors with respect to their stators. This a-c voltage is then fed into an amplifier. (In dual-speed systems, an electrical "synchronizing network" feeds the sum of the two rotor signals to the amplifier, but it disconnects or suppresses most of the fine synchro output if the gun deviates from gun order position by more than a few degrees.) The amplifier may be of the conventional vacuum-tube type, it may use transistors instead of tubes, or it may combine a tube or transistor preamplifier with a magnetic amplifier. Its output drives a motor, which regulates a pilot piston that positions or controls the position of the hydraulic A-end. The remainder of the cycle (including mechanical feedback to the synchro control transformers) is similar to the first type described.

In the third type, synchro control transformers, synchronizing networks, and amplifiers function as in the second type, but the amplifier output goes to an amplidyne drive system (something like an electrical A-end and B-end) described in chapter 3. Again, mechanical response drives the synchro stators to null.

How the Guns are Fired

Fire control does not end with control of gun aim. It also includes control of actual firing. This means initiating the firing impulse and originating (or relaying) the operational commands to gun crews. Generally, when a power drive is to be controlled automatically by a gun director or a plotting room (plot), its firing circuit is activated by whichever station is in control. Antiaircraft batteries are normally always fired by their respective directors. A dual-purpose battery is fired from either its director or the stable element in the plotting room, depending on the type of firing engagement and whether direct or indirect aiming is required. A general rule here is that when indirect-fire is used (i.e., the LOS is established by the use of maps and charts in the plotting room), firing is controlled by plot. (Indirect-fire is used only against shore targets.) This general rule works for a surface battery too, when it is engaged against shore targets or perhaps aircraft.

Surface fire against waterborne targets is just a little different. A surface target has a zero elevation angle, which means that the director pointer (the crewman who normally measures elevation) can be released from establishing the LOS in elevation. The required gun elevation is automatically established when the correct value of range is set into the computer. (Other switching at the computer is necessary but will not be discussed here.) In this setup the pointer will not know when the system is on target, so control of firing is from the stable element in plot. The stable element was selected because it is the only device in the system capable of measuring the two remaining variables in the problem—roll and pitch. The director measured bearing and range, and when compared to roll and pitch they are nearly constant; or at least predictable. We can assume that the system will be on target in bearing and range at the instant of firing.

Most of the time the followup devices in the stable element will be in automatic. This mode provides continuous measurement of level and crosslevel which are then sent automatically to the computer. Since level and crosslevel become part of the gun orders, the guns are stabilized regardless of the ship's roll and pitch. If the firing-selector switch on the stable element is in the "continuous" position, and if the level and crosslevel followups are in automatic, the guns can be fired at any time during ship's roll and

pitch by closing a hand firing key on the stable element. The hand firing key is not electrically dependent on the followups, but it wouldn't be closed until level and crosslevel were accurately measured. Level and crosslevel are measured automatically by followups, or manually by handcranks. The latter method is used in emergencies for continuous measurement in case the followups become inoperative, and for two other firing modes called selected-level and selected-crosslevel, which we will now discuss.

When the sea is very rough, automatic followups may not be able to provide a continuous, accurate measurement of level and crosslevel. Even if they can, the gun power drive may not be able to keep up with the changing gun order signals. Or, the changes may be so great that they drive the gun into its firing cutout limits opening the firing circuit. Under these sea conditions we could probably increase accuracy by removing the level and crosslevel inputs to the gun orders and allowing the gun to roll and pitch with the ship. At least we would eliminate the chances for error mentioned in this paragraph.

Level or crosslevel, one or the other, will usually have a larger variation, depending on the bearing of the gun and the roll and pitch of the ship. It is usually possible to leave the smaller variable in automatic and depend on its followup. An arbitrary value for the larger is "selected" at the stable element (stable vertical for turrets) and becomes a stationary input to the computer. The selected quantity must permit the gun to be correctly aimed at some point between the observed limits of the ship's roll and pitch; usually about the midpoint. Electrical contacts on the stable element automatically close the firing circuit (if the stable element automatic firing key is closed) at the instant ship rolls or pitches to the selected level, or to the selected crosslevel. The method of fire is chosen by the stable element operator who may operate his firing selector switch to the continuous, selected-level, or to the selected-crosslevel position.

OBSERVATION AND CORRECTION OF FIRE

Although the preceding discussion of fire control has referred often to the desired ideals of accuracy and speed in solution, and has at least hinted (it has not been possible to describe or even to refer to them all) at the refinements in modern fire control systems, it is still true that not all the factors which affect the flight of a

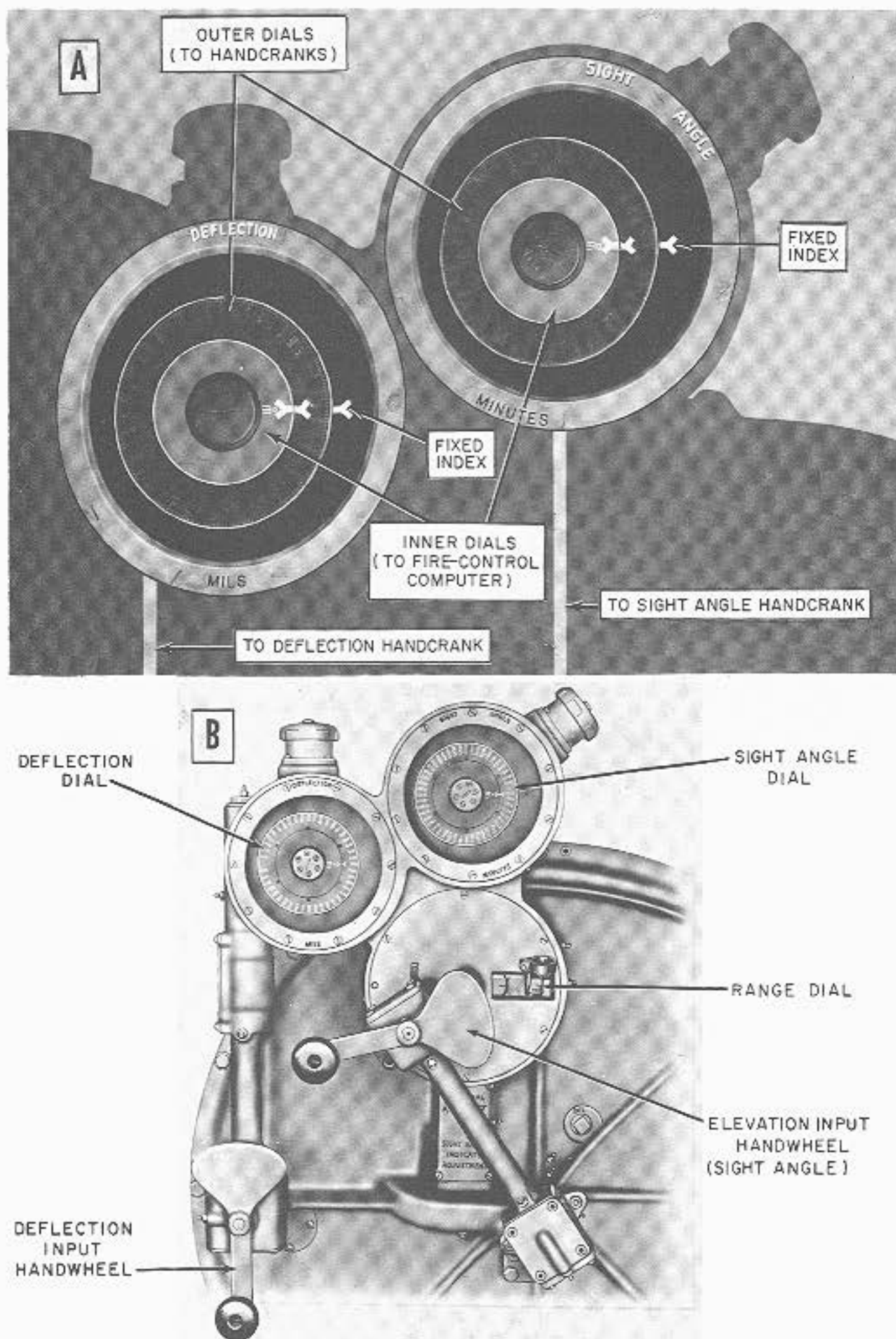
projectile can be precisely evaluated in advance of firing. Even with the best fire control equipment available, experienced gun crews, and efficient fire control personnel, the opening shots may not hit the target. It is therefore necessary to apply corrections to the initial firing data. These corrections are called SPOTS.

The initial spot is based on a system analysis of inherent errors. Even though the initial spot is figured precisely, external ballistic factors may still cause projectiles to miss the target. When this happens spots (based on where the rounds hit in respect to the target) are applied to subsequent salvos. Spotting is taken up in further detail in chapter 9 of this text.

SECONDARY METHODS

So far in discussing fire control, we have concentrated on the primary methods of battery operation. These are the ones most commonly used, and the ones which permit employment of the ship's armament with the greatest efficiency. But battle damage, personnel losses, and accidents can disable any system to the extent that some secondary operating methods are essential if the system is to keep operating at all, even if not at full efficiency. Aboard ship you will not only employ such methods in battle operations, but also in training for such emergencies.

All 3" gun mounts and larger are equipped with adjustable sights. With these, it is possible to offset the gun bore axis from the LOS to the desired sight angle and deflection. This function is performed by a crewman called the sight-setter, who mans the sight-setting indicator. In gun mounts 5-inch and larger, this unit contains handcranks and gearing for physically moving the sight optical units (or moving optical parts within the sights), and two sets of dials (fig. 6-22A or 6-22B). One set, driven by the sight gearing, displays present sight angle and deflection. The others are synchro-driven to display sight angle and deflection ordered by the computer. (3"/50 mounts do not have the synchro-driven dials.) Even in automatic operation the sightsetter mans his station and cranks the sight gearing to keep the sight indicator dials matched up with the computer-controlled dials so that the LOS of the gun sights remains on target even though the gun bore axis is offset in accordance with the sight angle and deflection components of gun order. In 3"/50 and 5"/38 mounts, an extra range dial coupled to the sight angle crank reads directly in yards of range to a surface target.



84.211.2
Figure 6-22. — A. Sight setting component arrangement. B. Sight angle and deflection dials.

In all types of secondary (local) control the gun must be laid by gun-laying personnel on the mount. In older types like 40-mm and 5"/38 mounts the pointer on the left side of the mount elevates and depresses the gun while the trainer (on the right) trains the mount. Each gun layer has a gun sight. They may either control the mount power drive or position the mount by their own muscular effort (manual operation).

In 3"/50 RF (rapid-fire) mounts, and automatically loaded 5"/54 mounts, there is no provision for completely manual operation. The mount can be operated in local, but only if the power drive is functioning. Manual operation is limited only to maintenance and stowing movements. In such mounts, either of the gun layers can take over complete local control of gun positioning.

In local control, gun layers must work with the sightsetter. Here is the basic procedure:

1. The gun layers position the mount so that their lines of sight are on target, and they continue positioning it to keep on target.

2. Most mounts have synchro-driven dials, as in figure 6-22A, which indicate computed sight angle and deflection. The sightsetter cranks in sight angle and deflection until the outer dials (positioned by his handcranks) match the inner (synchro-driven) dials. This action simultaneously repositions prisms in the sight optical systems, causing the telescope lines of sight to shift off target.

3. The gun layers drive the mount to keep on target. This automatically offsets the gun bore axis by the angles that the sightsetter has cranked in.

Figure 6-22B shows the handcrank arrangement; figure 6-22A shows in more detail how the dials look when matched. The fixed index shows the angular values actually cranked in. It is used when there is no synchrotransmission; under these conditions, the information is either transmitted by phone or comes from the mount captain, based on his estimate of range, ballistic corrections, and lead.

On mounts 5-inch and larger, the sights are carriage mounted. The sights therefore train with the carriage, but the carriage doesn't elevate. To make the sights elevate with the gun, they must be driven by a mechanical linkage from the elevating gear. Thus the sight angle prisms in the optical systems must be positioned

by the algebraic sum of two inputs—gun elevation and sight angle. This is the function of a mechanical differential in the sight angle gear train.

Mounts smaller than 5-inch have slide-mounted sights, which elevate and train with the gun barrel. The differential is not needed. Nor do mounts smaller than 5-inch have synchro receivers for sight angle and deflection. When necessary, computed sight values are transmitted by phone.

When the gun bore axis offset is correct, the gun layers have been staying on target, and the gun is loaded, the gun can be fired by the pointer's firing key. This may be done on the mount captain's command. In the complete absence of firing current or if the ammunition fails to fire electrically, some 5-inch guns can be fired by percussion when the pointer depresses a firing pedal, which actuates a mechanical linkage to the firing mechanism. Combination primers in the ammunition are necessary to provide this capability.

Secondary methods used in the director and in fire control plot are limited. In earlier linear-rate fire control systems, the director can be driven manually in the event of power drive failure. This is not true in newer systems; manual operation is used in storing the director or in maintenance only. If synchro transmission fails, range, bearing, and elevation data can be sent to plot by sound powered telephone, as can firing orders to the mount if the firing circuit fails. In the event of stable element failure, some older fire control systems can be stabilized manually by a crewman who keeps a telescope's line of sight aligned with the horizon. If synchro transmission fails with any computer inputs or outputs, data can be introduced manually or read from dials and telephoned from plot, but neither stable element nor computer can function without the proper supply. When any failure prevents data from reaching the gun mount, secondary methods must be used at the gun mount.

LINEAR-RATE FIRE CONTROL SYSTEMS

Gun fire control systems can be, on the basis of their fundamentals of operation, divided into

two main classes—linear-rate and relative-rate, as explained earlier in this chapter. There are several marks and mods of linear-rate systems, including two dual purpose types—the Mk 37 and the Mk 68. The main difference between these two is that the Mk 37 uses the Mk 1A electro-mechanical analog computer, whereas the Mk 68 system uses an electronic analog computer, and it is capable of tracking targets traveling at supersonic speeds.

GUN FIRE CONTROL SYSTEM MK 37

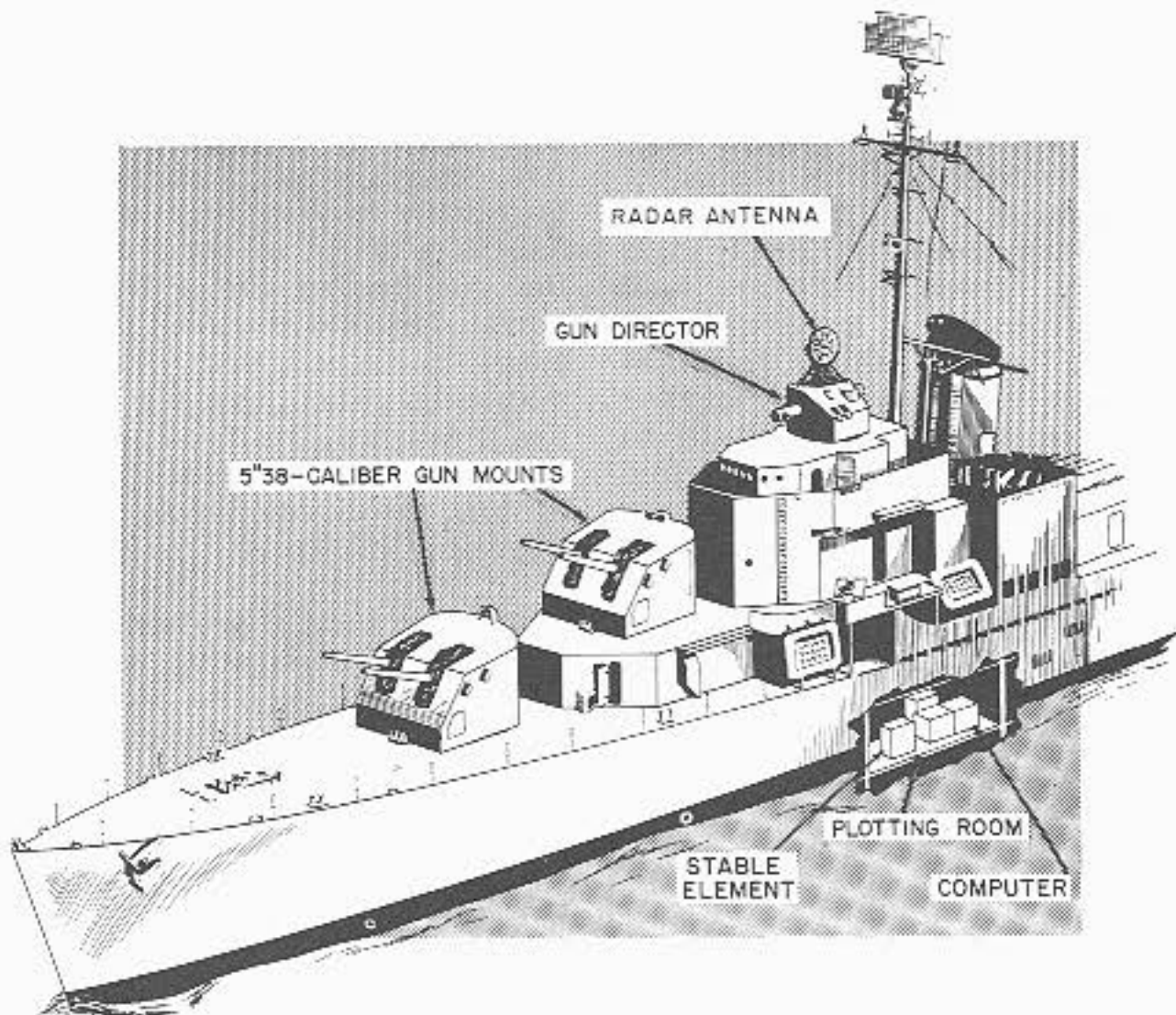
The Gun Fire Control System (GFCS) Mk 37 is installed in some destroyers, cruisers, carriers, and large auxiliaries. It is the primary means of controlling 5"/38 mounts for both surface and antiaircraft fire. It may be used, with appropriate cross connections, to control machinegun mounts, or major-caliber surface guns in special applications.

System Functions and Components

The primary functions of the Mk 37 GFCS are to provide:

1. Continuous automatic gun positioning.
2. Continuous automatic fuze setting.
3. Continuous sight-angle and sight-deflection indication at the guns.
4. Continuous-aim, selected-level, and selected-crosslevel fire.
5. Star shell fire control.

A complete system consists of three major units: a Mk 37 director with a radar; a Mk 6 stable element; and a Mk 1A computer, with the associated instruments at the gun. Destroyers and auxiliaries having Mk 37 systems carry one complete system (fig. 6-23). Larger ships (such as cruisers and carriers) may have more than one system.



84.216

Figure 6-23.— Mk 37 system, destroyer installation.

Directors are installed high in the ship's structure, and stable elements and computers are installed below decks in protected plotting rooms. All elements are connected by a synchro transmission system through one or more switchboards located in plotting rooms.

Normally, each director in a multiple installation controls a designated group of guns and is connected to a designated computer. However, switching arrangements permit any director to control any or all guns and connect to any computer.

Information Flow

Figure 6-24 is a simplified schematic showing the principal interconnections of a single Gun Fire Control System Mk 37. All electrical circuits between units of the system pass through the fire control switchboard.

The director carries sight telescopes and a rangefinder and radar equipment to measure and transmit to the computer director elevation, director train, and present range. The control officer in the director may estimate target angle, target horizontal speed, and rate of climb or dive and send these values by telephone to the computer operators. Hand-operated transmitters in the director provide electrical transmission of elevation, deflection, and range spots (i.e., observed corrections) to the computer.

The stable element receives director train from the computer and measures level angle and crosslevel angle. These values are sent mechanically to the computer. A third value, level plus crosslevel divided by thirty, is transmitted from the stable element to the computer to make up a LOS stabilization signal to be transmitted to the director. Other electrical inputs to the computer include own-ship course from the gyro compass and own-ship speed from the ship speed sensor. Lastly, computer personnel add manual inputs as required.

The computer transmits electrically to the gun mount:

1. Gun elevation order.
2. Gun train order.
3. Sight angle.
4. Sight deflection.
5. Fuze-setting order.
6. Train parallax for a 100-yard horizontal base.

These values are used for gun positioning, sightsetting, and fuze setting.

In addition, the computer generates and transmits to the director changes in range, elevation, and train. With level and cross-level, these changes are used to hold the director optics and radar on the target continuously. This process includes keeping the rangefinder and radar on the target.

The Mk 37 Director

The Mk 37 director is designed, primarily, to control 5"/38 dual purpose guns. Its primary function is to determine target position in terms of:

1. DIRECTOR TRAIN—the angle between the fore-and-aft axis and the vertical plane containing the line of sight, measured in the deck plane clockwise from the bow of the ship.
2. DIRECTOR ELEVATION—the elevation of the director's line of sight above the reference plane, measured in the vertical plane containing the line of sight.
3. PRESENT RANGE—the distance of the target from own ship, measured in the line of sight.

Briefly stated, the director's secondary function is to be the control station for the entire fire control system. Normally, all units operate by remote control from the director, and as long as the problem is being solved correctly, only the gun-loading crews have work to do. The remainder of the crew simply observe operations to insure that everything is operating correctly. When changes in the problem setup are necessary, the director crew can accomplish them by remote control. To control the entire system, the director is equipped to do the following:

- a. Spot service projectile fire.
- b. Spot illuminating projectile (star-shell) fire.
- c. Correct computer calculations.

CONSTRUCTION. — The director (fig. 6-25) is an armored steel box that can be trained (much like a gun mount) on a precision-aligned roller path mounted on an armored cylindrical barbette built into the ship's structure. It contains an optical rangefinder and pointer's and trainer's prismatic telescopes, radar equipment, power drives for positioning the director, an observation hatch used by a control officer (who may

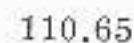
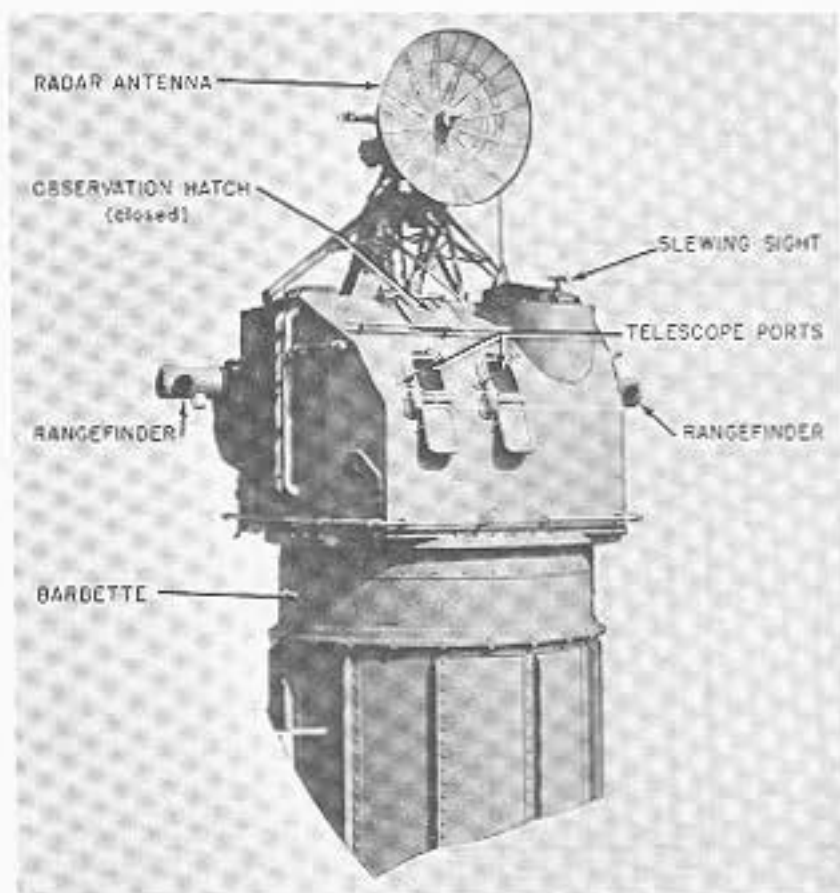


Figure 6-24. — Data flow in Mk 37 GFCS. Simplified schematic (Star shell data omitted.)



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Figure 6-25.—Gun director Mk 37.

also serve as a spotter), and a slewing sight for positioning the director to pick up the target.

GENERAL OPERATION.—The line of sight is kept on the target in train by turning the entire director on its roller path. The angle the director turns from the centerline of the ship is director train. Rotating the telescope prisms, the radar antenna and rangefinder, elevates the line of sight to give director elevation.

Train and elevation of the director line of sight can be done in four modes:

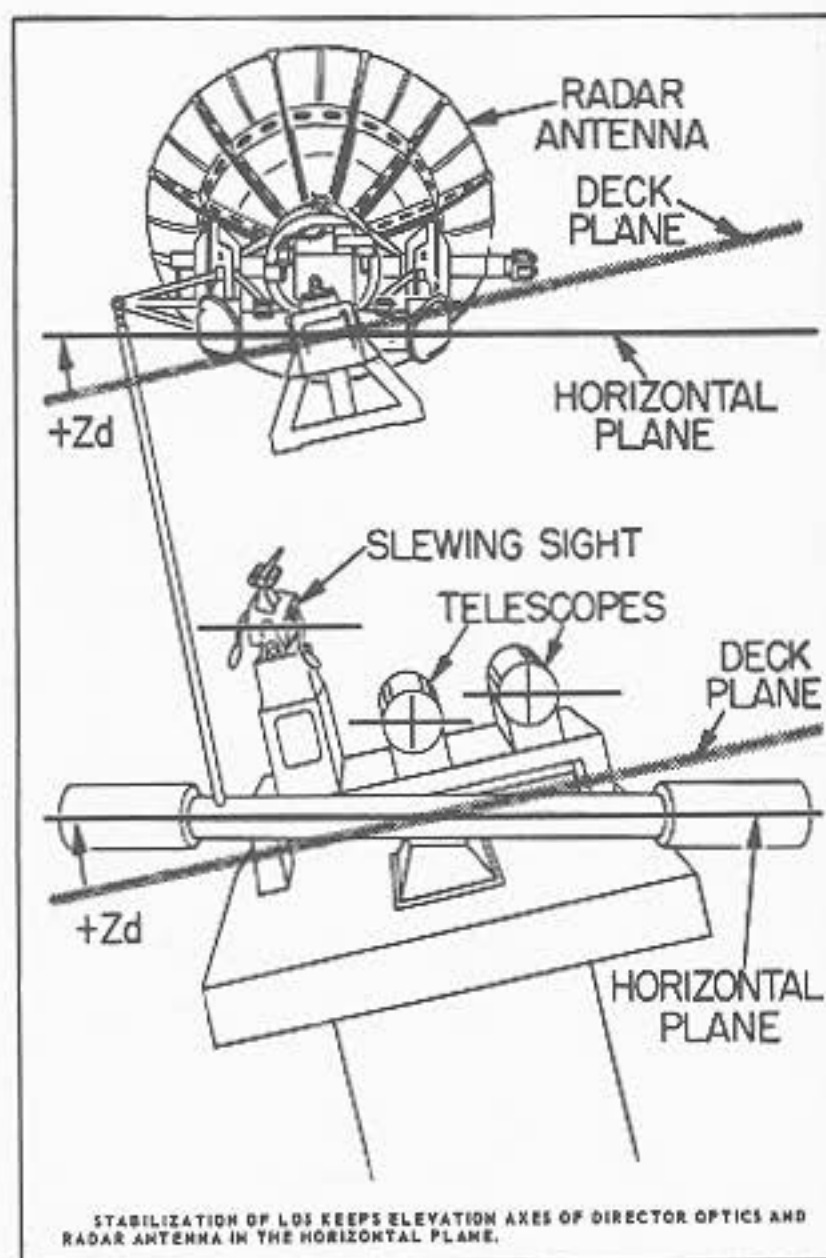
1. **AUTOMATIC** (or remote) control of the power drives by signals from the computer, modified as necessary by the handwheels.
2. **LOCAL** operation of the power drive by means of the handwheels.
3. **MANUAL** operation by direct gearing from the handwheels.
4. **SLEWING** or training and elevating rapidly to change targets.

The rangefinder determines range optically. The rangefinder operator can adjust the apparent position of the "wander marks" with relation to the target in the rangefinder field of view. This adjustment is transmitted by synchro to the

computer as a range signal. The computer generates change-of-range signals that are fed back to and control rangefinder adjustment.

Radar is used for target acquisition and tracking, as explained later. It also provides for automatic tracking.

STABILIZATION.—Director optics and the radar antenna are stabilized both in level and crosslevel. Stabilization in level is discussed below. Crosslevel stabilization is done by a servo controlled by a crosslevel synchro signal received directly from the stable element (fig. 6-26). The crosslevel servo motor is connected to the telescopes, rangefinder, slewing sight, and radar antenna. The crosslevel drive rotates the telescopes, the whole rangefinder, and the radar antenna about the line of sight by the amount of



55.243

Figure 6-26.—Crosslevel stabilization.

the crosslevel angle. Thus the telescope crosshairs, the rangefinder, and the radar antenna are kept horizontal, so that director elevation is measured in the vertical plane.

TRAIN, ELEVATION, AND SLEWING CONTROL.—This discussion is chiefly concerned with automatic optical control of the director. Automatic operation in regard to data transmission is similar for radar and optical track; radar will be discussed later. We begin our discussion with optical track operation.

Initially, the target is acquired by slewing the director to the target by use of the slewing sight. The slewing sight can drive the director to the target at a maximum rate of speed; much faster than speeds generated by the pointer and trainer handwheels. The slewsight also has a much wider field of vision than is available through the pointer and trainer optics. When the slewsight is on target, the pointer, trainer, and rangefinder operator should see the target in their optics. They then take over and provide more accurate tracking of the target. During the tracking process, director train, director elevation, and range (and any changes thereto) are automatically fed into the Mk 1A computer. Computer solution time can be shortened if the director officer telephones estimated values of target angle, target speed, and target rate of climb or dive to the plotting room. But, the computer can solve the fire control problem without these estimates, and that is most often the case. When the computer starts generating a solution, it transmits computed (generated) corrections to the director keeping it on target as long as the solution remains correct.

Computed bearing correction consists of increments of computed change in director train, including changes in train caused by relative target motion, changes in own ship's course, and the effect of deck tilt. If computed bearing correction is correct, the line of sight stays on target without handwheel motion.

If the director while in automatic tends to drift off target, the trainer can, by closing the rate control key and keeping the line of sight on target with his handwheels, introduce a correction into the computer. This is necessary if there is a change in target course or speed. If the target becomes obscured, the trainer allows computed bearing correction to continue to drive the director until the target reappears.

Rate controlling also can be accomplished by the computer operator.

The description of train control applies generally in elevation control. The telescope prisms rotate; the rangefinder rotates about its longitudinal axis; and the radar antenna rotates about its mounting to follow the target in elevation. Now director elevation is the sum of target elevation and level angle. To hold the LOS on target, in elevation, director elevation must be changed by adding increments of generated elevation and continuous corrections in the value of level. These are received from the computer and are fed to the sights, rangefinder, and radar, so that the LOS is stabilized in level as it tracks the target.

To shift from one target to another or to make any other large change in elevation and train, the director officer may slew the director. He does this by operating a key on the slewing sight and pointing the sight at the target. This takes away control of the director from the pointer and trainer, and drives the director at high speed until its line of sight coincides with that of the slewing sight. Slewing brings the target into the fields of the optics, and thus designates the target to the director crew.

RANGE CONTROL AND SPOT TRANSMISSION.—The rangefinder's optical elements and range synchro transmitter are adjusted for range by a differential, which accepts inputs both from the operator's knob and from a servo controlled by a generated range signal from the computer. Thus the rangefinder operator can correct the rangefinder adjustment and transmit an accurate value of observed present range. He also can rate control the system by pressing a button and operating his range knob, as explained in connection with train operation.

The rangefinder operator has a transmitter for sending spots in range to the computer. The director control officer has a transmitter for sending bearing and elevation spots to the computer.

RADAR.—The automatic-tracking fire control radar has its antenna and parabolic reflector mounted atop the director, with indicator scopes and other components in the director and below decks. This radar has three types of antenna scan: spiral for target acquisition, conical for tracking, and circle for spotting shell splashes in surface fire.

Normally, the automatic tracking feature makes rate control corrections unnecessary. Tracking signals—representing target range, bearing, and elevation—are generated from radar

information and compared with generated range, bearing, and elevation. Differences between computed and radar values are transmitted to the director as corrections, to reposition it in accordance with the radar information, and to the computer to correct its solution until it matches the radar values. Once the target has been acquired by radar, this process is continuous and automatic.

DIRECTOR CREW.—The director is normally manned by five men: a control officer, pointer, trainer, radar operator, and range-finder operator.

The control officer is in charge of the entire system when the director is in control. In addition to his mechanical functions of accepting target designation from the designating station, slewing the director, and making spots, the control officer must originate battle orders for the battery, relay orders and information from the weapons control station, and generally oversee the operation of his battery. A complete and detailed understanding of all standard commands, procedures, and safety requisites is essential.

The pointer and trainer keep the director line of sight on target in optical tracking; they rate control as necessary. Each has a firing key that can be selected to control the firing circuit, although the pointer is most often in control. In radar tracking, the pointer and trainer cause the system to shift into full-radar track by kicking foot switches when they are on target as viewed on their radarscopes. Or, by moving their power drive handwheels and watching their radarscopes, they can keep target video positioned and thereby provide an alternate method of radar tracking. The pointer and trainer also operate special handcranks which move the director in train and elevation when searching for the target around the designated target position.

The rangefinder operator mans the rangefinder, may spot in range and deflection, and may rate control in range. When the rangefinder is not used, he assists the radar operator.

The radar operator controls the operation of the radar, supervises the pointer and trainer in their use of elevation and train radarscopes, operates the radar in range, and assists the rangefinder operator when radar is not in use.

The Computer Mk 1A

The computer Mk 1A is the mechanical brain of the GFCS Mk 37. It computes continuous gun orders, which contain all significant factors that affect fire.

The gun orders, fuze-setting order, and parallax corrections are continuously transmitted from the computer to the gun mounts, where they are used to point the guns continuously, and to time fuzes so that the projectiles will explode at the predicted target position.

The computer is built in four sections: control section, indicator section, computer section, and corrector section. The first two are mounted on top of the second two, as shown in figure 6-27. The star shell computer, an independent unit, is mounted atop the main computer.

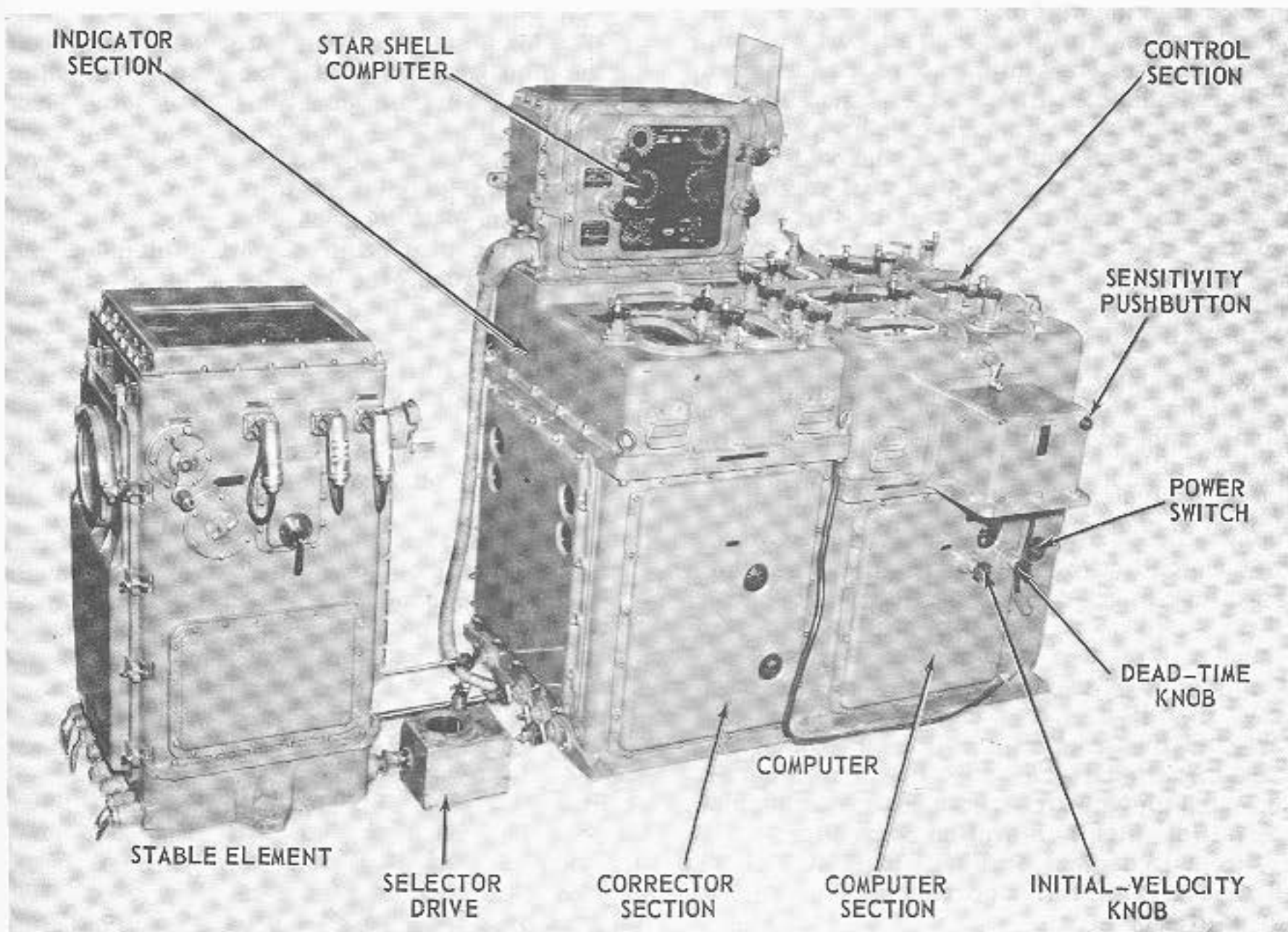
The control section contains the mechanisms for computing and controlling rates. This section has most of the knobs, cranks, and dials. The computer section contains the mechanisms used to calculate ballistics. The indicator section displays, on dials and counters, the results of ballistic calculations—sight angle, sight deflection, fuze order, and advance range. The corrector unit computes and indicates gun train order, gun elevation order, and parallax.

The computer's functions are:

1. To control continuously the positioning of dual purpose guns and the setting of fuzes and sights for either AA or surface fire.
2. To aid the director crew in keeping the line of sight on target.
3. With the star shell computer, to permit part of the dual purpose battery to be set continuously for illumination of a surface target while firing other mounts at the target in the usual manner.

STAR SHELL COMPUTER.—The star shell computer is an independent accessory with which it is possible to direct the fire of one mount for illuminating a target or target area while the rest of the battery, under the control of the main computer, fires for effect. The mount controlled by the star shell computer uses illuminating projectiles (colloquially called STAR SHELLS) that are aimed and time-fuzed to burst above the target.

OUTPUTS AND INPUTS.—Figure 6-24 shows schematically the outputs and inputs of the Mk 1A computer. Note the distinction between electrical synchro signals, electrical signals (used in



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Figure 6-27. — Mk 1A computer and Mk 6 stable element.

rate control) that are not synchro signals, mechanical inputs and outputs (between computer and stable element), and inputs manually introduced.

COMPUTATIONS PERFORMED AND FEED-BACK EFFECT.—The computer reckons relative target motion rates, which are used in generating changes in target range, bearing, and elevation. Changes in own ship's course are taken into account in computing changes in target bearing. Because rangefinder ranges are often somewhat erratic, the computer uses generated range for its calculations, to improve smoothness of operation. Measured relative target bearing and target elevation are used because they can be measured accurately and smoothly. Target elevation is obtained by subtracting level

from director elevation. Relative target bearing is obtained by adding deck-tilt correction to director train.

The computer generates increments of range, relative bearing, and elevation. Increments of relative bearing is sent to the director train receiver-regulator to position the line of sight according to the generated value of director train. It takes into account both deck-tilt correction and changes of own ship's course. Thus, if the solution is correct, bearing correction will keep the line of sight on the target in train while the ship rolls, pitches, and changes course.

Increments of elevation are added—in the computer—to the level plus crosslevel function quantity. The sum, called elevation correction, controls the director elevation power drive to

hold the LOS on target in elevation, if the computer solution is correct.

The changes in director train and elevation from bearing and elevation corrections show up in the new values of director train and elevation. Thus there is a continuous feedback into the computer, since the director continuously transmits director train and elevation to the computer. The computer and director together form a regenerative system. This allows the director to follow an obscured target by riding the computer solution; as long as the solution is correct, the director will remain on target.

Wind computations are made empirically. Air-density corrections are computed separately and applied to the computer as a change in initial velocity. Initial velocity settings are otherwise based on equivalent service round (E.S.R.) data—explained in chapter 5.

The quantities considered in the computation of sight angle, sight deflection, and fuze setting are:

Sight angle

1. Elevation prediction.
2. Superelevation.
3. Wind elevation correction.
4. Initial velocity elevation correction.
5. Complementary error.
6. Elevation parallax correction.
7. Elevation spot.

Sight deflection

1. Deflection prediction.
2. Drift.
3. Wind deflection correction.
4. Deflection spot.

Fuze setting

1. Time of flight.
2. Dead time.

The details of rate controlling are not discussed in this text. They are found in OP 1064.

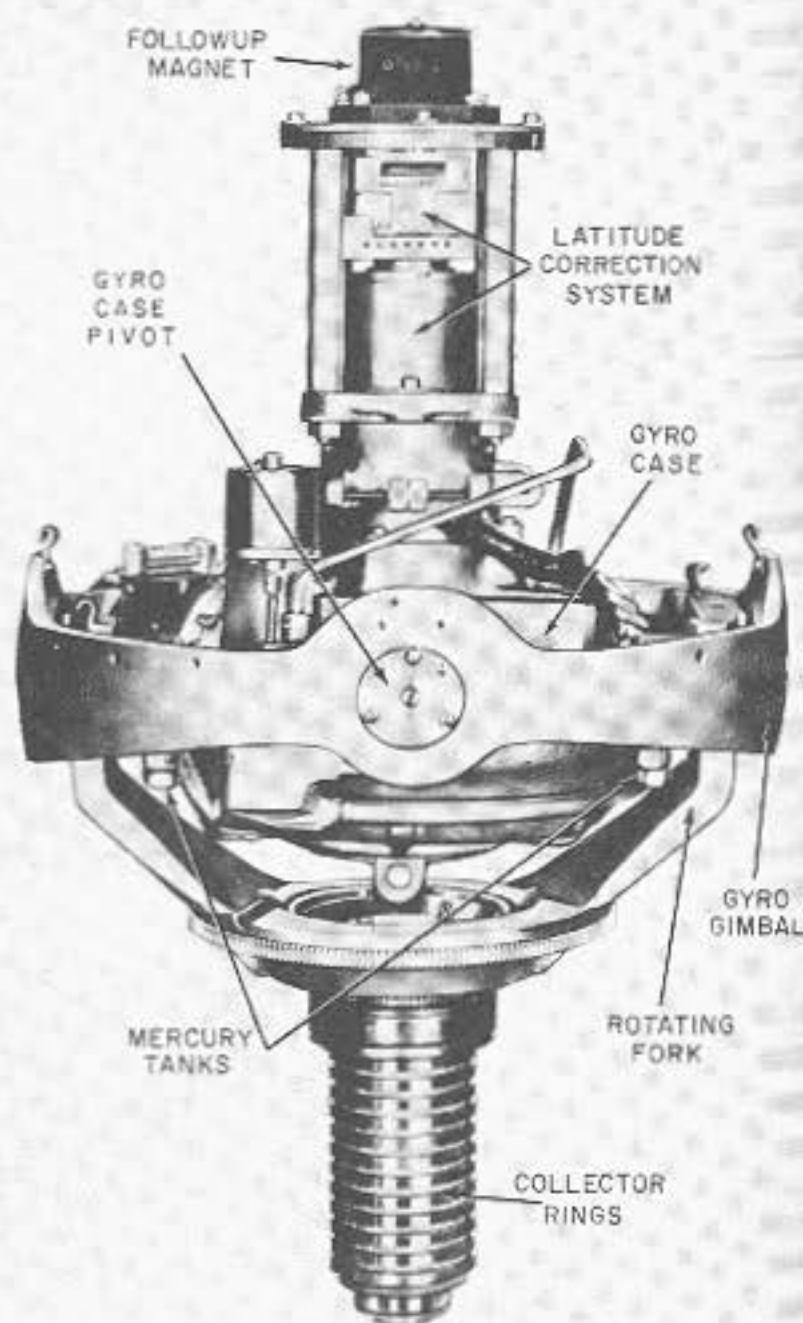
COMPUTER CREW.—The full operating crew for the computer consists of a range operator, a bearing operator, an elevation operator, and a star shell computer operator. In addition, a stable element operator and a switchboard operator are required for each computer-stable element combination.

The Mk 6 Stable Element

The Mk 6 stable element (fig. 6-28) is located in the plotting room next to the Mk 1A computer. In general, its primary function is to measure level angle and crosslevel angle. The stable element does this by using a gyroscope to establish true vertical and true horizontal.

The principal functional elements of the Mk 6 stable element are the sensitive element, the measuring group, the righting system, and the followup system.

SENSITIVE ELEMENT.—The sensitive element is the heart of the stable element; it consists



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Figure 6-28.—The Mk 6 stable element.

of the gyroscope, gyro case, gyro gimbal, and rotating fork (fig. 6-28). The gyro wheel and the ball bearing-mounted axle form the rotor of a high-speed (8500 rpm) induction motor. The gyro assembly pivots within the gyro gimbal on a case axis perpendicular to the spin axis. The gyro gimbal is supported by the arm of the rotating fork on the gimbal axis. This axis arrangement gives the gyro three degrees of freedom.

MEASURING GROUP.—The measuring group consists of an inner (level) gimbal, an outer (crosslevel) gimbal, training gear, and an umbrella containing two pairs of followup coils, one pair for level and the other for crosslevel (fig. 6-29). With this gimbal arrangement, level is measured in a vertical plane while crosslevel is measured in a plane perpendicular to the deck.

RIGHTING SYSTEM.—The righting system makes the gyro axis assume and maintain a true vertical position. It has two principal parts—the mercury control system and the latitude correction system (fig. 6-28).

The mercury control system consists of two interconnected tanks—one on each side—containing mercury and a gimbal rotation motor that rotates the entire gyro assembly at 18 rpm. While the gyro wheel is horizontal, the mercury level in both tanks is the same. If the wheel tilts from the horizontal, the tanks also tilt, and mercury flows at a controlled rate from the higher tank to the lower. The net effect of the mercury flow and gimbal rotation is that by the time the mercury has reached the lower tank, the tank has rotated 90° from the low point of the gyro wheel, and the pressure exerted here causes the gyro spin axis to precess back to vertical. Thus the gyro automatically erects itself when put into operation, and remains stabilized in a vertical position.

Now consider the latitude correction system. Figure 6-30 depicts the effect of the earth's rotation on a free gyro. A gyro (like gyro A in figure 6-30) located at either pole will be unaffected by the earth's rotation. But a gyro located at the equator will, to an observer standing on the earth, appear to turn backward (westward) with respect to the earth's rotation, at the rate of one revolution every 24 hours. At any point between the pole and the equator, as the figure shows, the gyro wheel will appear to gyrate westward once every 24 hours about an axis parallel to the earth's.

This effect can be compensated for by making the gyro precess slowly eastward at the same

rate. The gyro's plane of rotation will then remain horizontal. To do this, a latitude weight at the north point of the gyro wheel makes it precess eastward. The position of the latitude weight is adjustable, so that it can be set for the ship's latitude. A synchro which receives own ship's course, director train and other inputs keeps the latitude weight on the north point as the ship turns and the stable element trains.

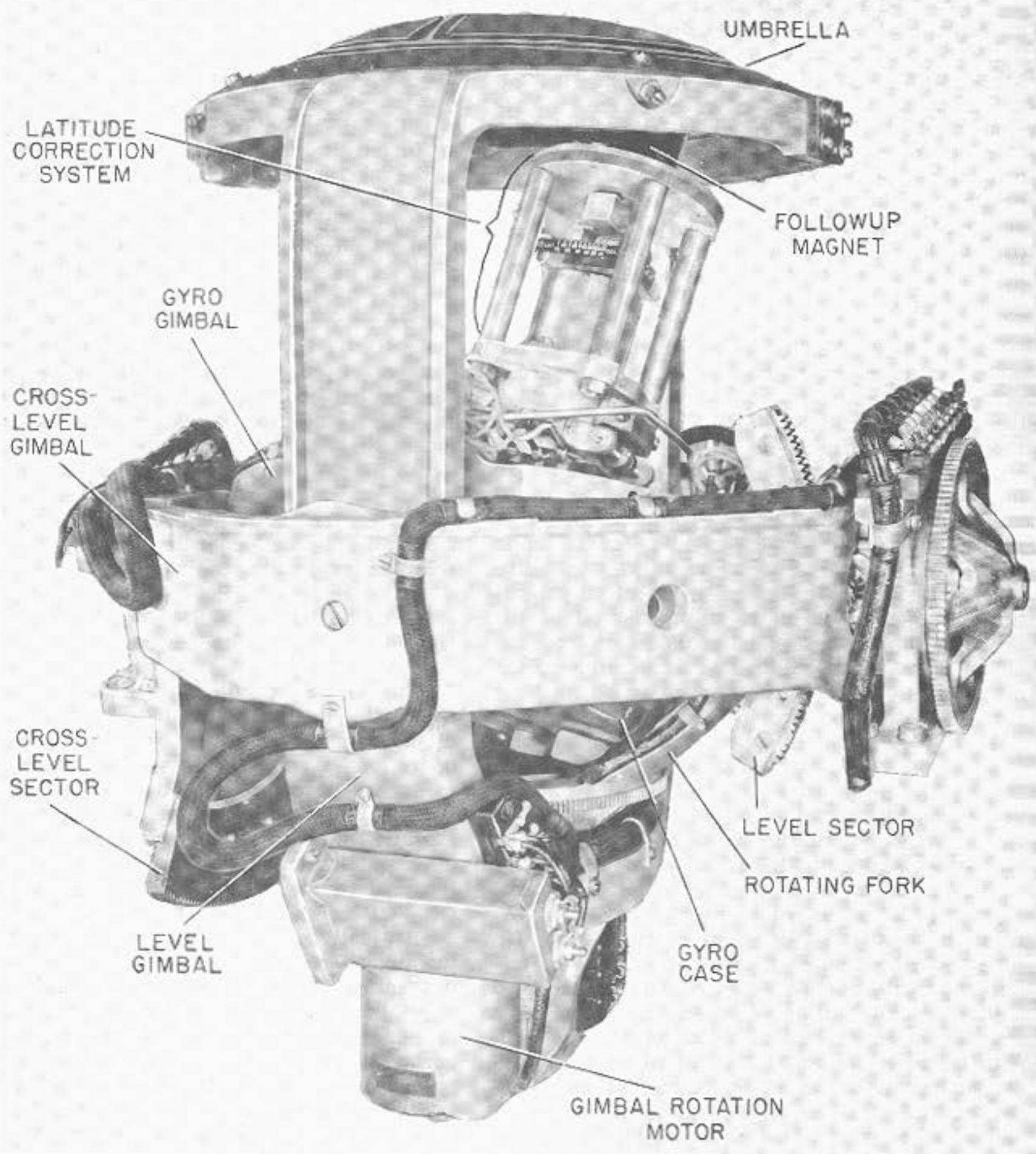
FOLLOWUP SYSTEM.—The followup system performs the actual measurement of level angle and crosslevel angle. The system (figs. 6-28 and 6-29) includes the umbrella and followup coils (mentioned in connection with the measuring group), a followup a-c electromagnet on top of the gyro case, and a level and crosslevel followup (not illustrated). When (because of ship's pitch or roll) the umbrella is not aligned with the gyro, the followup magnet induces unbalanced voltages in the followup coils. The algebraic sum of these voltages goes to an amplifier which uses the amplified signal to control rectifier tubes whose output feeds a d-c servo motor. The motor drives the umbrella until it is aligned with the gyro. Thus the umbrella "follows" the gyro spin axis. The followup units also drive synchro transmitters and operate firing switches for selected level and crosslevel fire.

FIRE CONTROL SYSTEM MK 68

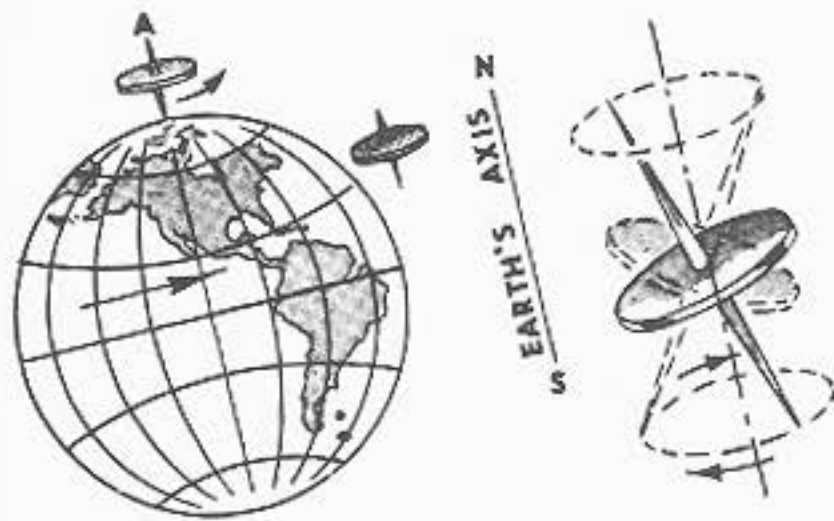
The GFCS Mk 68 is a dual-purpose, fully automatic system used to control 5"/54 and 3"/50 guns. Variations from fully automatic operation—discussed later—are possible, to meet certain tactical situations and emergencies.

The Mk 68 system discussed here is a representative system only; for a detailed discussion of a particular mode of the system (of which there are many), refer to the applicable system OP—OP2649, OP3836, etc.

Basically, GFCS Mk 68 performs the same functions as GFCS Mk 37 except that it is capable of tracking targets traveling at supersonic speeds. The Mk 68 system has numerous dials, hand-cranks, indicator lights, and similar operating controls, which gives it the appearance of being much more complicated than the Mk 37. Most of these, however, are for checks and test purposes and for placing the system in standby condition. Actually, the system is designed to operate very simply and with fewer personnel than the Mk 37 system. Testing and maintenance have also been simplified through plug-in module



110.67
Figure 6-29. — Complete stable element gyro assembly.



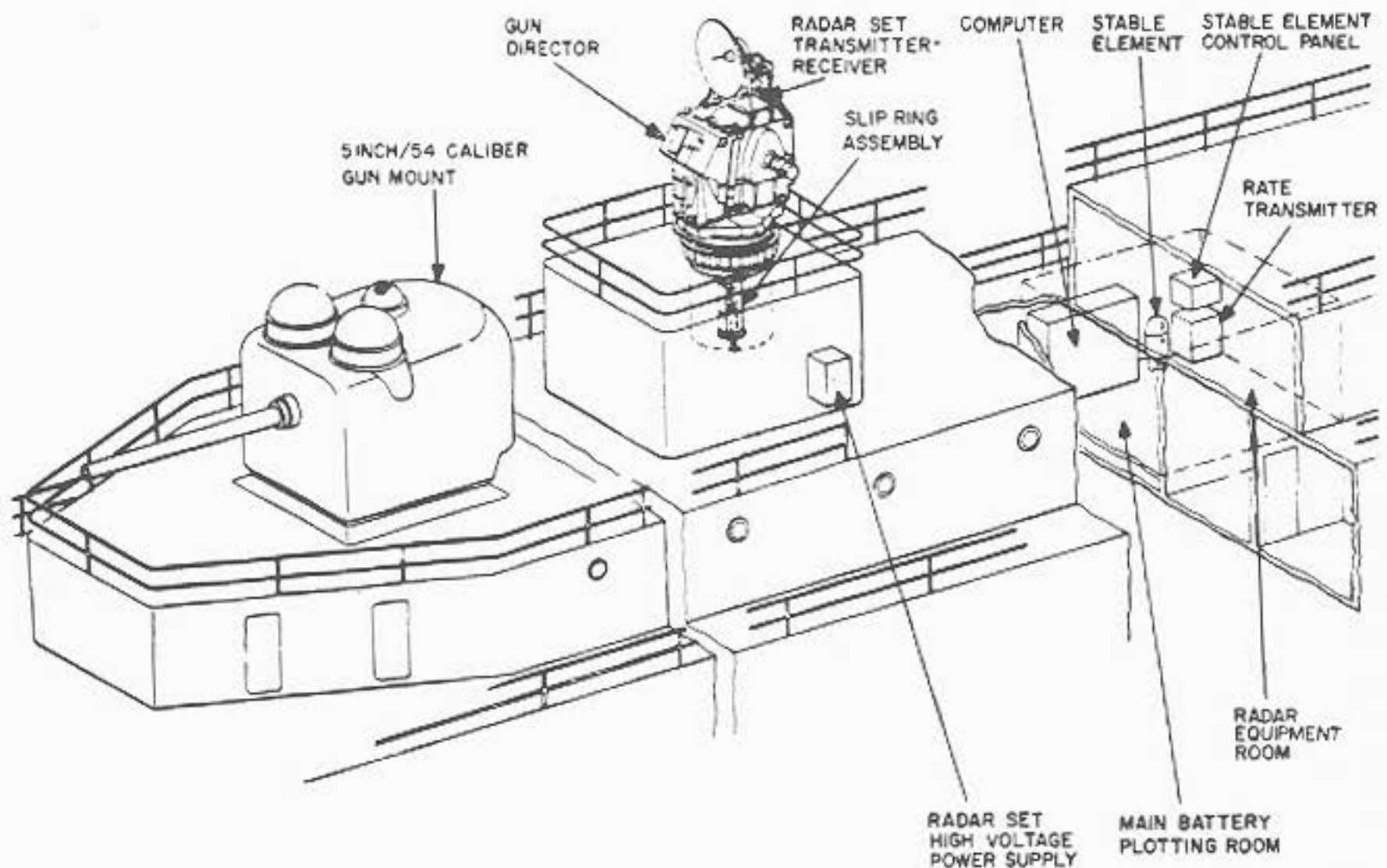
12.150
Figure 6-30.—Effect of earth's rotation on relative position of gyro.

design, built-in testers, and test panels. A typical Mk 68 system layout aboard a DLG is shown in figure 6-31.

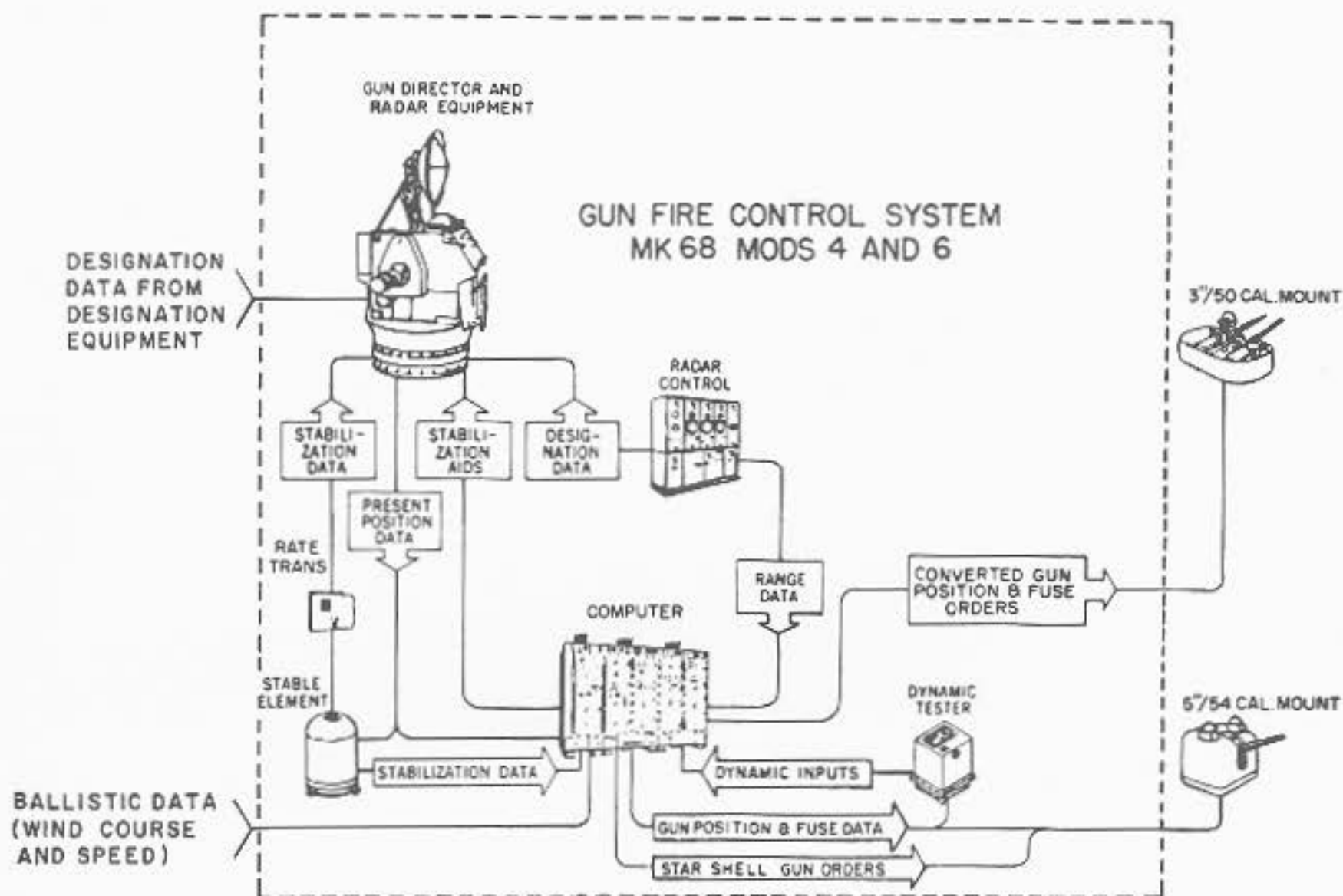
Information Flow and System Components

System components and primary data flow are shown in figure 6-32. The components are discussed separately as to their function in the system. Primary data flow is much the same as in the Mk 37 system.

Before discussing each unit separately, a brief, overall look at the system's data flow may be useful. The director, which serves as the battery control station, furnishes present target position to the computer and stable element. The computer Mk 47 uses this information plus own ship's motion data and ballistic



170.13
Figure 6-31.—Arrangement of GFCS Mk 68.



166.122

Figure 6-32.—Gun fire control system Mk 68 data flow.

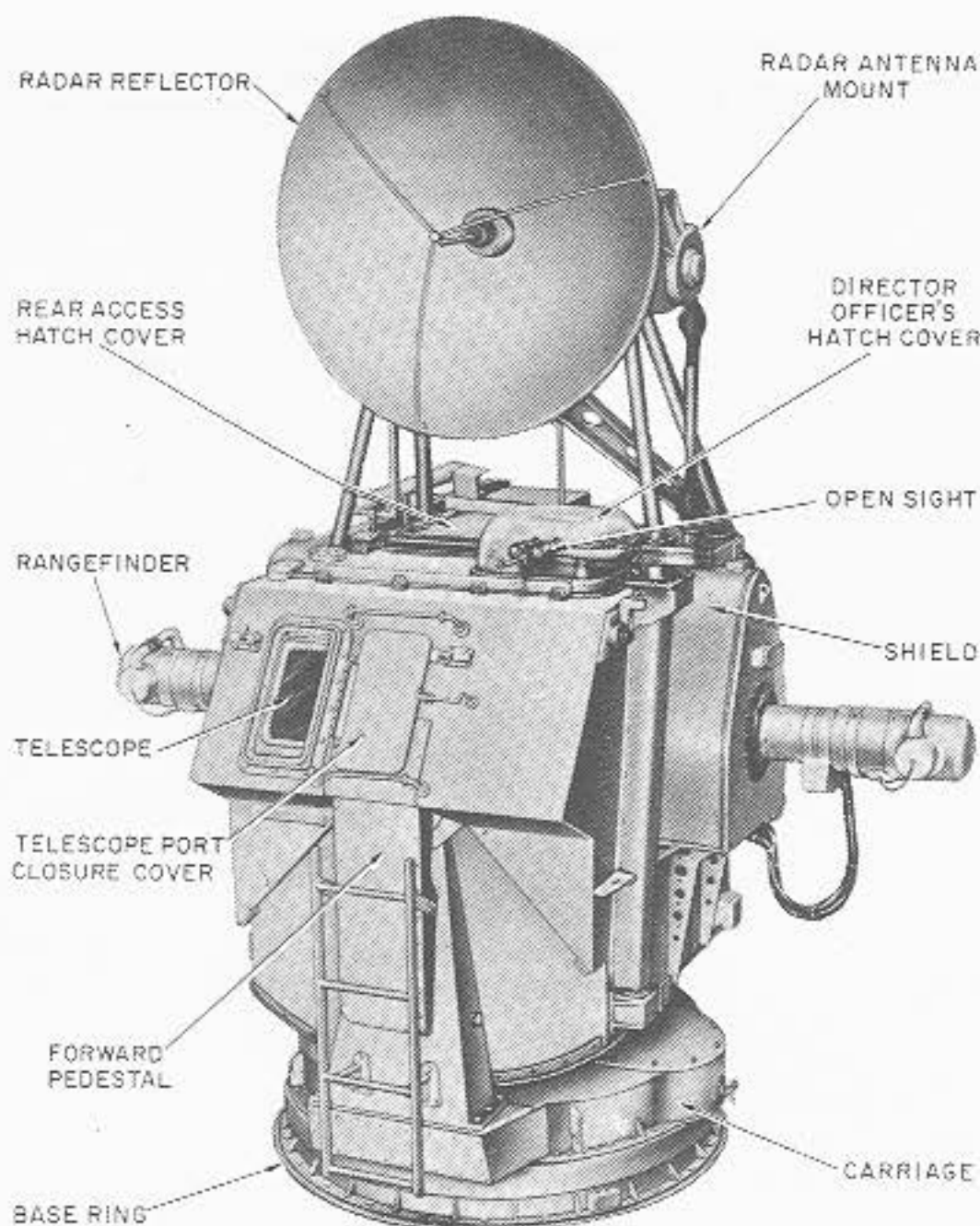
data to compute gun orders for the 5" guns. The computer Mk 116 (or the gun order converter Mk 20 and star-shell computer Mk 1) is used in conjunction with the Mk 47 computer to produce gun orders for the 3-inch guns and star-shell gun orders. The stable element, which establishes the stabilized horizontal reference plane, provides the director and computer with stabilization signals. Data flow between major units is routed through the fire control switchboard and is continuous as long as the director remains on target—either in radar control or optical control.

Gun Director Mk 68

Gun director Mk 68 determines the present position of the target by either optical means or radar equipment, part of which is located on the director. The optical equipment consists

of the director officer's open sight and binoculars mounted on a movable sight bracket, a tracker's telescope, and a stereoscopic range-finder; the radar equipment at the director (this will vary with different system mods) is the antenna mount and reflector (fig. 6-33). (The radar console is located in the plotting room.)

The normal tracking mode of the director is automatic radar control. The radar provides ranges and angle error signals to the train and elevation power drives. The train power drive rotates the entire director to position the line of sight in train; the elevation power drive rotates the optical equipment and the radar antenna about their elevation axis to position the line of sight. Another power drive (cross-level power drive) positions the director shield, keeping the elevation axis of the optics and radar antenna aligned with the horizontal reference plane established by the stable element. Thus



3.124(170)D

Figure 6-33.—Representative gun director Mk 68, front view.

director elevation is measured in the vertical plane.

Alternate methods of director control include power operation by means of handwheel or one-man control units, and computer control with regenerative aiding (table 6-1).

TRAIN MOVEMENT.—The telescope, open sight, rangefinder, and radar antenna mount are fastened to the shield and move with it in train. The entire director is rotated about an axis perpendicular to the deck plane to move the director line of sight in train. The electrical connections between the stationary ship structure and the rotating director are made through a slipping assembly in such a manner that train movement is unlimited in either direction. This

feature eliminates the necessity for train limit stops and electrical limits.

ELEVATION MOVEMENT.—The telescope, open sight, rangefinder, and radar antenna are mounted so that their lines of sight may be elevated with respect to the shield. The elevation axes of these components are all parallel and the lines of sight of each component are perpendicular to its elevation axis. For practical purposes, all of the elevation planes are parallel. The lines of sight and the radar beam are all moved through the same elevation so that they remain parallel.

The director elevation gearing can move the lines of sight and the radar beam from a depression angle of 25 degrees to an elevation angle

Table 6-1.—Operating modes

Mode	Angle Tracking by	Ranging by	Used for
Auto-track	Auto-radar tracker	Auto-radar tracker	AA, Surface
Console	Handcranks and scopes at radar console	Handcranks and scopes at radar console	AA, Surface
Director Officer's Control	One-man control Mk 4 Mod 4 and optics	Radar (at console) or rangefinder	AA, Surface
Tracker's Control	One-man control Mk 4 Mod 5 and optics	Radar (at console) or rangefinder	AA, Surface
Handwheel	Director officer's and tracker's handwheels and optics	Radar (at console) or rangefinder	Surface
Local control (indirect fire)	Director inoperative, tracking by Computer Mk 47		Surface

170.28

of 95 degrees. Limit stops and electrical limits in the power drive protect the drive mechanisms from damage that would result if these limits were exceeded.

The telescope is constructed so that the instrument body does not move in elevation. Elevation of the telescope line of sight is affected by rotating an objective mirror mounted on bearings inside the telescope body.

The open sight contains a binocular and peep sight at the end of the sight arm. The line of sight is moved in elevation by rotating the open sight about an axis parallel to the telescope elevation axis.

The rangefinder line of sight is moved in elevation by rotating the entire rangefinder about its longitudinal axis. An independent elevation mechanism in the rangefinder drive permits rangefinder elevation to be offset from director elevation when it is necessary to adjust the reticle pattern with the target.

The radar antenna is supported above the shield by a radar antenna mount. The radar beam is moved in elevation by rotating the entire antenna about an axis parallel to the elevation axes of the optical equipment.

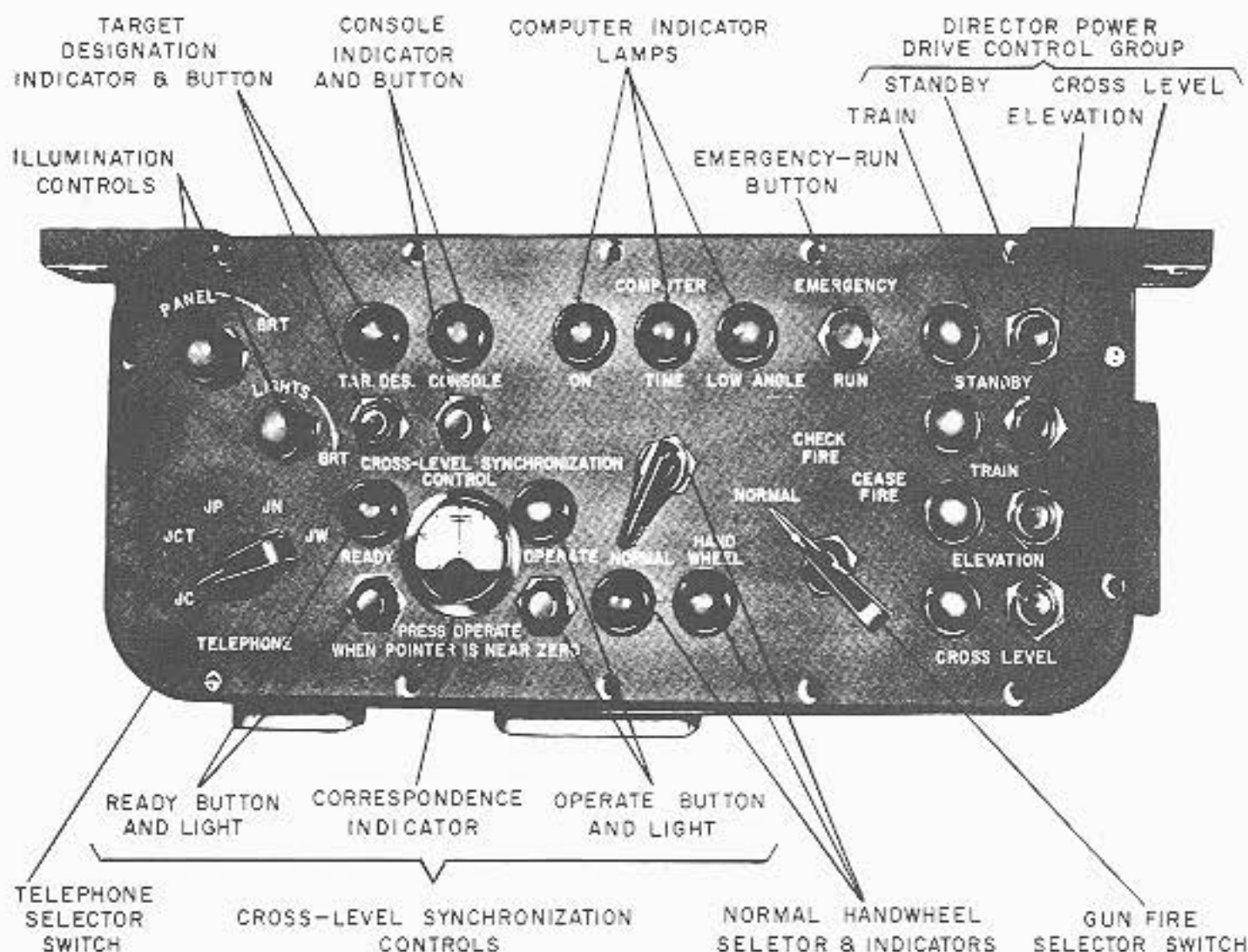
A level angle is geometrically added to the elevation of the lines of sight and radar beam to cancel the effect on elevation of roll and pitch of the ship. The level angle is generated by

a stable element below decks and is automatically transmitted to the director.

CROSS-LEVEL MOVEMENT.—The director shield is mounted on trunnions so that the entire shield can be rotated in cross-level to keep the elevation plane's lines of sight and the radar beam in a vertical position regardless of the ship's rolling and pitching. The axis of the crosslevel trunnions is parallel to the deck plane.

The director crosslevel gearing can move the shield through an angle of 34 degrees each side of the zero position. Limit stops and electrical limits in the power drive and buffers on the director pedestals protect the crosslevel drive and shield from damage that would result if these limits of movement were exceeded.

Primary control of firing is at Control Panel Mk 110 (fig. 6-34). A two-section, three-position selector switch controls firing and cease firing circuits. When this switch is in the NORMAL position, the gun firing circuit may be completed at one of two positions in the director shield; the director officer's firing key or the tracker's one-man control. When the selector switch is in the CHECK position, both gun firing and cease firing circuits are open. Opening these circuits results in a check fire tone signal being sent to gun positions, which indicates



170.15

Figure 6-34.—Director officer's control panel Mk 110.

that firing is temporarily suspended. When the selector switch is in the CEASE position, the cease firing circuit is completed, sending a tone signal to the gun positions indicating that firing is indefinitely suspended. All firing circuits from director to gun positions are completed through the fire control switchboard.

The director is equipped with two one-man control units (fig. 6-35). Each unit may be used for slewing the director or for one-man tracking in both train and elevation. The one-man control unit is rotated about a vertical axis to control the director train rate and the handgrips are rotated about a horizontal axis to control the elevation rate. The rates generated are proportional to the amount of rotation.

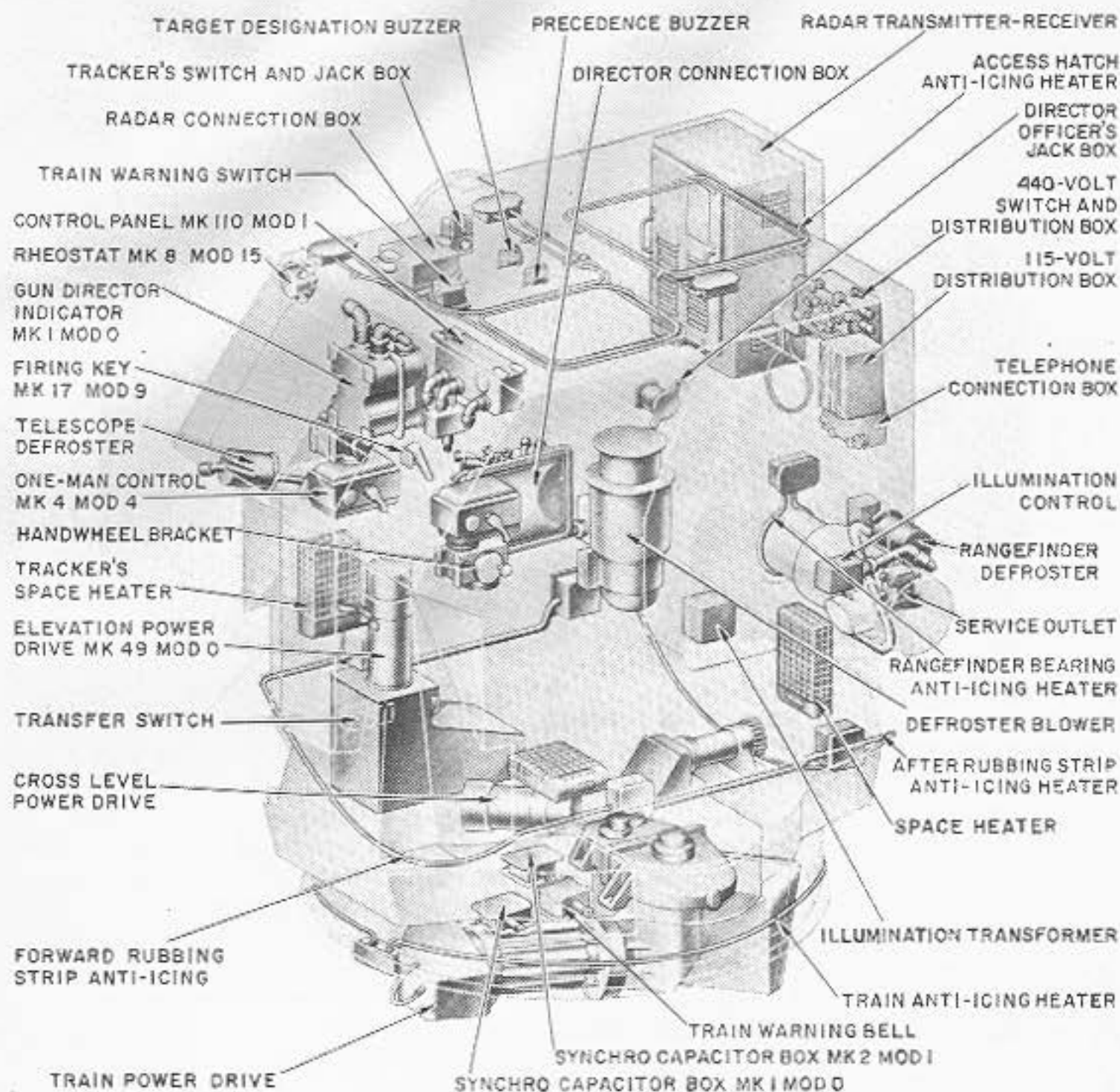
Director Crew and Their Duties

Gun director Mk 68 is operated by a director officer, tracker, and rangefinder operator. The

director crew's operating stations are inside the shield (fig. 6-36); they perform all procedures necessary to place the director in operation. Additionally, the director officer is responsible for selecting the operational mode of the director and controlling and supervising the operation of the GFCS Mk 68 and gun batteries controlled by the system.

The director officer, in addition to being in charge of the gun fire control system, maintains sound-powered telephone communication with other stations of the battery plus combat information center and air defense stations. He reports directly to the air defense officer. He notifies the gun stations when firing is to commence and can initiate firing from the director, and he supervises the director crew during all phases of operation.

The tracker assists the director officer, during optical search and target acquisition, in



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Figure 6-35.—Gun director Mk 68.

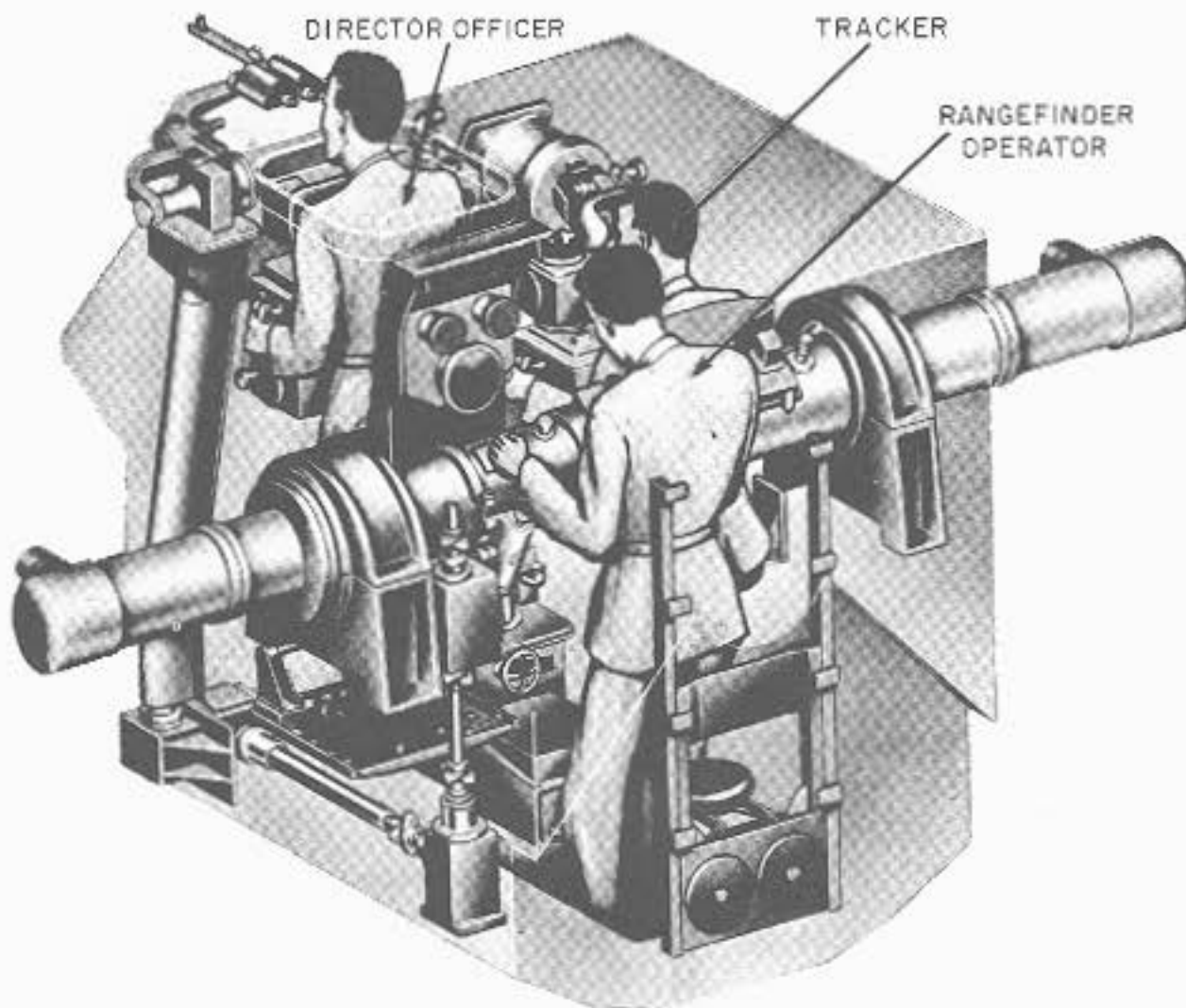
controlling director movement in train and elevation. Under certain conditions, he can cancel automatic radar control at his station. The tracker normally initiates gun battery firing with his firing key. He also assists in starting and securing the director.

The rangefinder operator has very little to do in automatic radar control. During surface engagements or gun fire support, he may be required to observe salvo splashes, supply spotting information, and identify targets. During air engagements when the radar is inoperative and shore engagements when the radar is unable

to track the target, the rangefinder operator is usually required to furnish ranges to the target. The rangefinder operator also is responsible for energizing the heating and anti-icing, defrosting, and illumination systems.

Director Control and Operating Modes

The director has two basic types of control—handwheel and normal. The type of control is selected by the director officer at his control panel (fig. 6-34). Handwheel control is used



166.123

Figure 6-36. — Director crew stations.

against stationary and slow moving surface targets. The director officer operates the elevation handwheel, and the tracker operates the train handwheel. Normal control is used against all other types of targets and has the following modes of operation:

1. Auto-track. The radar is locked on target and has control of the power drives.
2. Console mode. The radar has control of the power drives but not locked on target; the handwheel and the indicator scopes on the radar console are used to establish and position the line of sight.
3. Director officer control mode. The director officer's one-man control unit and optics are used to establish and position the line of sight.
4. Tracker control mode. Tracker's one-man control unit and telescope are used to establish and position the line of sight.
5. Target designation mode. In this mode the power drives slew to the designated position.

In NORMAL, the train and elevation brakes remain set until the director officer (a) closes his right trigger switch, or (b) presses the target designation button, or (c) presses the CONSOLE button placing the system in the director officer one-man control mode, the target designation mode, or the console mode, respectively. If the radar console footswitches have been cycled to AUTO, transfer from the target designation mode and the console mode to AUTO-RADAR track will be automatic when the director gets on target in range, bearing, and elevation. The director officer can assume control from any other mode by pressing and holding his right trigger switch; he can relinquish control by momentarily pressing his left trigger switch.

The target designation mode is usually employed when an accurate or approximate target designation is available during acquisition. In the designation mode after the director slews to the designated position, search can be made about that position by means of train and elevation handcranks at the console.

The mode-of-operation precedence circuits determine the order in which the operators can assume control of the director. The order of precedence in normal control is (1) director officer's one-man control unit, (2) target designation, (3) radar-auto track, (4) tracker's one-man control, and (5) console. The mode of operation is selected by the director officer and is determined by the tactical situation.

Radar AN/SPG-53

The AN/SPG-53 radar is a part of the Mk 68 fire control system. It affords control of the entire system from the radar console. The radar supplies present range to the computer and angle-error signals to the director train and elevation power drives. In the console mode of operation the two radar operators (range operator and radar trainer), using handcranks and slew controls, keep the line of sight on target by observing the target echo on indicator scopes. The radar console is shown in figure 6-37. The handwheels and slew controls are also used for modifying target designation signals in the target designation mode.

In the automatic tracking mode (normal mode), the director position is controlled by the angle tracking loop. The target-video signal is applied to the angle error detecting system, which determines the tracking error and generates bearing and elevation error signals. These error signals are sent to an amplifier, which supplies power to the director amplidyne.

Computer Mk 47

Computer Mk 47 is housed in two aluminum sections bolted together to form a single cabinet. Each section has a front and a rear compartment. The front compartments house the electro-mechanical assemblies, and the rear compartments house the electronic units and power supplies. All assemblies are plug-in type. All operating controls, switches, and indicating dials are conveniently located on the front of the computer.

The computer utilizes target present position to compute future target position. Gun and fuze-setting orders based on this information are then computed and transmitted to the gun mounts (fig. 6-32).

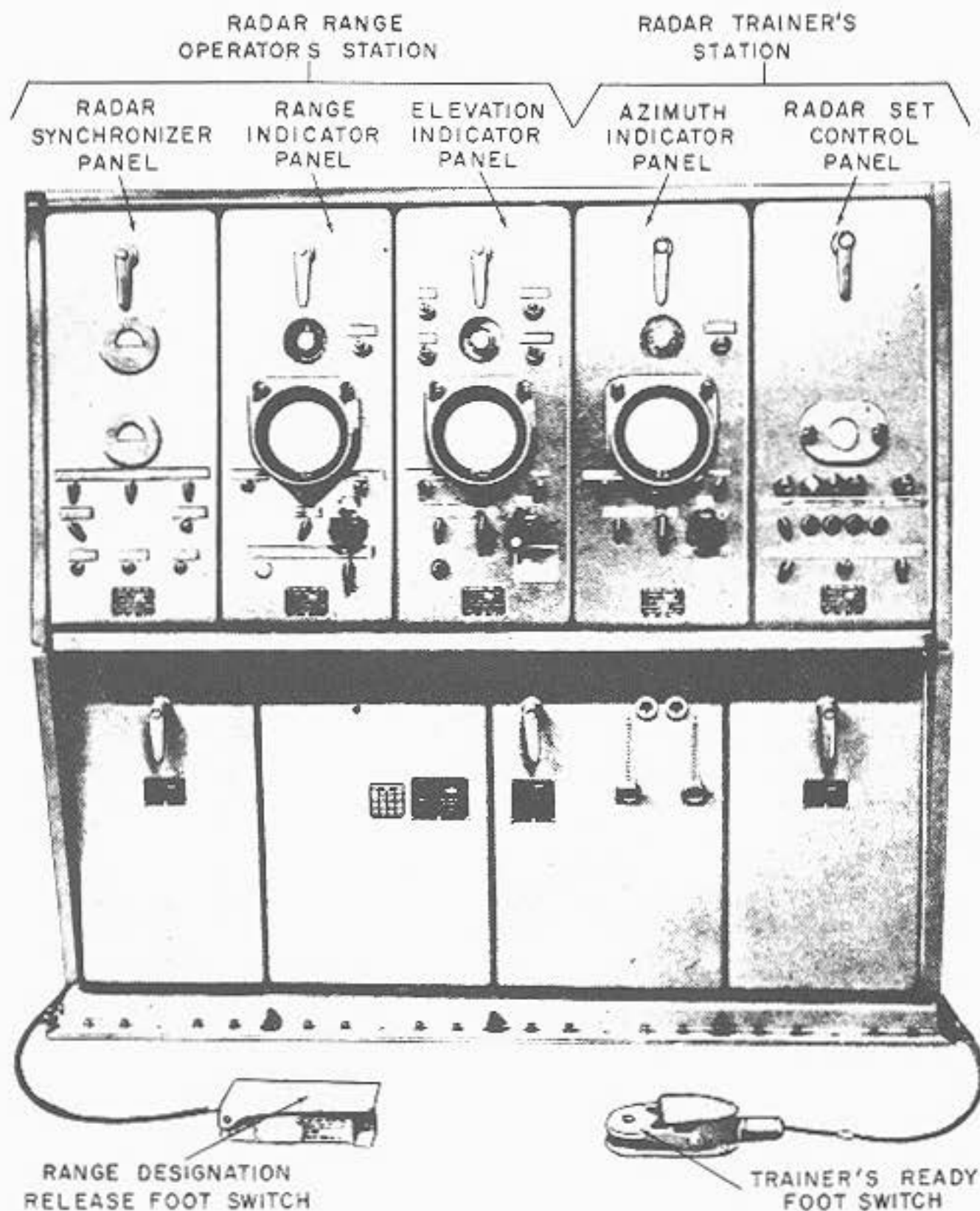
Automatic control is the normal method of computer operation. The computer has three primary modes of operation determined by the type of target—surface, AA-sonic, and AA-supersonic—and the wind track mode used to track weather balloons for gathering ballistic wind data. For surface targets, the computer can also be operated in local control, manual rate control, or optical range submode. In automatic control the computer receives continuous target position data from the director, stabilization data from the stable element, and own-ship course and speed from the ship's compass and speed sensor. It solves the relative motion problem by automatic rate control, and it supplies the director with the generated quantities and stabilization signals necessary to keep the line of sight on target.

The major difference between the modes of operation is a scale factor used to change the operating limits of the rate generating computing loops. The scale factor enters into the relative motion problem by way of the time line and is increased from the surface mode to the AA supersonic mode. Another difference is that in the surface mode of operation the output from the vertical rate of target motion computing loop is not used.

Once the computer has been set up for automatic control, the operator's main function is to monitor it for smooth and correct operation. But during certain types of fire, particularly surface fire, the computer may have to be shifted to local control, manual rate control, or the optical range submode of operation, depending on the tactical problem to be solved. A brief description of each follows.

LOCAL CONTROL.—In local control operation the line of sight DOES NOT originate in the director. The source of data used to establish the LOS in the computer is from outside the gun fire control system. Target position is manually set into the computer by handcranks. Local control is used for indirect fire.

MANUAL RATE CONTROL.—When tracking targets with slow relative rates, it is sometimes advantageous to manually rate control; solution time is reduced, and a smoother solution may be obtained. Because the computer operator has an overall picture of the tactical situation, he is in an ideal position to correct the rate errors without over or under rate controlling. Rate control corrective inputs are introduced by the computer handcranks.



166,124

Figure 6-37. — Radar operating stations.

OPTICAL RANGE OPERATION. — In the optical range submode of operation a continuous, correct, observed present range is not available to the computer. The range servo receiver is de-energized so that the computer's present range will not follow the observed present range signals. The computer's range system becomes a regenerative network, where increments of generated range are used to keep present range up-dated in

the computer. When a correct observed range is available, the computer operator uses his hand-crank to make present range corrections.

Functionally, the computer can be divided into three main sections—the present position section, the prediction and ballistics section, and the trunnion tilt and parallax corrector section—as shown in the flow block diagram

(fig. 6-38). As shown in this figure, the computer performs the following basic operations:

1. North-south and east-west stabilized coordinates of target present position and target height are established from inputs shown in figure 6-38. These inputs are received from the director, the pitometer log (or other speed sensor), the ship's compass, the stable element, and the wind system.

2. Target position data are compared with corresponding data generated by the computer; differences between compared quantities are utilized as error signals to correct target rate quantities until the correct motion rates are established in the computer.

3. The target motion rates are used to determine target position at the end of time-of-flight.

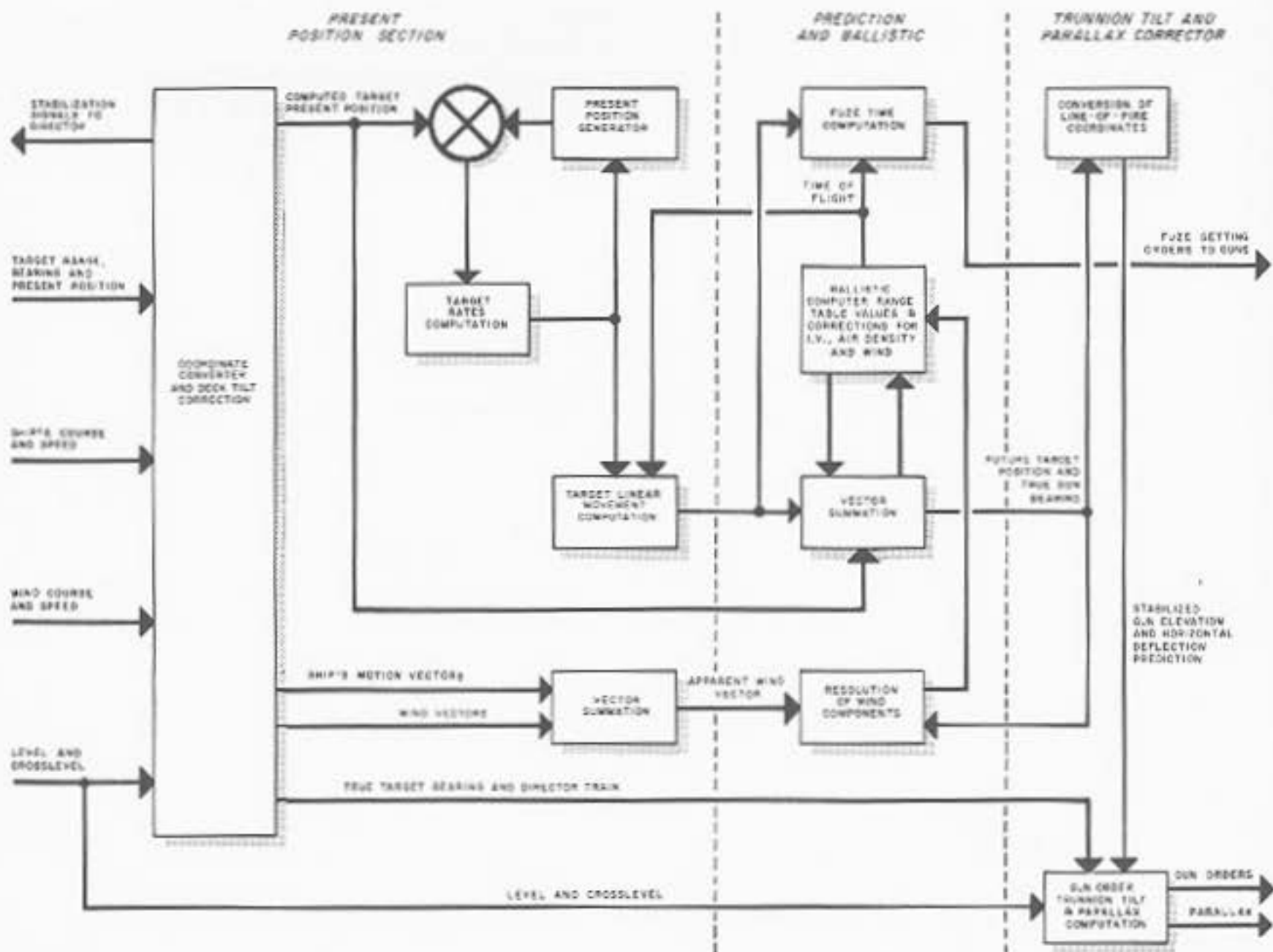
4. The computer determines a line of fire that will hit the predicted target position at the end of time-of-flight.

5. Gun orders are computed (based on the determined line of fire) and transmitted to the gun mounts.

6. Fuze-setting order is determined when mechanical time fuzes are to be used.

A brief description of each functional section, in the order of the fire control problem solution, follows.

PRESENT POSITION SECTION.—The present position section of the computer receives unstabilized, polar coordinate measurements of target present position (range, director train, and director elevation) from the director electrically. The first step by the computer is to convert this



53.105(110B)
Figure 6-38.—Computer Mk 47, flow block diagram.

data, except range, into stabilized quantities. (Range is measured from the system's reference point; therefore it requires no stabilization.)

The next step in the solution of the gun order problem is to convert these stabilized, polar coordinate quantities into rectangular coordinate quantities of target height, east-west horizontal range, and north-south horizontal range. The conversion is performed in two steps: (1) the determination of target height and horizontal range and (2) the determination of east-west and north-south horizontal range.

Target height and horizontal range are computed by a resolver using the equations: target height = range $\times$ sine of target elevation and horizontal range = range $\times$ cosine of target elevation. The resolver receives a mechanical input of elevation from the elevation servoloop and an electrical input of range from the director.

Target height, one output of the resolver, is used in the rates section and the wind track section. It is also transmitted electrically to the prediction section. The other resolver output, horizontal range, is used in the second step of coordinate conversion.

The north-south and the east-west components of horizontal range are computed by a vector resolver. The inputs to the resolver are an electrical input of horizontal range and a mechanical input of true target bearing. The outputs of the resolver are the required north-south and east-west components of horizontal range. These outputs are transmitted, electrically, directly to the prediction section of the computer and to the Computer Mk 116 (discussed later). These outputs also actuate servoloops that provide mechanical inputs of north-south horizontal range and east-west horizontal range to the rates section.

The present position section also develops stabilization aid signals for transmission to the director, where they are used to compensate for roll and pitch and change of ship's course. They maintain the line of sight on a stationary target as the ship is moving and are increments of changes in own ship's course plus deck tilt correction and rate of change of ship's course plus deck tilt correction.

To solve the gun fire control problem, rates of target motion relative to own ship must be determined. This is done by comparing the rates of change of the three stabilized rectangular coordinates—target height, north-south horizontal range, and east-west horizontal range—with corresponding rates generated in the computer. By correcting the generated rates until

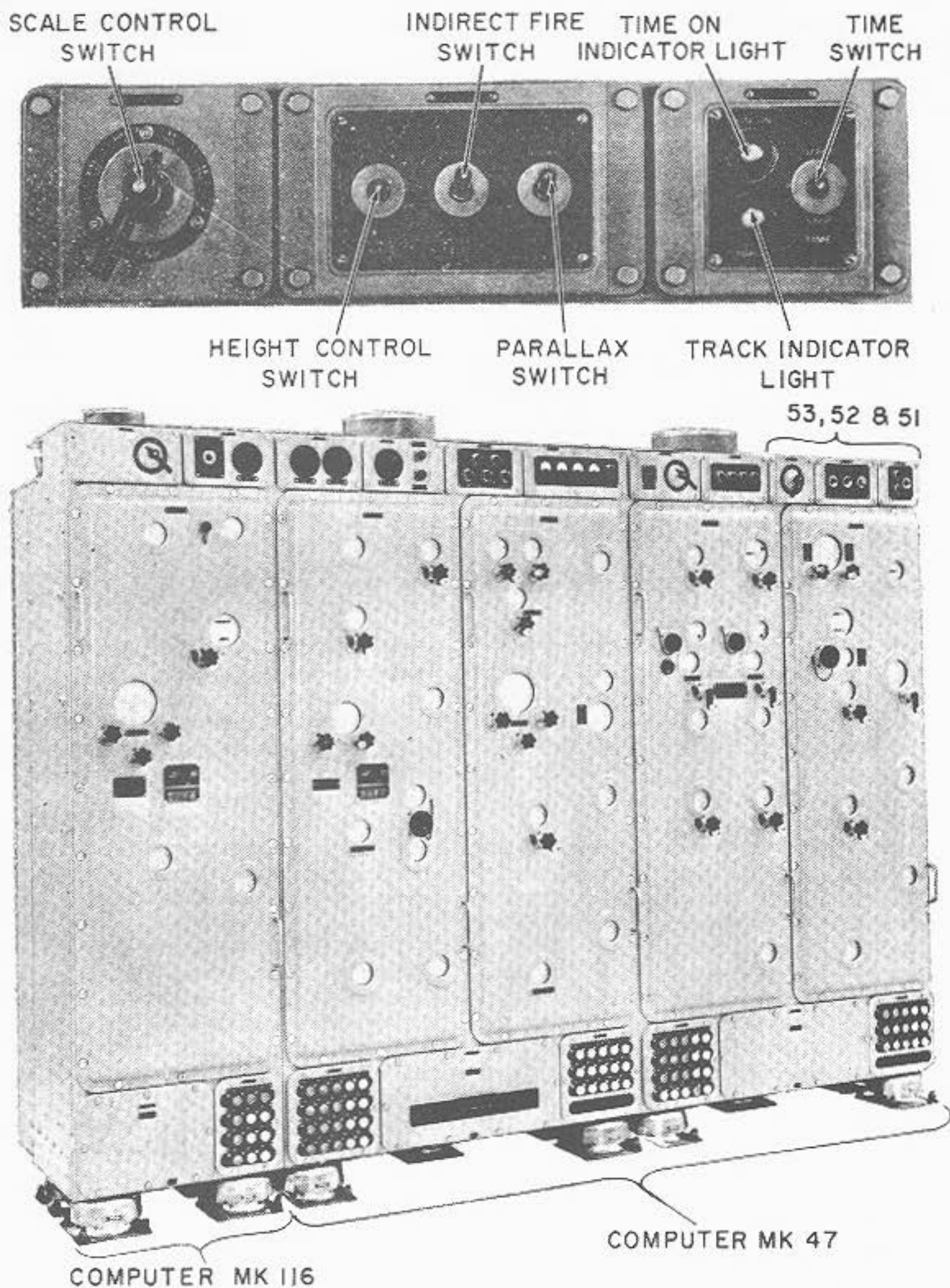
they agree with the rates of change of the measured coordinates, the correct target motion rates are established for use in prediction. This corrective process, called rate control, is entirely automatic in AA-sonic and AA-supersonic modes of control. A scale factor is introduced into all rate computations. This scale factor, which varies for the different modes of computer operation, is dependent on target speed. The scale factor for AA-sonic is considered to be unity. For AA-supersonic it is 2.5 and for surface it is 1/10. The value introduced is determined by positioning a selector switch on computer panel 53 (fig. 6-39).

Three separate rate loops operate in the present position section of the computer to derive target rate quantities. These loops compute the north-south horizontal range rate, the east-west horizontal range rate, and the rate of vertical linear movement. All three loops operate in the same manner; therefore only one, the rate of vertical linear movement, will be described.

When tracking begins, target height is compared with generated target height. (Actually, only incremental changes in these two quantities are compared.) The system immediately operates to bring these rates into agreement. Once the rates are in agreement, they will remain in agreement until the target's height rate changes. If the target maneuvers, thus changing target height rate, the resulting difference in target height and generated target height causes an error signal proportional to this difference to be transmitted to the corrective target height servoloop. The corrective setting of target height changes generated target height by an amount necessary to make it agree with target height.

PREDICTION AND BALLISTICS SECTION.—Although prediction and ballistics are discussed separately in this section, the computer groups making these solutions are completely dependent upon one another. The prediction group determines target future position based on the time of flight determined in the ballistic computer. At the same time, the ballistic computer uses target future data to determine time of flight. The prediction group and the computer operate simultaneously to make these two solutions. Wind rates and fuze time are also computed in the prediction section.

Prediction.—In order for the prediction group to determine the future position of the target (the position of the target at the end of time of flight) the assumption is made that the target follows a



53.105(170)D
Figure 6-39. — Covers No. 53, No. 52, and No. 51, switches and indicator lights.

straight line course at constant speed during time of flight.

The prediction group performs two distinct steps in the fire control problem solution. First, the future target position is established in rectangular coordinates with respect to the north-south and east-west planes and in the vertical plane. Second, these quantities, together with ballistics corrections, are used to determine the gun's aiming point—the point in space at which the gun must be aimed for the projectile to hit the target. Figure 6-40 illustrates some of the quantities determined by the prediction section.

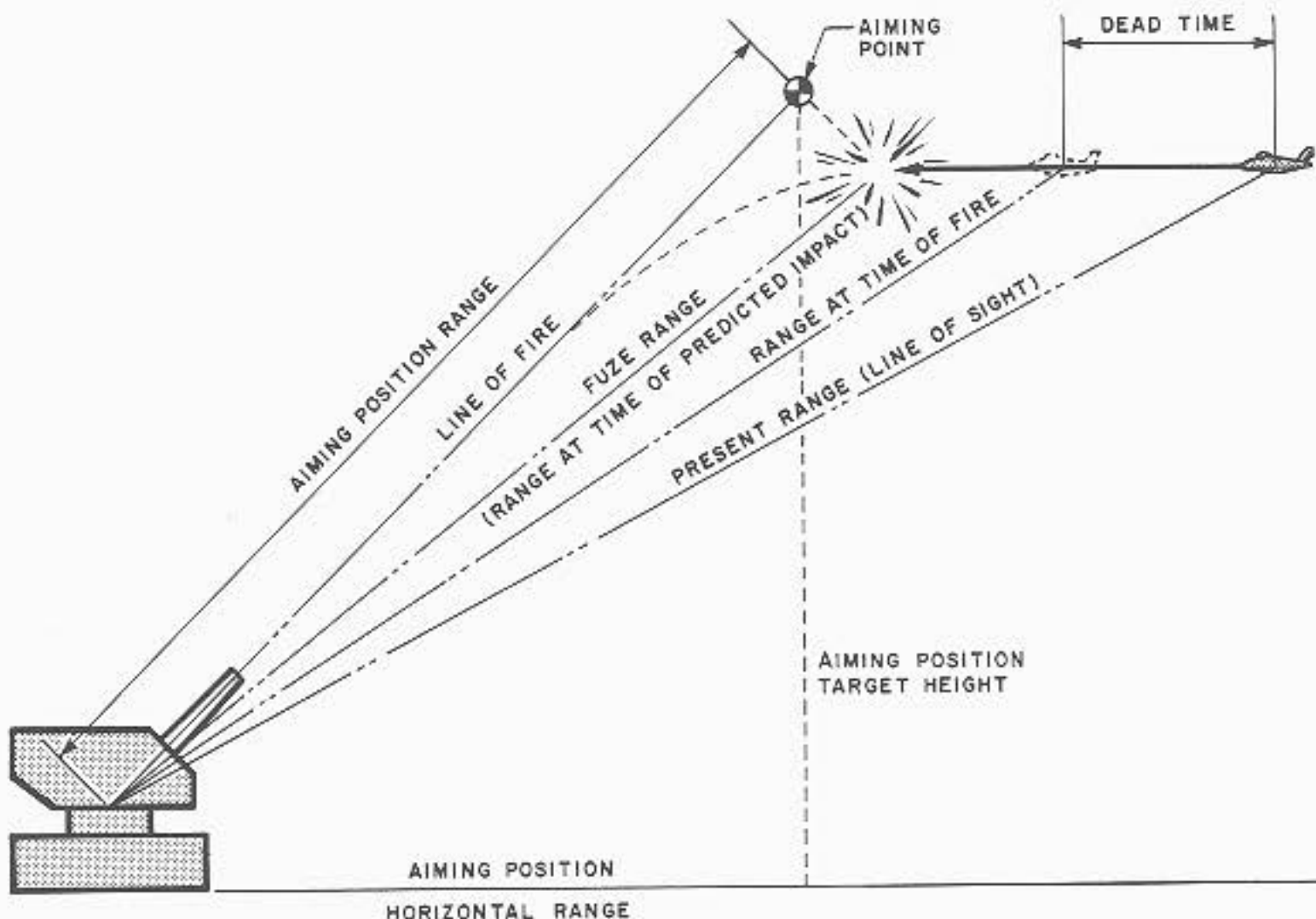
For the first step, the prediction group receives the target linear movement rates (height, north-south horizontal range, and east-west horizontal range) from which it determines the corresponding linear displacements of the target during projectile time of flight. Three potentiometers operate to determine these displacement quantities. The potentiometers receive the target linear movement rates as mechanical inputs and are energized by time of flight received from the ballistic computer.

Adding the linear displacement quantities (vertical linear movement, north-south linear movement, and east-west linear movement) to the respective rectangular coordinates of target present position (target height, north-south and east-west components of horizontal range) produce rectangular coordinates that define the position of the target at the end of time of flight.

In the second step, the computer's prediction group uses true gun bearing, gun elevation, and aiming position range to determine the gun's aiming point.

Wind System.—Apparent wind rates, necessary for ballistic solution, are computed in the wind system. The wind system receives inputs of own-ship speed and course, wind data, and true gun bearing for computing apparent horizontal wind in and across the plane of fire.

Ballistics.—The ballistic computer uses advance target position coordinates (aiming position range and aiming position elevation) from the prediction group and apparent horizontal wind,



110.136

Figure 6-40.—Computer prediction quantities.

in and across the plane of fire, to calculate the following functional quantities:

1. Time of flight—upon which all prediction computations are based.
2. Superelevation—elevation of the gun above advanced position elevation, necessary to compensate for the curved trajectory of the projectile.
3. Horizontal linear deflection correction—the displacement of the line of fire from the future target position.

The relationship between the ballistic computer and the prediction group is shown in figure 6-41. The computations performed by the ballistic computer are based on data furnished in the ballistic tables. These tables give values of time of flight, drift, and superelevation for projectiles fired under standard ballistic conditions in still air; they also give the effects of deviation from standard conditions.

Fuze Setting Order.—Fuze setting orders are transmitted to the gun mounts by the computer for use when firing projectiles with mechanical time fuzes. Fuze setting order or fuze time corresponds to time of flight and can be computed as a function of fuze range.

The computation of fuze range is based on the assumption that the target continues at a constant course and speed. The prediction solution used to determine fuze range (thus fuze time) is similar to that used to determine aiming range. The inputs for fuze prediction are the same as those for the prediction of aiming range except that dead time is used in computing fuze prediction. Dead

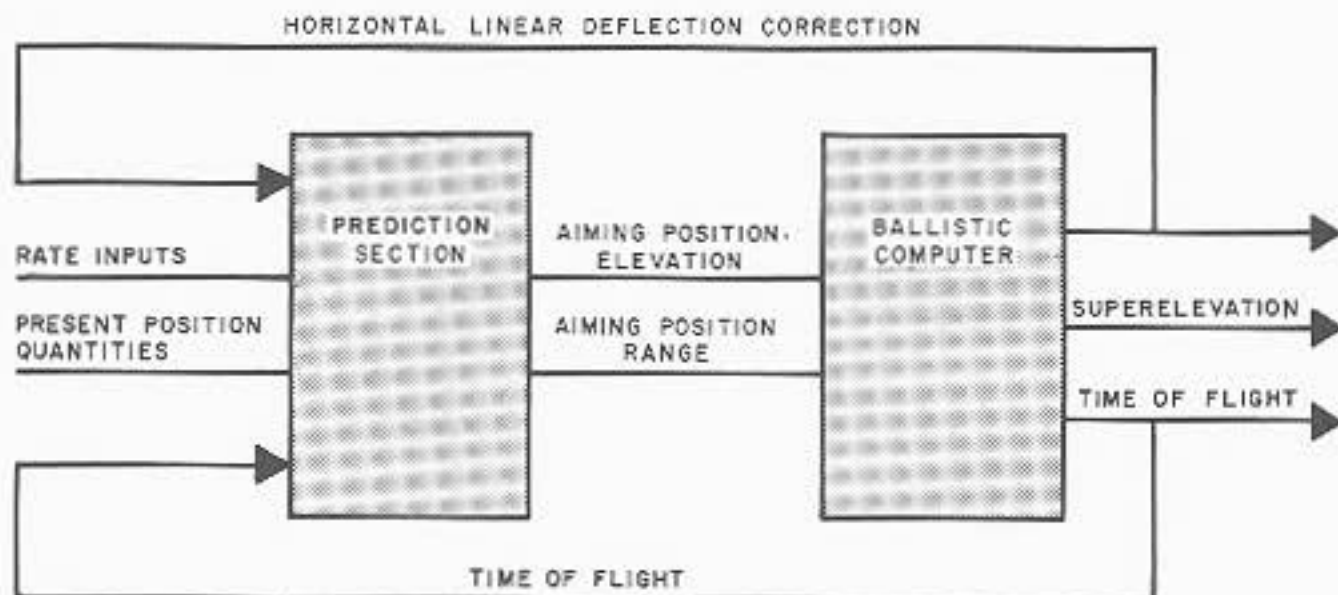
time is a hand input that is added to fuze-setting order in the fuze time computer.

TRUNNION TILT AND PARALLAX CORRECTOR SECTION.—This functional section of the computer solves for gun train order, gun elevation order, and parallax.

Aiming position elevation and true gun bearing, obtained in the ballistics and prediction section solution, located the line of fire relative to true north and the horizontal. Consequently, trunnion tilt corrections are required to stabilize the gun orders in the deck plane.

Figure 6-42 is a spherical diagram showing the relationships of the quantities involved in the trunnion tilt and gun order solutions. The steps performed in converting prediction quantities (aiming position elevation, superelevation, and true gun bearing) to gun orders are as follows:

1. Gun elevation, aiming position elevation plus superelevation, is computed in the vertical plane measured from the horizontal.
2. Horizontal sight deflection is computed. This is the angle between the line of sight and the line of fire, measured in the horizontal plane.
3. As part of the conversion from the horizontal plane to the deck plane, functions of level angle and crosslevel are combined with functions of horizontal sight deflection, gun elevation, and director train.
4. Gun train order is established and maintained in the deck plane by some of the quantities obtained in step 3.
5. Gun elevation order is obtained in a similar manner as gun train order.



110.137

Figure 6-41.—Relationship of prediction group to ballistic computer.

- 170.21

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The computations are performed by a series of resolvers and vector resolvers in the gun order computer step by step.

Parallax corrections are computed for a gun displacement of 100 yards forward of the reference point. By making a standard 100-yard displacement computation, only one computation need be made and transmitted to all gun mounts. At each mount, unit parallax is modified automatically to represent the actual displacement of the mount from the reference point; the individual corrections are then applied to gun orders at the gun mount.

Computer Mk 116

The computer Mk 116 (fig. 6-39) is designed for use with some mods of the Mk 47 computer. The Mk 116 computer discussed here functions in three different modes of operation—NORMAL 3"/50 mode, STAR-SHELL 5"/54 mode, and RAT (rocket-assisted torpedo) mode. In NORMAL 3"/50 mode, it operates in conjunction with the Mk 47 computer to derive gun orders for 3"/50 caliber guns; it transmits these gun orders directly to the 3-inch gun mounts. In STAR-SHELL 5"/54 mode, it operates with the Mk 47 computer in surface mode to derive 5"/54 caliber gun orders and fuze-setting orders for illuminating fire, and it transmits these orders directly to the 5-inch gun mounts. In RAT mode, it supplies relative target bearing, which is used as an aid in the control of anti-submarine rockets.

Except for a few hand inputs (spots and I.V.), the Mk 116 computer receives all inputs from the Mk 47 computer.

The primary function of the Mk 116 computer is to produce gun orders for the 3"/50 caliber battery. The computer contains a prediction and ballistics section for determining target position at the end of time of flight, and a deck tilt section for converting and transmitting gun orders in the proper coordinates.

Converter Mk 20

Converter Mk 20 is used with some Mk 47 computers that are not supplied with Mk 116 computers. The converter, which is installed in the plotting room adjacent to the Mk 47 computer, is used to change 5"/54 caliber gun orders to 3"/50 caliber gun orders. All power and information (other than spots and I.V.) necessary to perform the conversion computations are received from the Mk 47 computer. Therefore,

the converter will operate only when the computer is on and transmitting gun orders. Except for setting in spots and I.V., operation of the converter is automatic.

Star-Shell Computer Mk 1

In some systems not supplied with Mk 116 computers, Star-Shell Computer Mk 1 is used to compute star-shell gun orders and fuze-setting orders for 5"/54 caliber gun mounts. It can be operated in two modes—controlled fire or search. In the controlled fire mode, employed when a specific target is to be illuminated, the Mk 47 computer must be operating. In the search mode, the star-shell computer can be operated independently of the Mk 47 computer.

Stable Element Mk 16

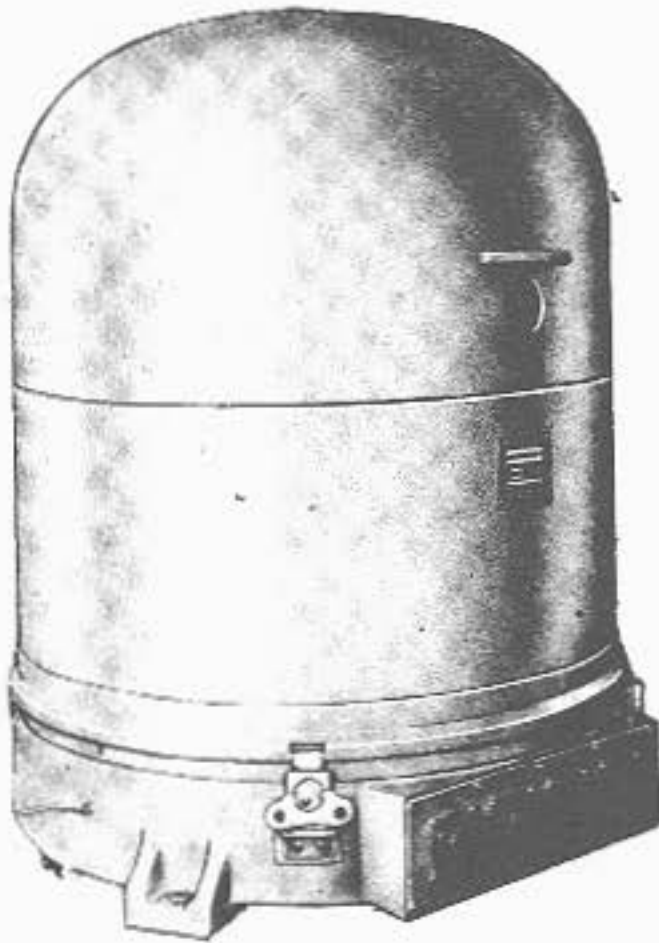
The primary function of the Mk 16 stable element and its associated equipment (fig. 6-43) is basically the same as that of the Mk 6 stable element, that is to provide a stabilized reference plane independent of ship's movement. The construction and operation, however, are quite different. The basic principles and problem to be solved are explained in Fire Control Technician G 3 & 2, NavPers 10207 and OP 2209.

The stable element contains the sensitive element, gimbals, pendulums, pickoff coils, and servo mechanisms that maintain the gyro at a true vertical (fig. 6-44) and generate outputs of level and crosslevel. These outputs are used in the Mk 47 computer deck tilt corrector to compute position angle and true target bearing. Crosslevel is used to keep the director stabilized in crosslevel. Level and crosslevel are sent to the rate transmitter Mk 36 (fig. 6-43), where they are used to develop stabilization signals in elevation for all modes of operation.

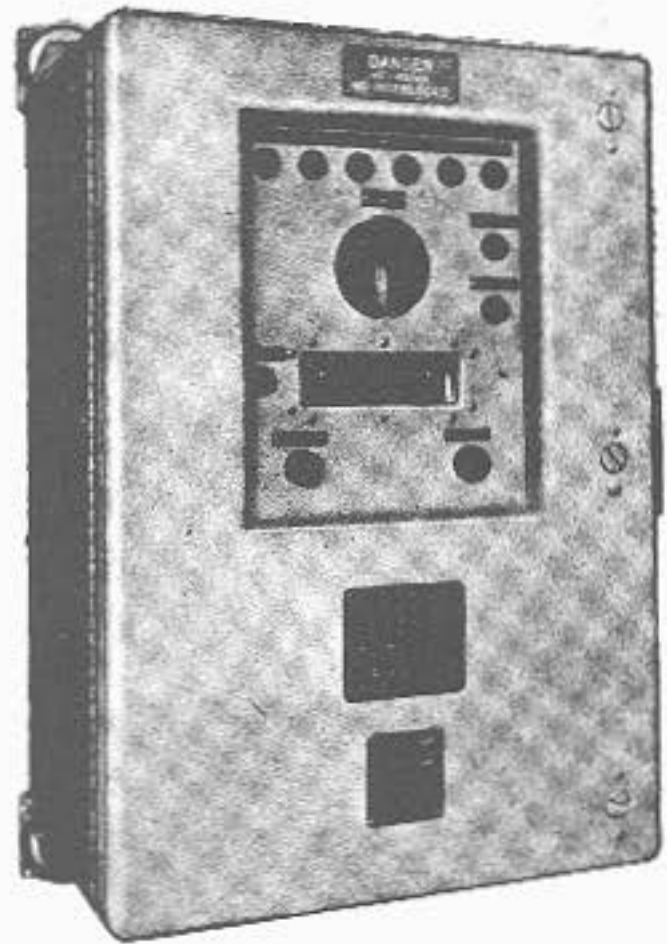
Stable element panel Mk 156 (fig. 6-43) contains the controls, indicators, and protective devices required for operating the stable element and rate transmitter.

Dynamic Tester and Error Recorder

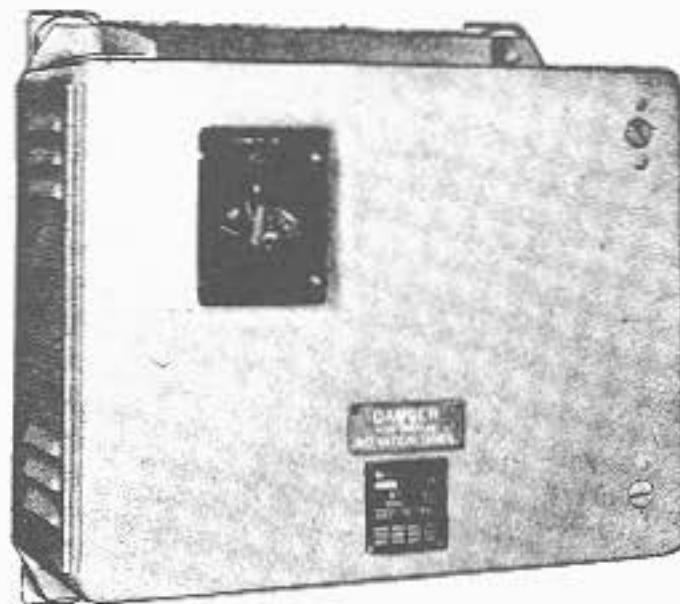
The dynamic tester provides a simulated air target for the fire control system. It may be used to check the performance of the entire GFCS Mk 68, or the performance of the director power drives, the computer Mk 47, or the gun order converter.



STABLE ELEMENT MK 16

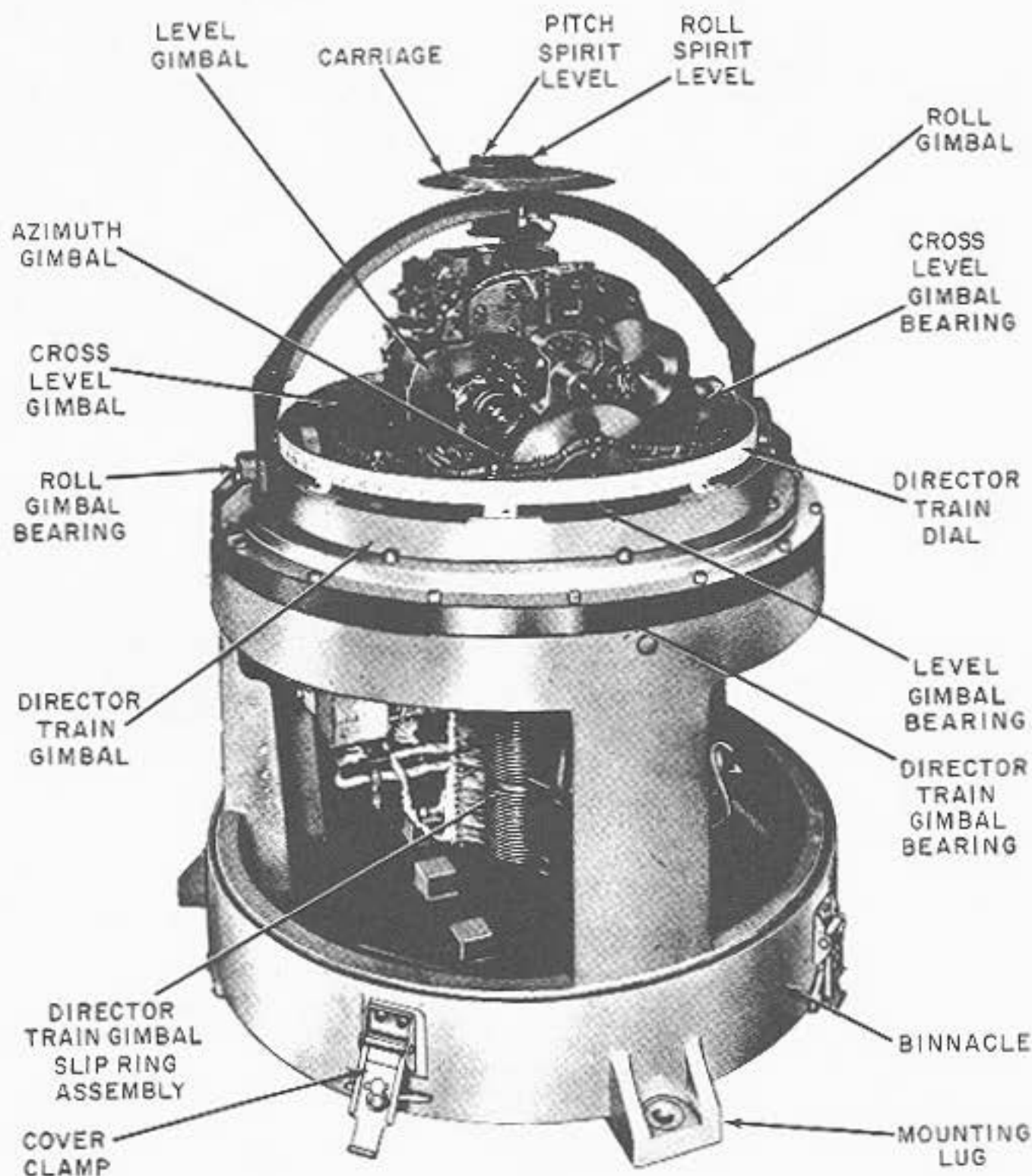


STABLE ELEMENT PANEL MK 156



RATE TRANSMITTER MK 36

Figure 6-43.—Stable element Mk 16 and associated equipment. 170.26



170.27
Figure 6-44.—Stable element Mk 16, cover removed.

The error recorder uses gun order and fuze order error signals from the dynamic tester to record the amount and direction of error in system or system component performance. This error is recorded on a roll of graph paper.

RELATIVE-RATE FIRE CONTROL SYSTEMS

Relative-rate fire control systems are based on gyroscopic lead-computing sights or computing

mechanisms. A number of fire control systems that work on this principle are in use in the Navy at the present time. Most of them are generally associated with 3-inch and smaller guns although some are set up to control larger weapons also. This is in contrast to the Mk 37 and Mk 68 linear-rate systems, which are primarily associated with heavier weapons. The general characteristics and principles of relative-rate gun fire control systems (especially as compared with linear-rate systems) were discussed earlier in this chapter. This section is chiefly devoted

to a somewhat more comprehensive description of one such system—the GFCS Mk 56. However, it is not intended as a fully detailed description of the system.

GUN FIRE CONTROL SYSTEM MK 56

The Mk 56 GFCS (fig. 6-45) is an intermediate-range gun fire control system primarily designed for use against high-speed subsonic targets, but usable also against surface targets. It is most commonly used with 3-inch guns, but can control 5-inch guns also. It is a dual-ballistic system—that is, it can provide elevation, train, and fuze-setting orders simultaneously to two different batteries of different calibers. It can produce a fire control solution within two seconds after tracking begins. The system is capable of either optical or automatic radar tracking in bearing, elevation, and range, and of remote control from the control room below decks. This feature provides for rapid radar acquisition of obscured targets and for blind firing (i.e., firing without visual contact).

The system consists essentially of a two-axis, power-driven, direct-line-of-sight director located above decks, and various computing units located in a control room below decks. Complete radar equipment is included as an integral part of the system. The radar antenna is mounted on the director, and all radar indicators are in the control room (fig. 6-45).

The system is operated by a crew of four men, including the control officer. The latter and the pointer are stationed in the director for optical acquisition and the tracking of visible targets, and the two other men are at a console in the control room. On the console are all radar indicators and operational controls for handling range and positioning the director. Acquisition of obscured targets is accomplished from the console by matching designation dials.

Director line of sight (including radar antenna) is stabilized by a gyro unit in the director. Computation of lead angles is based on director angular rates of motion in stabilized coordinates.

Mk 56 GFCS Fire Control Problem Geometry

The fire control problem is expressed somewhat differently in the Mk 56 GFCS than in the linear-rate systems. Figure 6-46 shows the planes in which the values are expressed and the

solution is developed in the director and computer. Two gyros in the director are used during tracking to establish the planes and values used in the solution of the fire control problem. A vertical gyro, similar to the stable element of the Mk 37 system, establishes and maintains the true horizontal and true vertical reference planes. A rate gyro precesses during tracking to develop angular rates proportional to the movement of the director.

The angular velocity of the LOS during tracking can be resolved into angular rates in two mutually perpendicular planes (fig. 6-46). One of these angular rates is elevation rate; the other is traverse rate. The solution, however, requires the use of linear rates of target motion, in a plane perpendicular to the line of sight at target's position. This plane is called the cross-traverse plane and contains linear elevation rate and linear deflection rate. Since the target is not moving entirely in the cross-traverse plane, the range changes at the rate of *RANGE RATE* measured along the line of sight. Linear elevation rate, linear bearing rate, and range rate are the three basic linear rates of target motion.

Mk 56 GFCS Fire Control Problem Solution

The first step in the solution of the problem is determination of target position. Target bearing and elevation are measured by the director. As the target is tracked, director train and director elevation are measured and transmitted by synchros to the computer. Target range is measured by radar and transmitted automatically to the computer.

Tracking the target is done either optically or by radar. A tracking control unit and a telescope on the director are used for optical tracking. In automatic radar tracking, the tracking signals originate in the radar equipment, and are accurate within one-half mil.

The primary purpose of the vertical gyro is to establish a stable reference plane called the true traverse plane (fig. 6-46). It also measures true elevation of the director line of sight above the horizontal, and cross-traverse angle. Like crosslevel, cross traverse is motion about the line of sight due to movement of the deck, but cross traverse is measured in the cross-traverse plane, which is perpendicular to the line of sight, and therefore differs from cross-level. The values of true elevation and cross-traverse angles are picked off electrically and are transmitted to the computer, where they

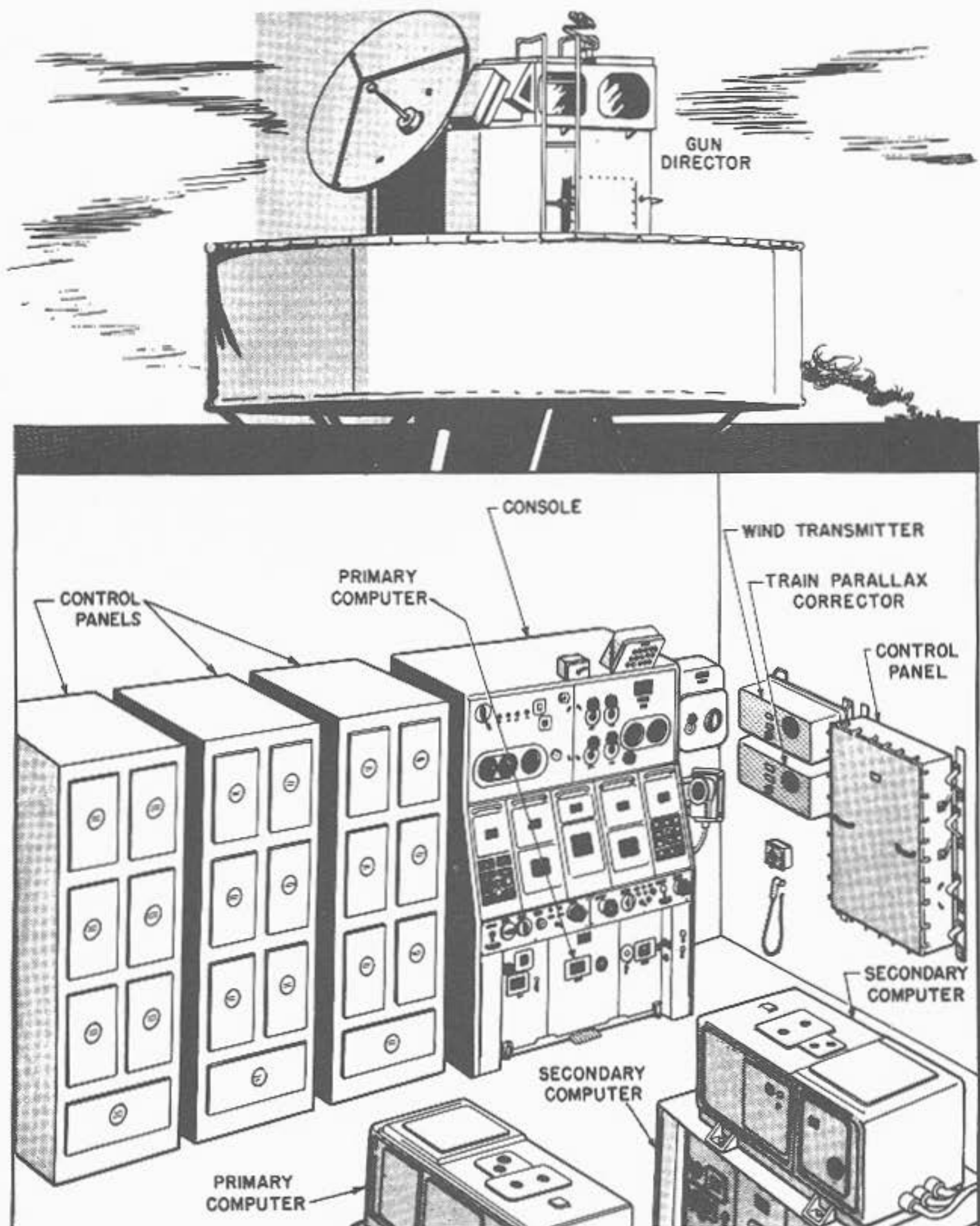
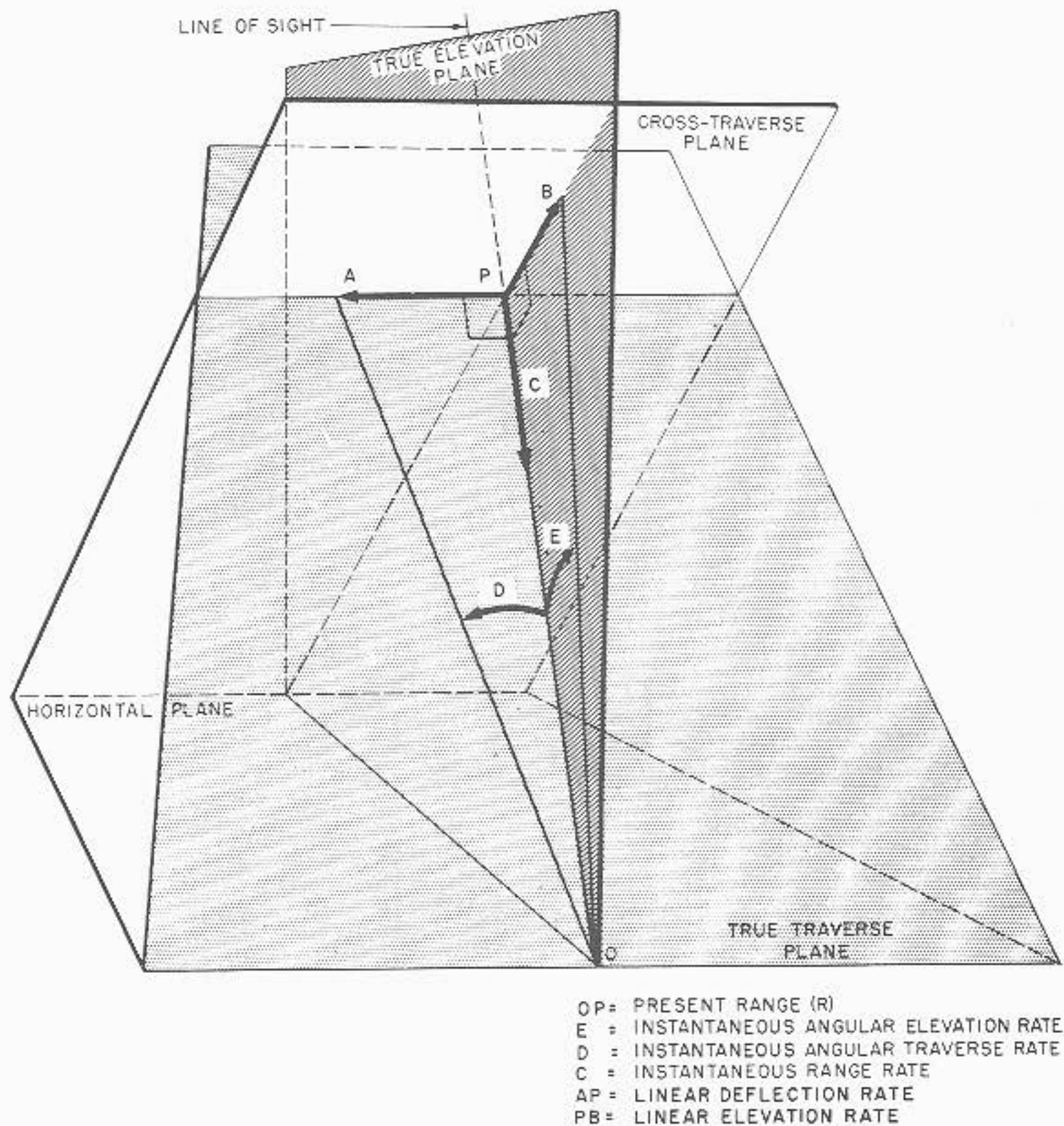


Figure 6-45. — Components of gun fire control system Mk 56.



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Figure 6-46.—Geometry of the Mk 56 GFCS statement of the fire control problem.

are used in calculating ballistic corrections and gun orders. Cross traverse also goes to the cross-traverse drive gear of the rate gyro.

The rate gyro controls the drive motors that position the director in train and elevation. It does this by measuring the angular rates of target motion in the forms of electrical tracking signals and by combining these signals with the

stabilizing signals of true elevation and cross traverse from the vertical gyro. The algebraic sum of these signals is obtained in a set of pickoff coils that function somewhat like the umbrella and coil arrangement in the Mk 6 stable element discussed earlier in this chapter.

The second step in solving the fire control problem is measuring the rates of target motion.

As described earlier, the target is tracked in elevation and train, and error voltages generated in the pick-off coils go to the computer as rates of target motion (angular elevation rate and angular traverse rate). As for range data, the Mk 56 director has no optical rangefinder; range information is normally supplied by radar, or it can be cranked in manually if necessary. As the radar tracks the target, changes in range (range rate) drive a tachometer generator—a generator whose output voltage is directly and accurately proportional to speed—that produces a range rate voltage signal. From these three rate signals (angular elevation, angular traverse, and range) the computer can calculate lead angles in true traverse and true elevation.

The remainder of the solution process takes place in the computer, which includes the ballistic computer, wind transmitter, parallax corrector, and gun order converter, with associated amplifiers. Computations are performed by electrical and mechanical networks distributed among these units. Any of these units or all of them together may be considered as the computer.

From present target position and the rates of target motion the computer calculates superelevation and drift. To correct for wind the computer receives by synchro own ship course from the ship gyro compass, and manually introduced values of true wind speed, true wind direction, and own ship speed. Initial velocity and dead time are also cranked in manually. Ballistic corrections are computed in terms of rates. Angular rates (elevation and traverse) from the director are multiplied by range to give linear rates of elevation and deflection. The linear rates are corrected and used to calculate superelevation and other prediction quantities.

The Mk 56 system's geometry is based on the true elevation and true traverse planes as described earlier, but gun orders must be expressed in deck coordinates. The computer therefore converts the computed lead angles to deck coordinates. Additional computer units simultaneously convert these values to produce gun orders for another battery of a different caliber.

Finally, parallax correction must be made. Parallax correction is in principle similar to that already described for linear-rate systems, with standard horizontal correction computed on a 100-yard base and converted at each mount to the proper value. The Mk 56 system also computes vertical parallax correction.

Mk 56 GFCS Summary of System Operation

Figure 6-47 shows the flow of basic quantities in the system when using automatic radar tracking (the usual method of operation). Radar receives target echoes from the antenna and transmits traverse and elevation error signal to the gyro unit as tracking signals, and to the computer as rates of target motion. Signals from the optical tracking control unit in the director may be selected in place of radar. The radar equipment transmits range and range rate to the computer during both radar and optical tracking.

In the gyro unit, tracking signals are combined with stabilizing signals to control the director power drives. As the director tracks the target, director position is measured by synchros, and director train and elevation are transmitted to the computer. The gyro unit also transmits values of true director elevation and cross-traverse angle to the computer.

Own-ship course is introduced to the computer electrically, while own-ship speed, true wind speed and direction, initial velocity, and dead time are introduced manually. The computer calculates lead angles and ballistic corrections. The secondary computers make up and transmit gun elevation order, gun train order, fuze time order, and unit parallax correction. Within two seconds of the start of steady tracking (either optical or radar), the computer is producing accurate gun orders.

OTHER GUN WEAPON SYSTEMS

Thus far we have discussed representative linear-rate and relative-rate gun fire control systems. Although these systems are typical and widely used, they are not the only ones employed in the fleet. In the following paragraphs we shall briefly discuss other systems used in the fleet.

SURFACE FIRE CONTROL SYSTEMS

Surface fire control systems are used to direct the fire of turrets. Most ships having these systems (cruisers and battleships) are in the reserve fleet. These systems are designed to control guns of 6-inch caliber and larger. They are, in general, similar to the Mk 37 linear-rate system. They use rangekeepers instead of computers and stable verticals instead of stable elements; from the

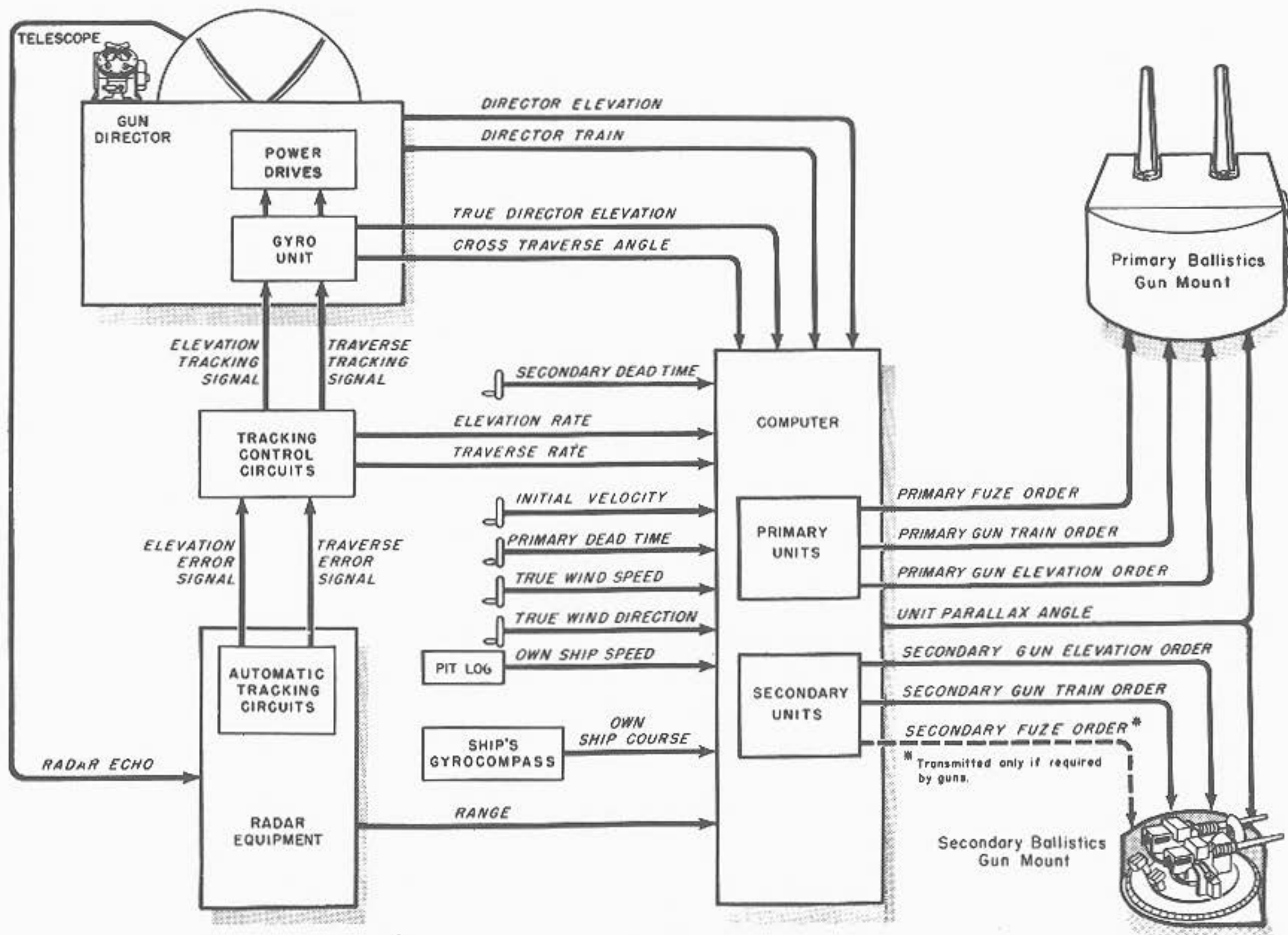


Figure 6-47. - GFCS Mk 56. Simplified data flow schematic.

point of view of the student of this book, these are differences in nomenclature rather than general function.

RELATIVE-RATE SYSTEMS

There are several relative-rate fire control systems used in the Navy. None, however, are used as extensively as the Mk 56 system discussed earlier in the chapter. Some, such as the Mk 63 and Mk 87 are used to a lesser degree than the Mk 56 system, and some (such as Mk 52 and Mk 57) are almost nonexistent. This discussion will be confined to the Mk 63, Mk 86, and Mk 87 systems.

Mk 63 Gun Fire Control System

The Mk 63 system (fig. 6-48) is designed to control 40-mm and 3"/50 guns and is equipped to deal with air targets from 800 to 7,000 yards range, moving with speeds up to 800 knots. The major units in the system are

1. Lead computing sight.
2. Director pedestal (on which the sight is mounted).
3. Radar equipment (with the radar antenna located on a gun mount).
4. Wind transmitter—actually a computer which calculates and introduces wind correction into the system. Its inputs are own-ship course, gun train order, own-ship speed, wind direction, and wind speed.
5. Target acquisition unit (TACU). This unit aids the sight pointer in locating the target when visibility is poor or there are many targets in sight.

The director operator tracks the target manually (the director has no power drive) by training and elevating the lead computing sight on the director and keeping the target image centered in the reticle. The lead angle generated by the sight is transmitted to the gun mount power drive, so that the guns will lead the target. Lead angle is also transmitted to the radar antenna's independent power drive on the gun mount, but here it is applied to cause the antenna axis to lag the gun bore axis by an angle equal to the lead angle. The result of this, of course, is that the radar antenna is always aimed at the target (as is the director line of sight); the axis of the director case (with no parallax input) is parallel to the gun, which points to the future position of the target (fig. 6-48).

Mk 86 Fire Control System

The Mk 86 fire control system is designed to control lightweight 5"/54 guns and other weapons against surface, shore, and air targets. The system is very flexible; it can—with minor changes—be adapted for use with a variety of weapons against all type targets. Some modification with guided missile systems in the controlling of semiactive homing missiles such as TARTAR.

The Mk 86 system has operating modes to cover just about all possible conditions of readiness. It can operate in (1) Radar Surface Fire, (2) Visual Surface Fire, (3) Indirect Shore Bombardment (with or without a beacon), and (4) Air Action radar, visual, or a combination of both. Three men, a control officer and two gun controllers, operate the system from below decks. On ships with single gun installations, one gun controller's console (and thus one gun controller) is eliminated.

Components of the Mk 86 fire control system are shown in figure 6-49. A detailed description of the Mk 86 system can be found in OP 3645.

Mk 87 Fire Control System

One of the most recent developments in gun fire control is the GFCS Mk 87 (fig. 6-50). It is a dual-purpose, lightweight system designed to control 3"/50 and 40 mm guns. Like the Mk 86 system, it can easily be modified to control larger guns. In its principal operating modes, all system functions are automatic, from the time of target designation to system ready to fire. The components of this system were designed to operate as a balanced and completely integrated weapon control system. The system is self-contained and has three operators—two at the fire control console and one at the optical sight topside.

Of the two manned stations, the fire control console is the heart of the Mk 87 system. It houses the computer (a solid-state digital machine), displays, and control panels. The optical sight, the other manned station, is mounted on a stabilized platform located topside. It comprises various components including gear trains, servomotors, synchros, and a binocular mount for optical tracking and visual observation.

The system can engage two targets simultaneously. It can engage two surface (or shore targets) or one air target and one surface target at the same time.

Additional information on the GFCS Mk 87 can be found in OP 3452.

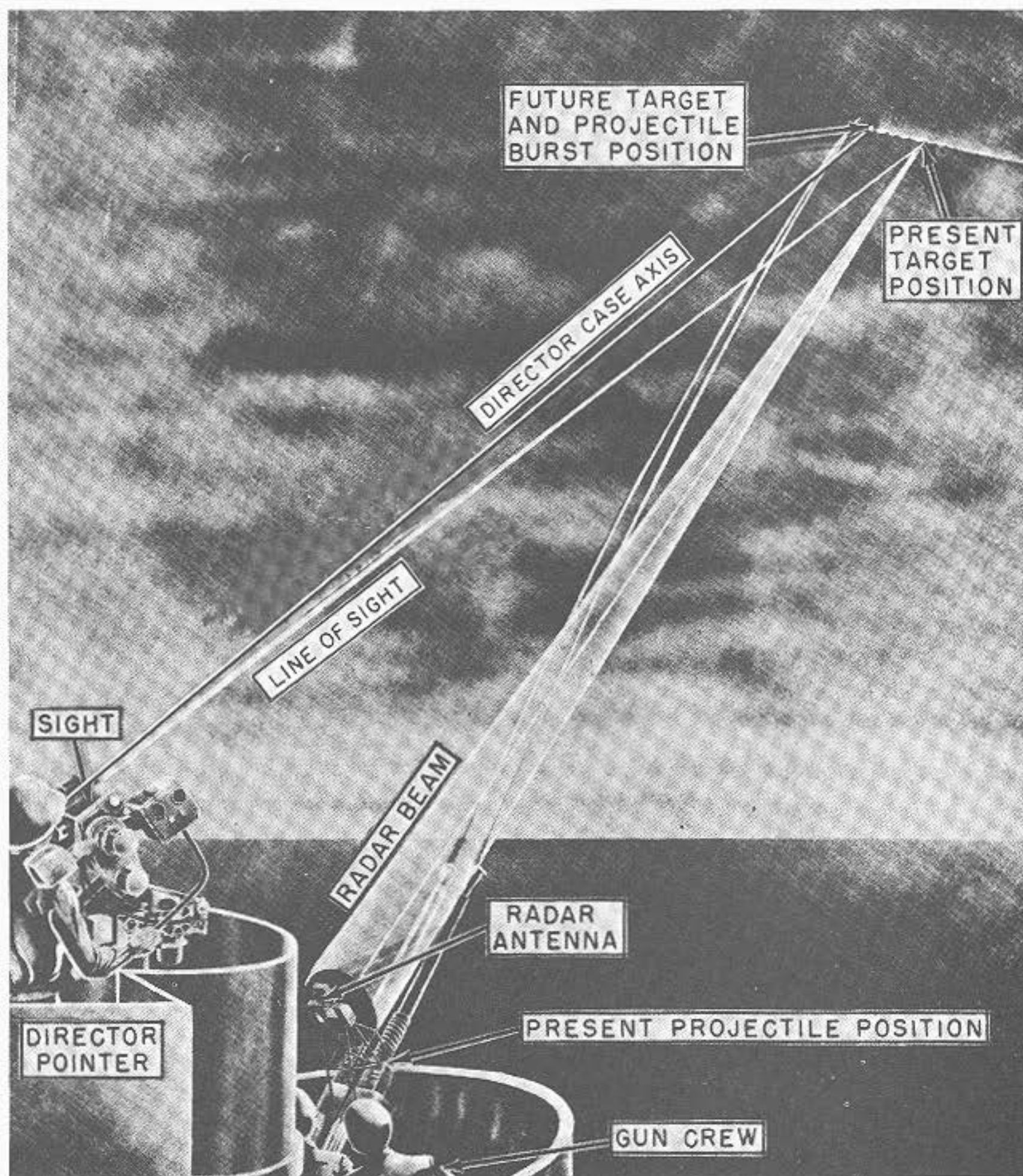
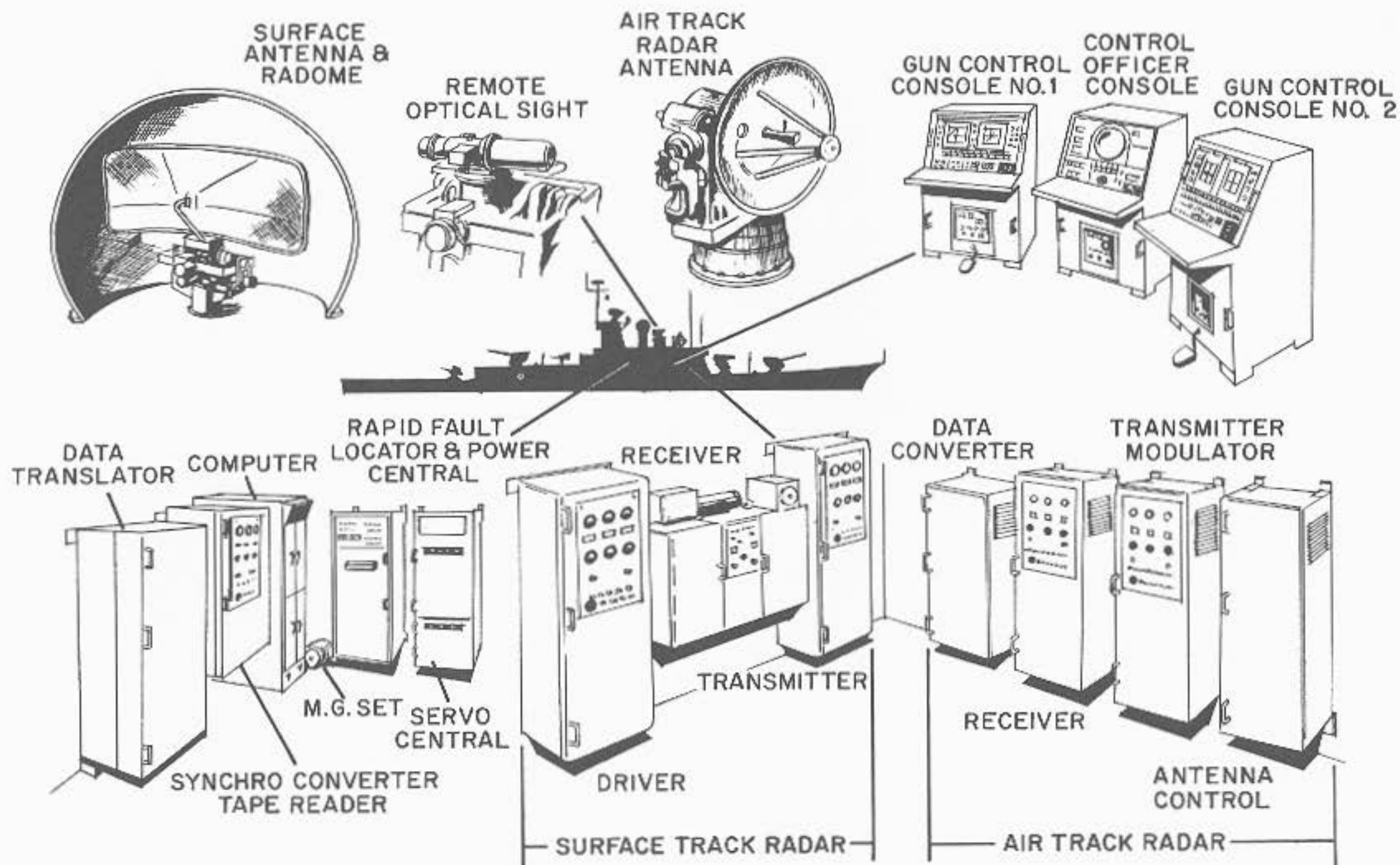
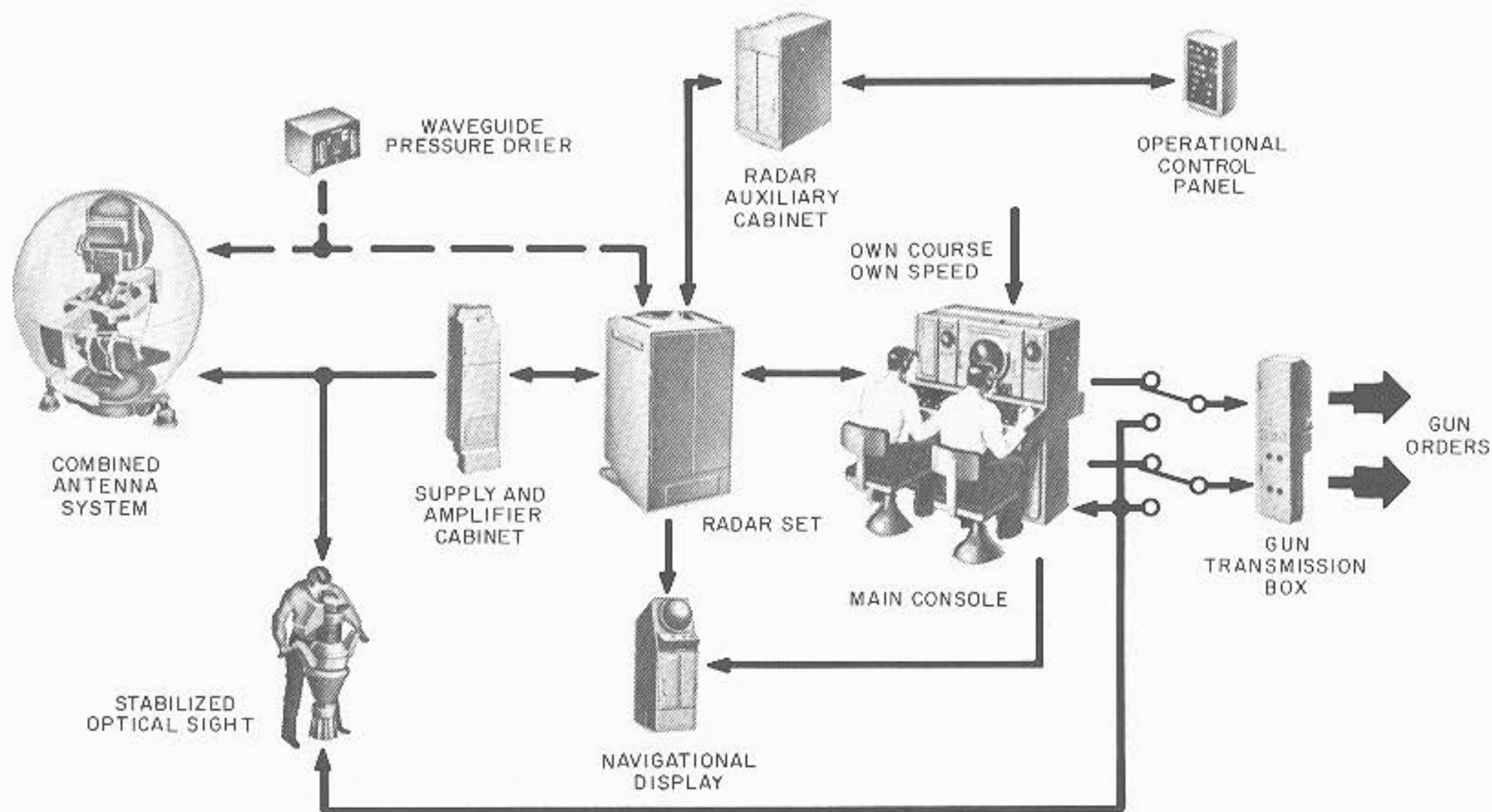


Figure 6-48. — Mk 63 GFC system. Principle of fire control problem solution. 110.72



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Figure 6-49. - Gun fire control system Mk 86.



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Figure 6-50. — Gun fire control system Mk 87.

CHAPTER 7

DETECTING AND ASSIGNING AIR TARGETS

INTRODUCTION TO ANTIAIR WARFARE

Antiair warfare includes all measures designed to nullify or reduce the effectiveness of attack by hostile aircraft or guided missiles. The following broad capabilities are necessary to defeat the airborne threat.

1. Ability to eliminate the enemy threat at its base before it is airborne.
2. Ability to defend tactical units by defeating airborne attacks launched against them.

An enemy may attack with aircraft, or with missiles launched from land, from water, or from air. The trend in missiles and aircraft is for higher and higher speeds, and more distant weapon launching capability. Consequently, the time available for surface units to defend against an attack is becoming shorter and shorter. Surface units must be deployed in formations that take advantage of the defense-in-depth concept. This means (1) beginning the effort to counter the enemy attack at as great a distance as practicable from the forces to be defended, and (2) continuing this effort against the attack until it is defeated, or withdrawn.

An AAW operation may be divided into three phases occurring successively as the attacking aircraft approach the force being defended.

FIRST PHASE. The first phase includes searching for, detecting, or receiving knowledge of, and evaluating and reporting the enemy attack force.

SECOND PHASE. The second phase encompasses employment of initial active defense measures taken while the attacking aircraft are at a considerable distance from the forces to be defended. Long-range surface-to-air guided missiles (SAMs), and/or combat-air-patrol interceptor aircraft are used in this phase.

THIRD PHASE. The third or final phase is the use of AA guns, short-range guided missiles,

and evasive action. During this phase the attacking aircraft are near or within AA gun range of the main body.

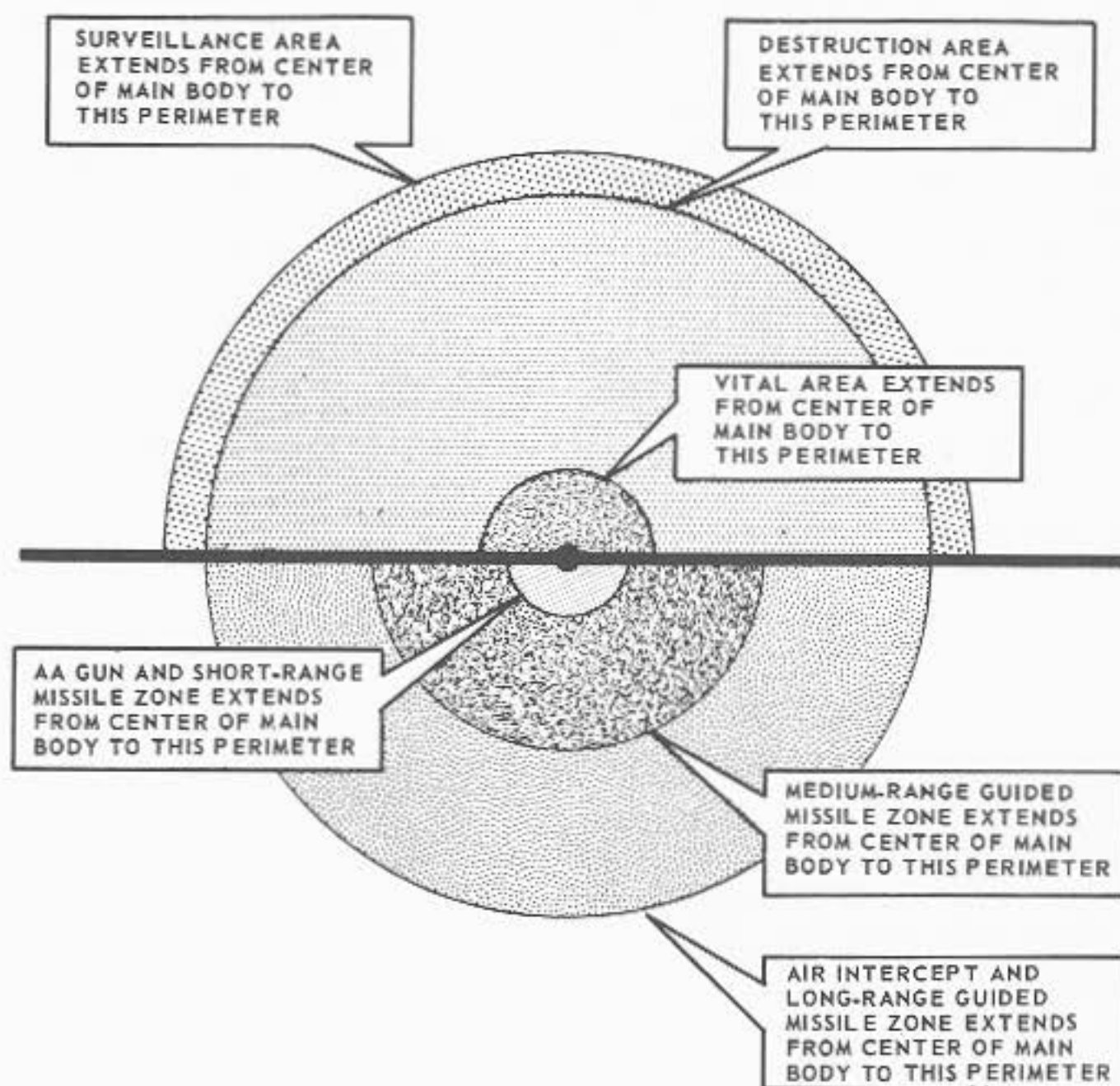
Associated with these three phases is a designated AAW area; figure 7-1 is representative. Notice in the figure that three concentric circles divide the total area into a surveillance, a destruction, and a vital area. The actions taken in these areas generally adhere to the explanations of the three phases above, with the surveillance area akin to the first phase, and so on. Figure 7-1 does not describe the area diametric limits; these change, depending on the nature of the expected attack. Following is a brief description of the areas:

SURVEILLANCE AREA. The surveillance area is an area in which search, detection, evaluation, and tracking are accomplished. Its outer limits are the outer limits of the AAW area.

DESTRUCTION AREA. The destruction area is the area within which destruction or defeat of the enemy airborne threat should occur. It may be subdivided into (1) an air intercept and long-range guided missile; (2) a medium-range guided missile zone; and (3) an AA gun and short-range guided missile zone.

VITAL AREA. The vital area is the area within the destruction area occupied by the forces for which defense is planned. The radius of this area is the enemy EWRR (estimated weapon release range).

Throughout this discussion of AAW, we will consider the force in question to be a fast carrier task group, controlled in AAW matters by one assigned officer. The AAW commander might not be the officer in tactical command of the task group, but he will usually be an officer of flag rank. When formations of more than one task group are involved, the AAW responsibility will most likely be split into sectors and there will be an officer in control of each.



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Figure 7-1. — AAW areas.

AAW UNITS

Ships and aircraft are joined in a task group to accomplish the mission of the group. The mission is dictated by strategic necessity; its accomplishment depends on the proficiency of the group in antiair and antisubmarine warfare, and on the group's offensive striking capability. The number and type of ships and aircraft (hereafter called units) in a task group depend on the operational objectives of the group. Other groups, with similar or different objectives, are joined as needed to fulfill a mission.

An AAW formation is designed to protect an attack carrier, which is the offensive striking unit of a fast-carrier task group. The group is comprised of guided missile and conventional cruisers and destroyers; various fighter, strike,

and AEW (aircraft early warning) aircraft; and the carrier itself. Submarines on radar-picket duty may also be part of the AAW formation. (An actual formation showing the locations of the AAW units may not be listed in this unclassified text.) A unit is stationed within a group so that it strengthens the defense capabilities of the group. It must be prepared to direct CAP (combat air patrol) to a target, or to use its own armament. The unit must also engage in passive AAW as regards target detection and evaluation, and transmitting target information to the AAW command ship.

Aircraft are the front line of defense; they have the speed, flexibility, and striking power necessary to engage the enemy at a considerable distance from the friendly force. These fighter aircraft are classified as interceptors, day

fighters, and all-weather fighters. Interceptors are high-speed, short-range aircraft designed to destroy the enemy before he reaches the vital area. Day fighters are designed to engage the enemy aircraft under visual flight conditions. Day fighters also perform interception and area patrol missions. All-weather fighters destroy enemy aircraft under any weather conditions. They are larger and heavier than the other fighters and have greater endurance.

Specially equipped aircraft (AEW) are used to supplement ships and submarines in providing and extending radar coverage of the air defense area, to give early warning of airborne threats, to conduct ECM search, to control fighters, and to serve as radar and communication links between pickets and the main body.

SHIPBOARD AAW WEAPONS

After aircraft, guided missiles and guns are the next lines of defense.

Missiles are classified according to their effective range as follows:

1. Short-range guided missiles have an effective range of 20,000 yards and augment the AA guns in defense of the gun zone.
2. Medium-range guided missiles have an effective range of up to 100,000 yards and engage air targets inside the first line of pickets.
3. Long-range guided missiles have an effective range greater than 100,000 yards.

For further details regarding the use and classification of guided missiles, refer to the next two volumes in this series.

Guns are used against targets that are relatively close to the ship—within 25,000 yards. The most common types of guns used for AAW are 3"/50, 5"/38, and 5"/54 (described earlier).

The 3"/50 RF is a postwar (WWII) product, whereas the 5"/38 was widely used during World War II. The 5"/54, a newer gun, will, in time, replace the 5"/38; primarily because of its faster rate of fire. This does not mean that 5"/38 guns will be removed from ships, but rather that those combatant ships with 5"/38s will gradually be phased out of the fleet. At present, most newly constructed ships do not have 5"/38s, but some converted missile cruisers do.

Auxiliary ships and smaller craft use machineguns in addition to, or in place of, the guns

described above. The three types of machine gun mounted on ships are:

1. .50 cal—on small craft.
2. 20 mm—called a light machinegun in the Navy and mounted on small ships.
3. 40 mm—called a heavy machinegun and mounted on small ships and larger auxiliaries.

Machineguns have a high rate of fire, short effective range, and a limited AAW capability. The 40mm has a maximum effective range (MER) of about 4,000 yards, which is greater than that of the other two. The 40s and 20s use impact-detonating projectiles, and a lead computing gun-sight to control their fire.

Each type of AA gun has a range (its effective range) at which that gun is most effective. However, it is impossible to set this range precisely. One factor of primary importance is that the effectiveness of gunfire increases as the range decreases. Other factors are considered when establishing maximum ranges for opening fire at air targets. Although gunfire at ranges greater than effective range may result in a few hits, any damage, no matter how insignificant, increases the probability of a kill and has a detrimental effect on the enemy. Opening fire beyond effective range also may effect operation of the equipment and gunnery personnel by the time the target reaches effective range.

Consequently, the maximum effective range of opening fire has been arbitrarily set as the range which will permit approximately 10-second time of flight for the projectile. The approximate MER of opening fire for presently installed AA guns is tabulated in NWP 32.

The probability of kill on targets requiring angles of elevation above 70° is small, because of mechanical limitations of the power drive on AA guns. Therefore, high position-angle crossing targets are extremely difficult to hit. A closing air target at high altitude is also difficult to hit. As a general rule, any enemy air target above 15,000 feet will be assigned to the combat air patrol or to the missile battery for destruction.

THE AAW PLAN

Defense against an air attack demands a high degree of coordination between widely dispersed units in the formation. The attackers can climb to very high altitudes, or they can come in just

over the wave tops. No matter what their altitude, their speed in many cases is supersonic. This means that instantaneous reactions and quickly computed solutions are absolutely essential to the defenders. Even after attaining maximum proficiency, a ship's individual efforts would probably prove futile unless she were deployed in a defense-in-depth formation. Defense in depth requires intensive coordination. Teamwork is then the order of the day and the captain of the team is the AAW commander.

The AAW commander and his staff are usually embarked in a missile cruiser where the entire AAW picture is presented on various display plots. He maintains communications, except during some conditions of electronic silence, with all of the AAW units. He receives all "bogey" (unfriendly air contact) information from the detecting ship or aircraft. Speed of communication and dissemination of target data are essential. Therefore, NTDS (Naval Tactical Data System) was developed to fulfill these requirements.

NTDS General Information

The NTDS is fast and accurate in evaluating and processing naval combat data. It rapidly correlates tactical data from a number of collecting points to provide force commanders with an essentially complete picture of their current tactical environment. NTDS has three basic purposes:

1. Generation of target descriptions.
2. Presentation of the tactical situation.
3. Communication of tactical data.

System components include a variety of electronic equipment, as follows:

- Automatic highspeed, general purpose, stored program, solid state, computers.
- Displays.
- High-speed digital data communication facilities.
- Radar video processors.
- Readout devices.
- Magnetic tape handlers.
- Manual data entry devices.
- Analog-to-digital converters.

Peripheral to the system are a wide spectrum of sensors and weapons systems. Data derived from radar, IFF (identification friend or foe),

sonar, ECM (electronic countermeasure) intercept equipment, and other units of a force, as well as inputs of own ships's course and speed, are entered into the computer for processing. The computer performs data-handling calculations and derives information required for threat evaluation, weapons assignment, dead-reckoning navigation, and communications by way of data links. It also performs the functions of tracking, identification, and height and size determination of an unknown force. All tactical data are presented visually on all display consoles. A representative NTDS diagram is shown in figure 7-2.

NTDS Communications

NTDS provides three separate communication links:

1. The A-link (link 11).
2. The AN/USC-2 link (link 4A).
3. The B-link (link 14).

The A-link is a long-range digital communication link between tactical data units (ships and/or aircraft). Three basic types of information may be received and transmitted via this link—

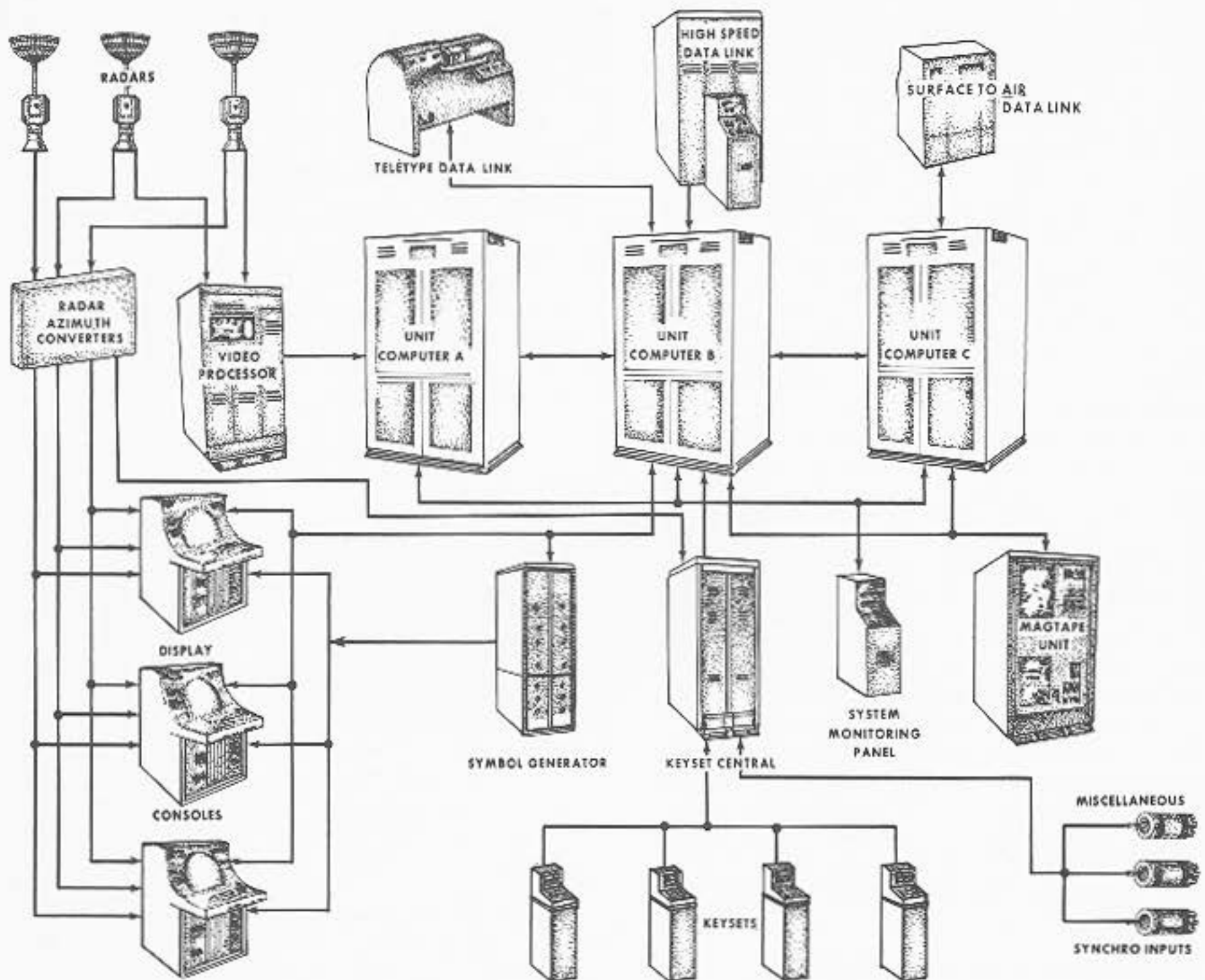
1. Target tracks.
2. Weapons status and orders.
3. Control messages which regulate the operation of the data link network.

Under normal operation, the data exchanges between NTDS ships proceed automatically and continually on each ship. The unit computer that controls the link equipment is in direct contact, via radio, with unit computers on all other NTDS ships in the force.

The AN/USC-2 data link is used to communicate automatically between the ships and aircraft equipped with this data link. Guidance instructions to interceptors or bombers may be transmitted via this link.

The B-link provides automatic broadcast of tactical data from NTDS-equipped ships to non-NTDS-equipped ships via radio teletype facilities. Generally, one NTDS ship is designated by the officer in tactical command to broadcast NTDS track information to non-NTDS units in the task force. This link may also be used to transmit NTDS data to shore installations.

With the entire tactical situation on visual display before him, and the status of all weapons indicated, the tactical commander is able to best employ his defensive units (aircraft, missiles,



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Figure 7-2. — Naval tactical data system diagram.

or guns). Merely by pressing the required button, he can assign the desired unit instantaneously. Target track and control data are then automatically transmitted to the assigned unit to effectively engage the target. The unit assigned to engage the unfriendly aircraft (bogey) may be a Combat Air Patrol (carrier-based patrol aircraft) or a surface unit.

Weapon Employment

If the bogey does pose a definite threat, the AAW commander decides which weapon in the defense arsenal is to be used. Normally, CAP is vectored to the target if in the target area. The

intercepting aircraft may be able to visually identify the target, thereby confirming its belligerent status.

We can miss with CAP just as we can miss with the guns or missiles. CAP may be out of position, the relative speeds may be so great that the attacker might slip by, and conditions of poor visibility or poor radar reception during the terminal phase of the intercept might render CAP useless. Now comes our second line of defense, the surface-to-air missile.

Many things were happening on the missile ship while the CAP intercept was attempted. Extremely accurate fire control radars were being designated (directed) to the target by an

elaborate weapons direction system. The direction system sent continuous target information in three coordinates (range, bearing, and elevation) to the fire control directors in the gun and missile systems. The directors then "locked on" (shifted to automatic radar track) and became electronically independent of the weapon direction system. A computer solution started generating simultaneously with director lock-on in each fire control system. The computers solved the fire control problem and computed the required launcher, missile, and gun orders.

When a ship is ready to engage the target with missiles, it reports this fact to the AAW commander. Upon receipt of more than one such report, the commander decides which ship is to take the target under fire. He considers which ship is in the best position for a kill, and the type and number of missiles remaining on board. If the target is not destroyed after multiple missile salvos have been fired, reliance must be placed upon the last line of defense—conventional gunfire.

Conventional guns are still very much a part of the Navy's armament and they continue to be effective in AAW as indicated by target practice results against high speed jet targets. Gunfire can also disrupt an otherwise orderly mass attack. A gun is not invalidated by a target's speed, but it is seriously limited when the target's RELATIVE MOVEMENT in bearing, elevation, and range exceeds the designed limits of the gun fire control system.

STEPS IN THE SHIP'S DEFENSE PROCESS

The preceding section showed how units are integrated to protect the task group's vital area. But the plan of action for any one unit is necessarily more precise; its broad outline neatly dovetails into the overall AAW plan. In order of occurrence, a ship must detect, display, evaluate, disseminate target information (within the ship), and destroy air targets. If a ship is the first unit in the formation to detect a target, most of its internal steps become steps in the AAW sequence for the task group. Detection, evaluation, dissemination within the task group, and (possibly) destruction of the target become one and the same for the detecting ship and the task group. Other ships will participate in destruction or evaluation if directed or needed, respectively; but they will all use the same internal sequence as outlined above. Note that

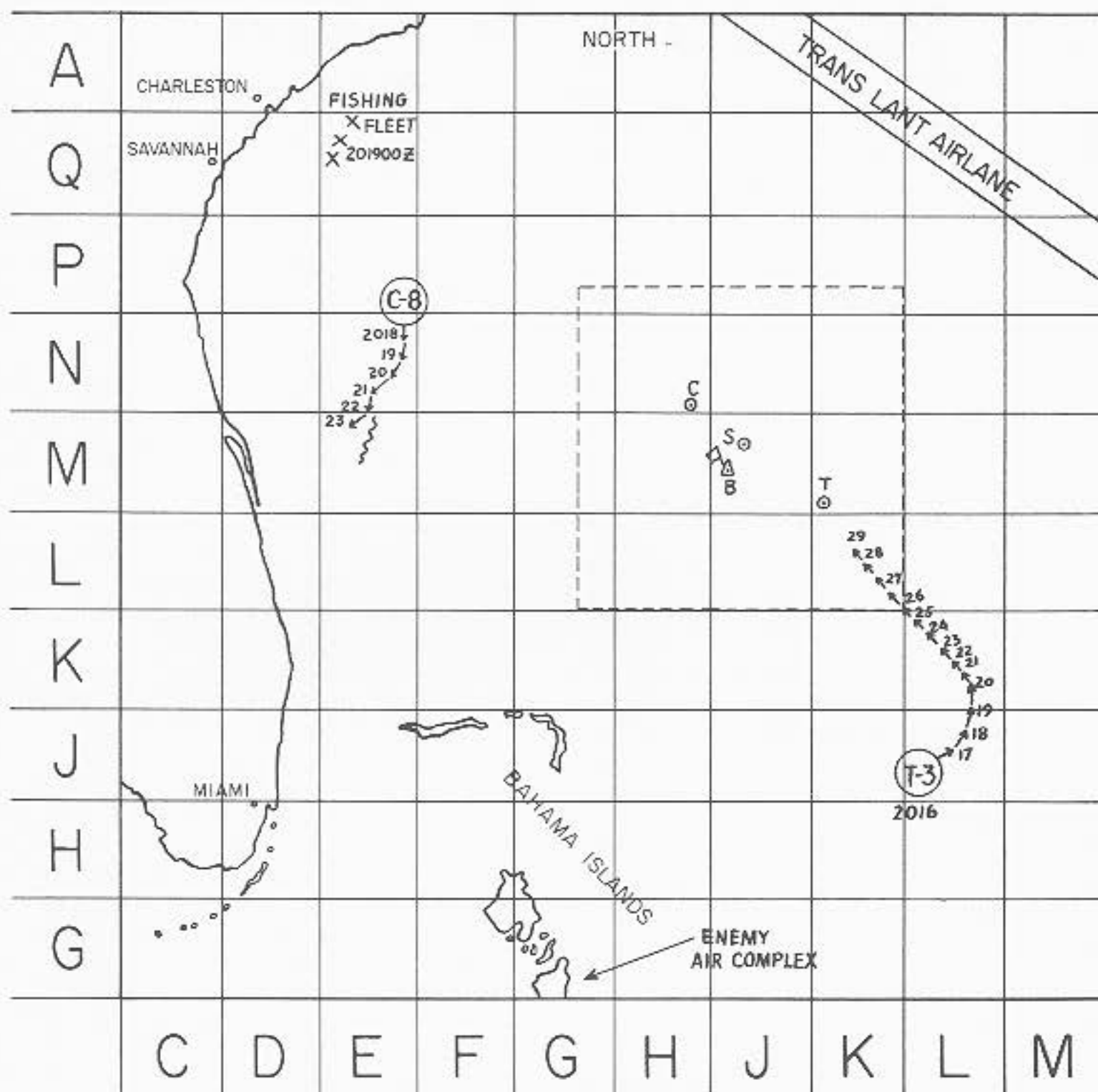
displaying and disseminating within a ship are always internal steps. Following is a description of the internal steps:

1. DETECTING. Detecting the target is the first and probably the most difficult part of the problem. We have devoted the next section in this chapter to detecting. Air search radars (of various designs) are the primary detecting means, but surface search radars very often detect low flying aircraft. Two other detecting methods are visual, and passive with ECM (electronic countermeasure) equipment.

2. DISPLAYING. Target data are displayed in the CIC (combat information center) of each ship. There are three main display boards, which are called phase 1, phase 2, and phase 3 summary plots. (Smaller ships such as DDs use only two displays.) Phases 1, 2, and 3 stand for long, intermediate, and short range respectively; or, if you prefer, the first, second, and third phases of the AAW problem. Don't confuse these phases with those previously mentioned, because these are relative to a single ship; not to the vital area of the task group. For example, an outer perimeter ship may be in its phase 3, while units in the vital area are in phase 1 or phase 2.

Figure 7-3 shows a phase 1 plot. Each small square has sides which are equal to 60 nautical miles. Since there are 100 small squares, the square mile area covered by the plot is 360,000. GEOREF coordinate identifying letters are inscribed on the edges of the board, and grid lines connect the coordinates vertically and horizontally to "checker" the board. The resulting GEOREF squares make it possible to fix a contact's position in much the same manner as a city is located on a standard road map. You will see later how numbers are used to fix the position within a square.

The main purpose of the phase 1 board is to provide a long range look at the situation. All unidentified air contacts beyond 100 miles from a ship are plotted here. Also plotted is the whereabouts of the formation center. Flagship B in figure 7-3 is the formation center of the four-ship task group shown (ships B, C, S, and T). Notice that certain intelligence items are plotted. Even though the Southeastern United States and the grid lines are drawn approximately to scale, the letters used here are not the actual letters for that locale. Bogey C-8 was detected by ship C at 2018 local time and lost after time 2023—it



63.16

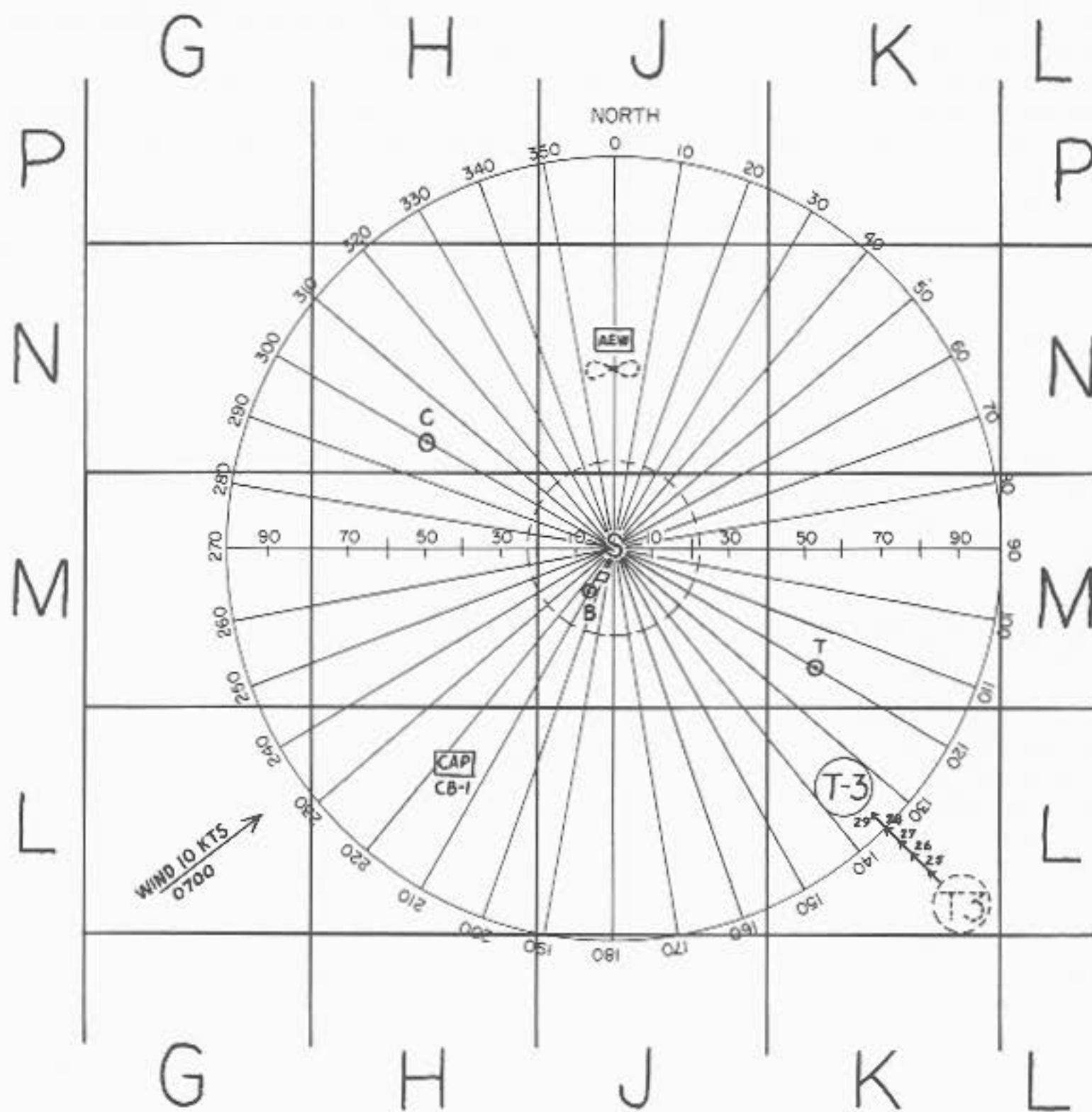
Figure 7-3.—Phase 1 plot.

was then said to be in a "fade" (depicted by the wavy line). Ship T picked up bogey T-3 and made continuous reports to the formation.

Locate ship S. Notice that it is within a small square that has GEOREF coordinates of JM. (The longitudinal coordinate is always given first.) Ship S is a little northwest of center in the JM square and exactly in the center of a larger square which is shown by the broken lines. The broken-line square represents the area that will be covered by the phase 2 plot on board

ship S. The phase 1 plot is also the one on board ship S. Now shift to figure 7-4, the phase 2 plot.

Ship S is in the center of the plotting board and northwest of center in the JM square. Bogey T-3 is making an attack from the southeast and his position in the KL square is the same as that which he occupied in the phase 1 plot. The physical dimensions of the squares on the phase 2 plot have been enlarged but the geographical area they represent remains the same. Now there is a quick and convenient way of relating bogey T-3 to ship S. He bears 135° true at about 90 miles.



63.17

Figure 7-4. — Phase 2 plot.

Knowing the approximate bearing and range enables ship S to make an intensified search in the area with her own airsearch radars.

The phase 2 plot shows the surface units of the formation plus all friendly aircraft (AEW and CAP) within its radius. This plot differs from phase 1 in that the center of the plot is made to represent the geographical position of the ship (ship S in this case). The grid coordinates are adjusted periodically as the ship moves over the ground. Unlike the grid lines that are inscribed on the phase 1 board, these are wires which are

attached to rods that border the board. It is a simple matter for a Radarman to adjust the wires and change the grid letters to make the center of the board correspond to the approximate position of the ship. He gets his 'posit' information from the DRT which has been set to agree with the ship's radar, loran, or navigational fixes.

The phase 3 plot is an enlargement of the close-in area of the phase 2 plot. Unidentified air contacts within a 50-mile radius are displayed here. The phase 3 plot is important in ships

that do not have a long range target acquisition capability.

Figure 7-5 shows how to fix a target's position within a GEOREF square. The square is divided into equal increments in both latitude and longitude. Bogey T-3 would be reported as KL 23. The numbers shown in the figure are not inscribed on the plotting board or on the grid wires. It is useless to scribe wires that can move with respect to one another. The Radarman who is reporting the bogey's position merely estimated the divisions of the square. Other numbering systems which have about five increments are used, but the principle remains the same.

Finally, GEOREF posits are not "right on the nose." Inaccuracies stem from reporting delays and from grid wires that have been incorrectly set. Moreover, the actual position within a square is an estimate by the person reporting the contact. Since NTDS was developed, however, reporting delays have been greatly reduced, and the actual target position within a square is more accurate.

3. EVALUATING. The process of evaluating is continuous from the moment of detection to the subsequent intercept of the target. The tools used most often are the target's relative

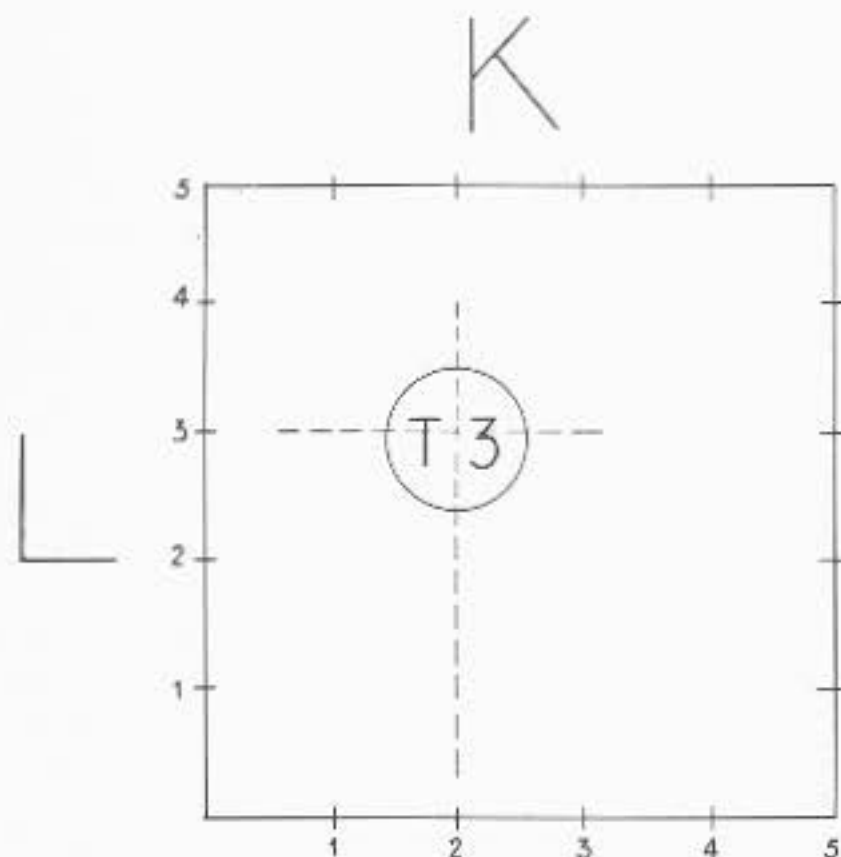
position, his course, speed, and altitude, and his response to an IFF (identification friend or foe) challenge.

As we have seen, a contact may first appear on our display as a GEOREF report from another AAW unit. Included in this report will be a calculation of the contact's course, speed, and altitude. This information is sometimes hastily computed because of the need for immediate dissemination to the other units in the task group. Initial minor inaccuracies will be noted quite often when compared to the subsequent reports from that same reporting unit.

The mere mention of a contact on the reporting net indicates that the reporting unit is unable to receive the correct IFF response. It is quite possible that the IFF equipment may be functioning improperly. The only reasonable recourse in the event of no IFF return would be to get as many AAW units as possible on the contact. Perhaps they can receive the correct IFF response or locate the contact on their ECM gear. If the IFF equipment fails to identify, maybe the contact can be recognized by evaluating ECM radar characteristics. You might also identify the bogey by accounting for all of the known friendlies in the area. This process of elimination and the evaluation of ECM information consume time, and time is not always available. If time is short and we can't receive the correct IFF response, we must assume that the contact is an enemy.

Most of the defensive decisions for the group will be made by the AAW commander, but each ship is set up to evaluate independently, and to make its own decisions if necessary. The factors and questions which follow are considered simultaneously by the AAW commander and each ship's CIC evaluator.

The evaluator is responsible for identifying the contact, and for determining the type of attack he is most likely to make. He is also responsible for an estimation of the target's weapon release range. Generally speaking, the determination of the target's weapon release range is not of paramount importance when intercepting with aircraft, since the practice is to get out there with CAP as soon as possible. It would be a definite factor however, in the case of a saturated raid when the evaluator must select the most critical target. The most critical target, excluding the type of weapon he carries, is usually the target with the nearest or quickest CPA (closest point of approach), or a target involved in jamming.



63.18

Figure 7-5.—Locating a Bogey within a square.

The target's radar characteristics, along with his speed and altitude, may reveal his aircraft type and, therefore, his weapon capability. Armed with this information, the evaluator, who is well versed in aircraft tactics, can make an educated guess as to which is the most critical target in regard to weapon type and release point.

Along with the selection of the most critical target comes the necessity to know the ship's defensive capability. The evaluator must be knowledgeable in this area in order to recommend the type of armament to be used in the kill, and to be reasonably sure that the selected weapon is capable of a kill. What are the weapon limitations? How high and how far can the missiles go? Is the missile control equipment locked on and ready? Will the target enter the missile blind zone (firing cutout area caused by ship's structure)? If so, will the ship have sufficient time to change course and unmask her missile battery? Or, would it be better to fire a nuclear missile in the face of a concentrated raid? Are these nuclear missiles available? For that matter, what is the actual count of all missiles remaining on board?

Further, are all of the missile directors engaged? Can AA gunfire cope with a particular target? Once again, how high is he, what is his relative movement, is he in the blind zone, or will he reach his weapon release point beyond the range of AA gunfire? In the latter case, perhaps a shifting of targets at one of the missile directors is indicated. These are only some of the many questions confronting the CIC evaluator.

All intelligence information is collected and made available to the evaluator. A knowledge of enemy aircraft capabilities and limitations, both in equipment and tactical application, is essential. The evaluator must be able to estimate the target's priorities and probable intentions. He must be aware of the geographical location of friendly forces, particularly in relation to enemy air facilities. In addition, he must keep abreast of any weather or atmospheric developments and their effect on flight operations and radar performance.

Evaluation is a process which involves a continuing appraisal, or estimate of the existing air threat. It terminates with the "splashing of the target." With very little time available to detect and successfully counter a raid, it is mandatory that responsibilities be decentralized as much as possible. There may be no time for the commanding officer to request permission

from the AntiAir Warfare Commander to launch short range missiles, and there may be no time for the evaluator to ask the commanding officer for permission to take the raid with CAP. And sometimes, when confronted with a surprise attack, there is no time for the weapons officer to wait for information from CIC. As a matter of fact, the director officer may commence firing if the situation warrants.

4. DISSEMINATING. Transmitting information to the other units in the group, and keeping stations on a ship informed, is disseminating externally and internally, respectively. External dissemination to other AAW units, and the AAW commander, is the responsibility of CIC personnel. Internal dissemination is of more concern to the readers of this text.

All ships use sound-powered telephones to complete the communications link between CIC and weapons' battle stations. Newer ships, specifically those armed with missiles, often have closed-circuit television equipment on board. A television camera is focused on the phase 2 plot in CIC and receivers are located in various control stations throughout the ship. Examples of receiving stations are:

- a. Weapons Control Station
- b. Commanding Officer's Tactical Plot
- c. Flag Plot
- d. Air Control Section of CIC

Television equipment has done much to eliminate the excessive time consumed when transferring bogey data exclusively by sound-powered telephones. But telephones are still used for action commands and to provide an audio backup for visual information. They continue to be the sole information link to stations that do not have a critical evaluation or a weapons control assignment.

The most important information disseminator for weapons personnel is the weapons liaison officer (WLO). This officer is stationed in CIC at a location which commands a good view of the phase plots and facilitates direct conversation with the evaluator. The WLO is on the weapons battle control telephone circuit, which also includes all officers who are assigned in weapon control stations. It is his responsibility to keep all stations on the circuit fully informed in all matters pertaining to the battle. He forwards information such as "warning red, yellow, or white" which means that an attack is imminent, probable, or improbable. Warning conditions

are prescribed further by "weapons tight" or "weapons free." Weapons tight means that ship-board weapons will not be fired (unless enemy aircraft are committing hostile acts) because friendly forces (usually CAP) are in the firing area. Weapons free means that there are no weapon delivery restrictions, and may be used as the authorization for a ship to "fire when ready." The latter usage depends on the standard operating procedure for the task group. The WLO performs other, more mechanical, actions in getting directors on targets; these will be discussed later in this chapter.

5. DESTROYING. There is very little we can say here about destroying targets. Once a gun projectile is launched it follows a ballistic flight plan which cannot be controlled by the launching ship. Effective gunfire depends on solving the fire control problem, aiming the guns correctly, and maintaining a continuous ammunition supply. The destruction of targets by missiles will be discussed in the next two volumes of this series.

TARGET DETECTION

It is possible to detect a target by using passive equipment such as electronic counter-measure (ECM) gear. This supersensitive equipment detects electromagnetic radiation, indicates its direction, and measures the transmitter's frequency, pulse width, and pulse repetition rate (PRR). We can even determine the antenna's rotation rate with this gear.

The ECM operator refers to a publication which described the operating characteristics of known radiating equipment. He then ascertains, what type of equipment he has detected and, more important, what type of vehicle the equipment is probably mounted on. In other words, he makes an educated guess as to whether the contact is a particular type of enemy aircraft, submarine, or perhaps a member of his own operating force. ECM gear has serious drawbacks in that it cannot measure the range or altitude of the contact, even though range might possibly be determined by ECM triangulation.

Air search radar is the primary means by which we detect targets. The air search radar fixes the target's position in two coordinates—range and bearing. Some CIC air search radars, particularly those associated directly with fire control equipment, have a height- or altitude-finding capability. The three coordinate radars

have a distinct advantage when designating a fire control director to the target. The height quantity is converted into an angle of elevation and eliminates large sector searching in elevation by the director. In order to make use of height, we must have a weapon direction system which can designate in three coordinates. The result is a decrease in the target acquisition time required by the fire control director, provided the search radar has been correctly aligned with the FC radar. Since radar is such an integral part of modern weaponry let's discuss it in more detail.

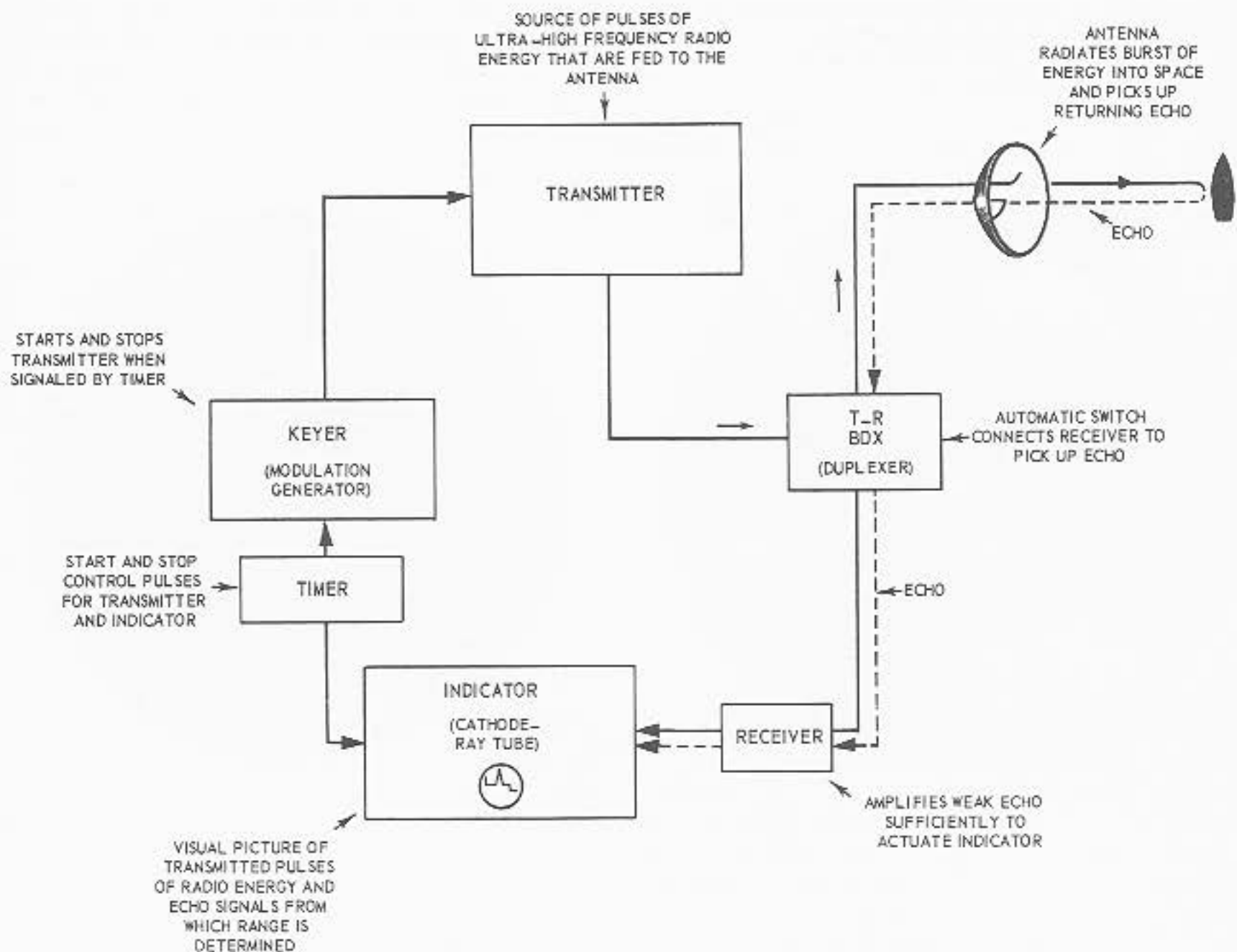
ELEMENTARY RADAR THEORY

As you remember from an earlier chapter, radar essentially is a method for determining, by radio echoes, the presence of objects, their range, bearing, and elevation, for recognizing certain of their characteristics, and for making use of this information. A complete radar installation is itself referred to as a radar; the term is used to denote the equipment as well as the technique.

The bare elements of a radar system's operation are shown in figure 7-6. A high-powered transmitter sends out a short pulse of intense high-frequency radiation from a special antenna so that it issues more or less as a beam. Then the antenna is switched by a duplexer to a sensitive receiver, which picks up radio echoes reflected by targets in the path of the beam. The echo (pip or blip) shows up as a bright spot or a kinked line on the screen of a cathode-ray tube. (The tube is like that of a television receiver, but doesn't present a picture—only blips or pips.) The functioning of the system is coordinated by a timer, which transmits pulses to the receiver and keyer. The keyer in turn starts and stops the transmitter.

With electromagnetic radiation traveling at the speed of light (186,000 miles per second), it's obvious that all of this happens quite fast. In 1/1,000,000 second (1 microsecond) radio energy travels 328 yards. Since the pulse of radio energy has to travel to the target and return, a time indication of 6.1 microseconds represent 1,000 yards range, although the pulse has traveled 2,000 yards going to and from the target.

Now that we have a general idea of the functioning of a basic radar, let us discuss (briefly) search radar.



53.106

Figure 7-6.—Elements of a Radar System (block diagram).

SEARCH RADAR AND IFF

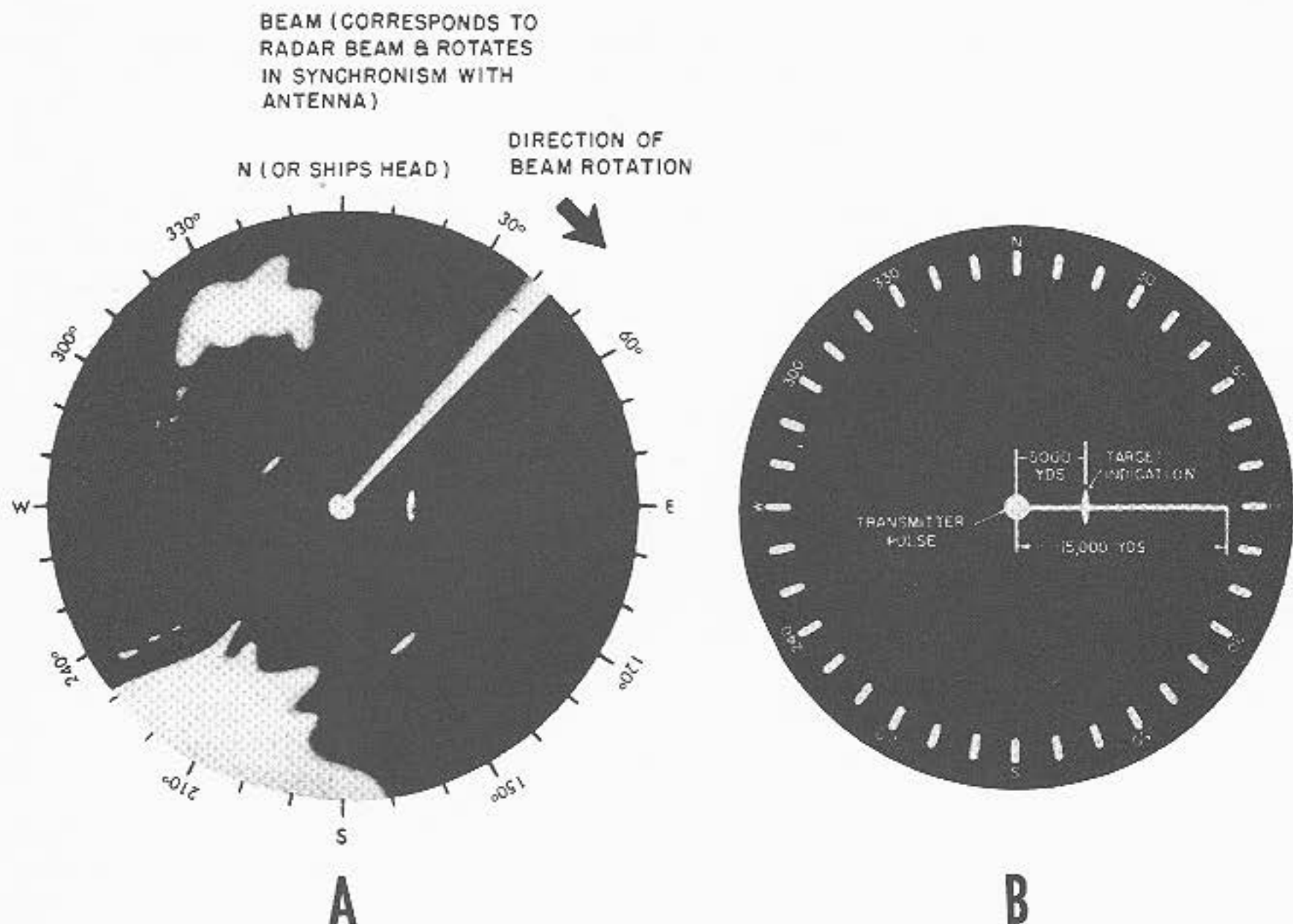
Aboard ship, radar equipment has two general applications—for search and for fire control. Search radar displays are centered in CIC. Although we are primarily concerned with fire control radar, you must in order to understand the target detection and acquisition process know something about search radar. The three types most commonly used in surface ships are air search, height-finding search, and surface search. A representative search radar presentation is shown in figure 7-7; this is the commonly-used PPI (planned position indicator) display.

An air search radar's primary function is warning of the presence of aircraft at extreme

ranges. It is called a two-coordinate radar since it measures only range and bearing.

Height-finding radars are three-coordinate radars. They are capable of discriminating between targets that are close together, and they are capable of measuring range, bearing, and altitude. The altitude quantity is converted in the weapon direction system to an angle of elevation by the fire control directors, thereby decreasing their target acquisition time.

Surface search radars measure the range and bearing of surface contacts to assist in navigating the ship, or to send surface target information to the weapon direction system. They are also effective in detecting low flying aircraft, since their radar energy is concentrated at low angles of elevation.



53.109.1

Figure 7-7.—PPI Scope presentation.

As we stated earlier, on a radarscope presentation a target is a blip, not a picture. It's either a shapeless blurred spot or patch, or a jagged distortion in a line. Around the blip is "grass"—the visual equivalent of audible noise in a radio transmission. (It's called "grass" because in an A-scope presentation electronic noise in the line traced by the electron beam in the cathode-ray tube does appear as wavering, moving filaments reminiscent of blades of grass.) In search radar units, any target smaller than a geographical feature has no discernible shape. This is especially true of aircraft targets. When aircraft come within search radar range, there's nothing in the blips to indicate whether they're friendly or enemy.

To deal with this problem we have IFF. IFF equipment aboard ship functions in conjunction with a search radar, but the IFF system includes

also equipment aboard the aircraft. The radar beam from the interrogating ship "triggers" automatically the IFF equipment on the friendly target. The latter then transmits a coded signal which shows up on the indicator scope of the regular radar set on the interrogating ship. The interrogating ship and the target must carry matching IFF equipment. For security, we use coded signals.

FIRE CONTROL RADAR

Fire control radars must be able to determine range, bearing, and elevation of a target with a high precision to achieve destructive gunfire. They must also have good target resolution; i.e., they must be able to distinguish between blips which are very close together. This is necessary to permit accurate pointing, training, and spotting.

Surface fire control radars (e.g., Mk 13) are used in conjunction with surface batteries on cruisers. This radar must measure range and bearing accurately to provide data for the solution of the surface fire control problem. Figure 7-8 shows a B-scope of the type used in surface fire control radar. The transmitted pulse and the start of the time-base sweep are on the bottom horizontal line. The sweep is made to move from bottom (minimum range) to top (maximum range) on the scope face. The range line is an electronic measuring indication which is made to move up and down the scope face in response to mechanical gearing and electronic circuitry controlled by the radar operator. To measure range, the operator rotates a handwheel until the range line just touches the bottom edge of the target echo and then reads a range counter; we are slightly under ranged in the figure.

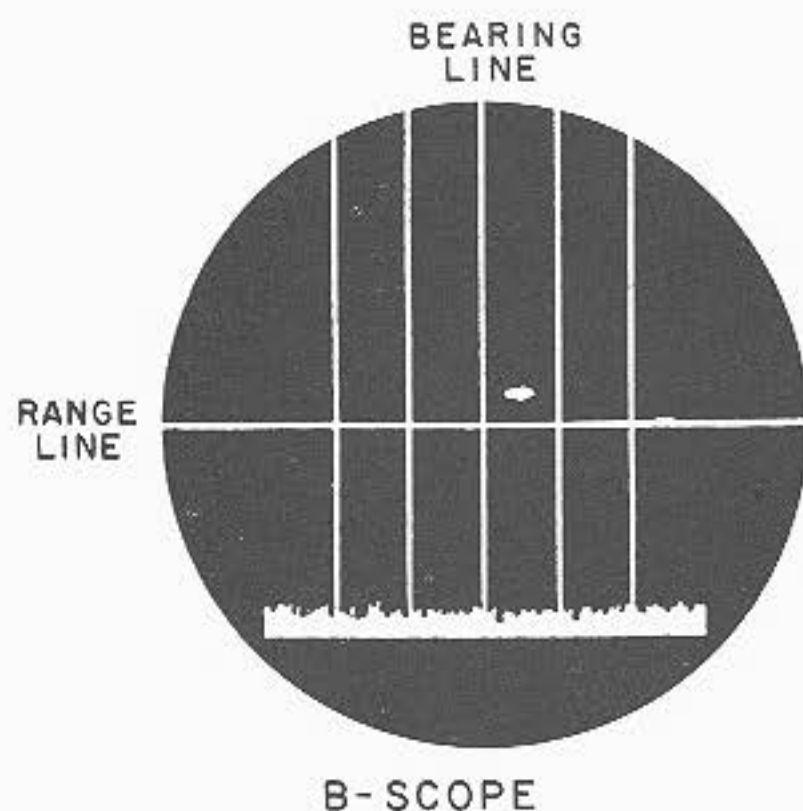
Notice the five vertical lines in the figure; these are not sweep traces. The intensity of the sweep traces has been decreased by the operator so that he can better see the target pip. If the intensity were increased to maximum, the scope face would be illuminated within the limits of the horizontal transmitted pulse line. This tells you that there exists a vertical range sweep for each minute horizontal segment of the transmitted pulse line. The actual number of range sweeps is determined by the pulse repetition

frequency of the radar and the antenna scanning frequency which will be covered in a moment. In figure 7-6 we learned that a timer fires the transmitter and starts the range sweep simultaneously. The pulse repetition frequency of a radar is the operating frequency of the timer measured in cycles of operation per second.

Now let's measure bearing. The center vertical line is called the bearing line; it always represents the exact trained position of the director. Or you could say that it is aligned with the vertical crosshairs in the director's optical telescopes. If optical tracking is impossible the director can get on target by training right (in the illustration) until the bearing line exactly bisects the target pip. The target would appear to move to the left on the scope as the trainer moves the director and its antenna on target. If optical tracking were used, the bearing reference would be the vertical crosshair in the director trainer's telescope, but the radar picture would be the same as if radar tracking were used.

The bearing relationship between the target echo and the director's line of sight (or the bearing line) is obtained by causing the radar antenna to scan horizontally. Scanning in surface radars means oscillating the antenna back and forth rapidly through a small angle; the center of which is the bearing line of sight of the director. When the director is exactly on target, the target is illuminated on the scope when the antenna is at the middle of its scanning arc, thus causing the bearing line to bisect the target echo. In figure 7-8 the target was illuminated when the radar beam was positioned to the right of the line of sight. To present this relationship electronically, the vertical range sweeps (without which no pip indication is possible) are made to scan left and right on the scope. When the antenna is at its farthest rightward position, the range sweep will be farthest to the right on the scope. When the antenna scans back to the middle of its arc, the range sweep occurs coincident with the bearing line, and so on. The sweep is made to scan left and right by applying an a-c signal to the scope's horizontal deflection plates; the same a-c signal which drives the antenna back and forth. The other vertical lines in the figure are spotting reference lines for deflection spots.

Antiaircraft fire control radar is more complicated than surface fire control radar. This is due primarily to (1) greater target velocities, (2) target elevation measurement, and (3) a need for automatic radar tracking. The automatic tracking feature is not found in all AA systems,



53.109.2
Figure 7-8.—B-scope.

but it is included in all missile systems and in the newer gunfire systems. In this discussion we'll concentrate on the automatic tracking Mk 35—the radar used with the Mk 56 GFCs.

The Mk 56 system has four displays—a double display for range (the A/R-scope), a display for bearing (the B-scope), and a display for elevation (the E-scope).

The A/R-scope displays two traces—the A trace and the R trace. The A trace extends from zero to 30,000 yards. The significant features of the trace as illustrated in figure 7-9 are:

1. Outgoing transmitter pulse blip. This is an up-down jog of the trace at the zero range point.
2. Range notch. This is a depressed portion of the trace. By cranking a control on the radar console the operator can shift the notch in range so that target blips may fall within it, as illustrated in the figure. When the notch is adjusted so that a target blip is in contact with the left-hand side, the target is said to be gated.
3. Target blips. These are up-down jogs of the trace, each corresponding to one target.

The R trace is an expansion of a portion of the A trace. Only the left side of the range notch shows on the R trace; this is the range step. The R trace is 1000 yards long; there is a small gap in the trace to represent the location of the nearest even 1000-yard point in range. As the radar operator cranks the range notch uprange or downrange, it moves correspondingly on the A trace, but on the R trace the range step remains fixed in the center of the trace while the blips and range markers move past it. In addition, the blips move leftward or rightward on both traces to correspond to their movements downrange (decreasing range) or uprange.

The diagram above the illustrated A/R traces in figure 7-9 shows the spatial relationship of radar and targets which the traces indicate.

The E-scope (fig. 7-10) shows range (horizontally) from 0 to 30,000 yards, and director true elevation (vertically) in degrees from -10° to 90° . The vertical width of the trace depends on the type of antenna scan. There are two types of scan—spiral for searching and conical after the radar has locked onto target. As the radar beam goes through a complete spiral scan cycle, the trace covers a 12-degree band, the center of which is at the angle corresponding to the true elevation of the director. In conical scan, the trace covers a 3-degree band. The range

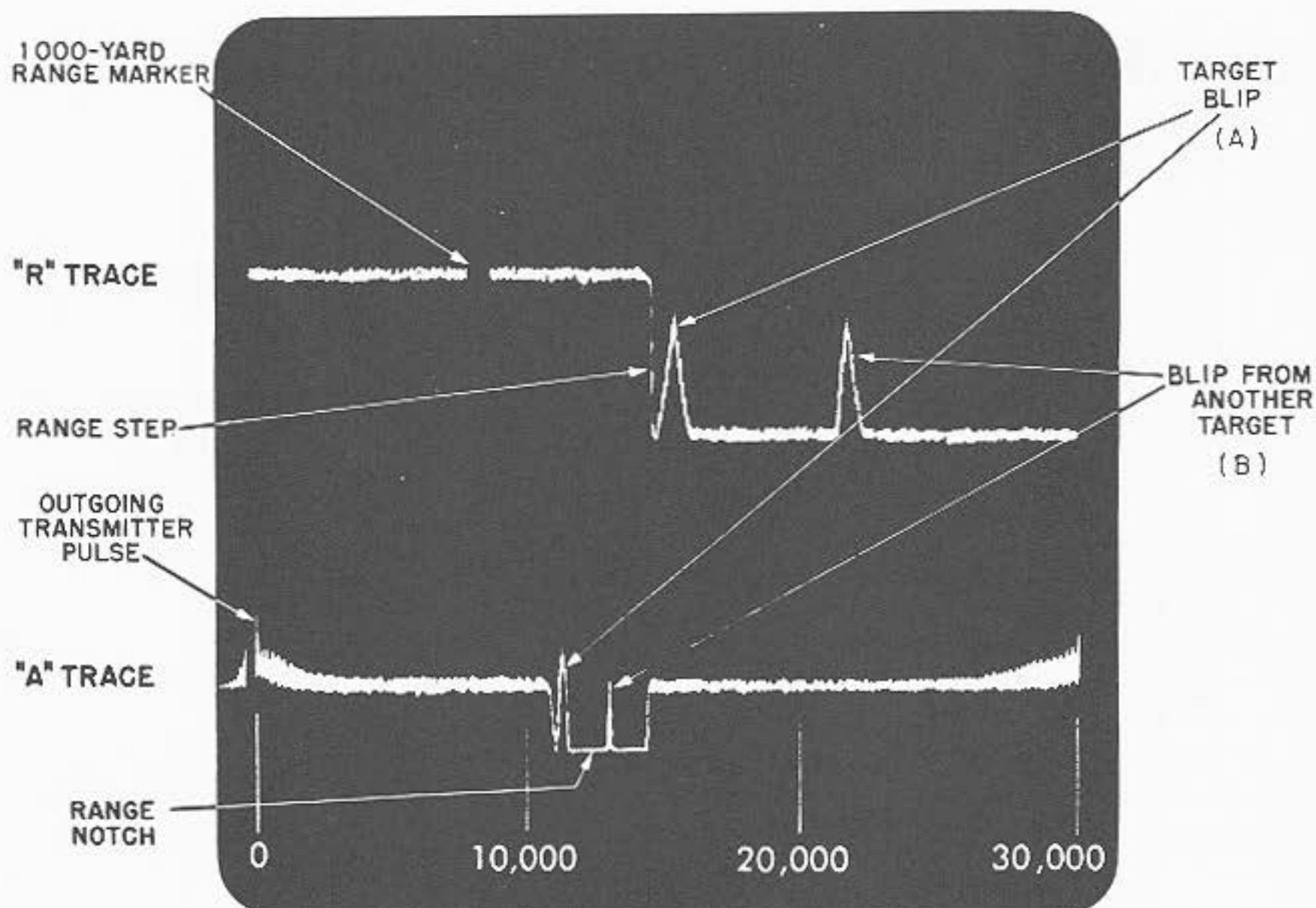
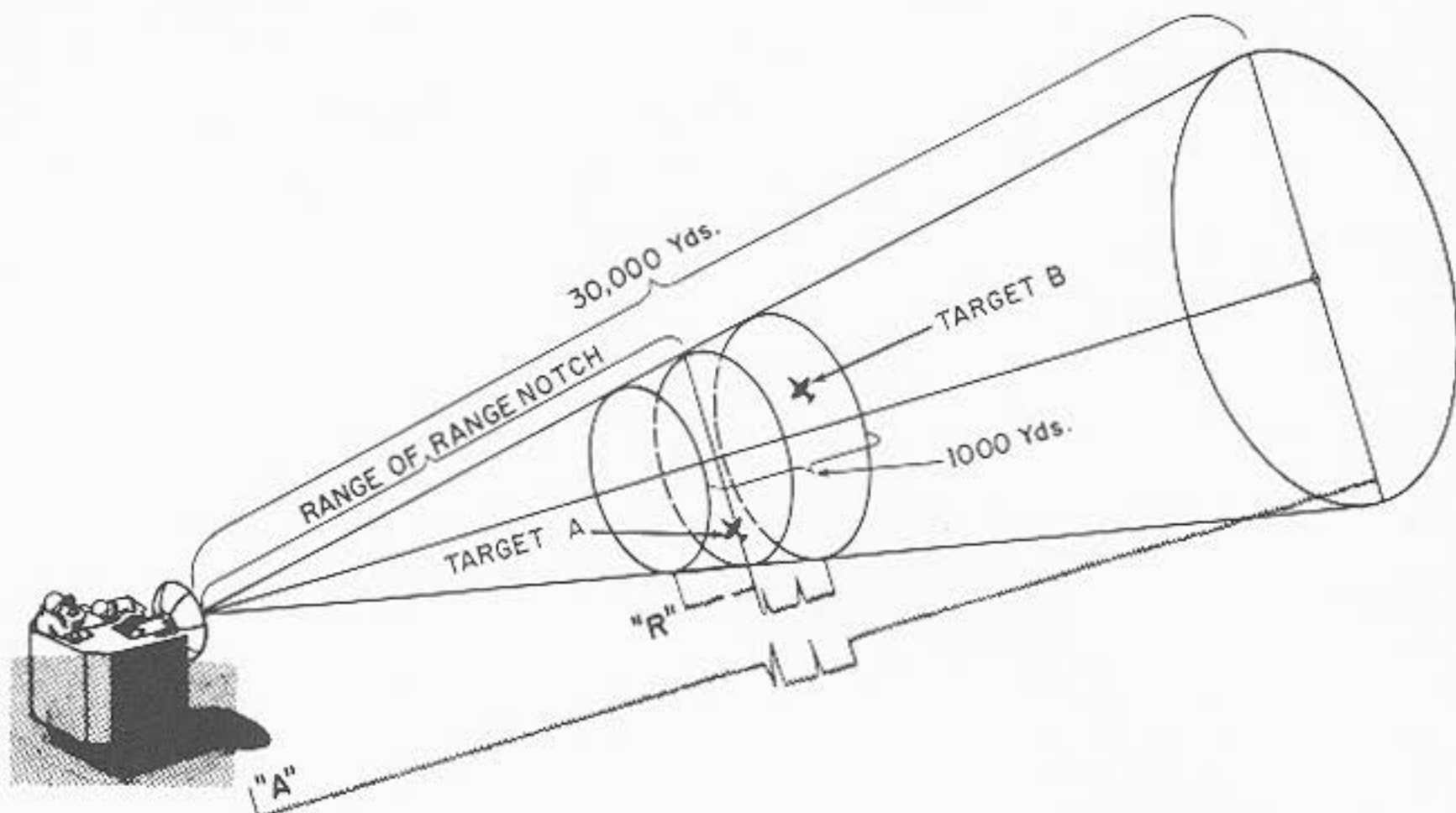
strobe line (range mark) appears as a bright vertical line extending from top to bottom of the sweep. Target echoes appear as short vertical lines. Two curved lines on the scope face furnish an indication of target altitude in feet. A target on the lower curved line is at 10,000 feet altitude; target on the upper line is at 30,000 feet altitude. Other target altitudes can be estimated.

The B-scope presentation (fig. 7-11) shows bearing (horizontally) 6° either side of director train, and range (vertically) 1000 yards either side of the range mark. The trace appears as a vertical band, with its center always at the center of the scope. The trace width in bearing depends on antenna scan: 3° for conical scan, and 12° for spiral scan. The range mark appears as a horizontal line at the center of the scope, extending across the entire width of the trace. Target blips appear as horizontal lines.

When searching for a target, the radar tracker watches the E-scope. Since spiral scan is used for searching, the target blip will be visible on the E-scope when the director line of sight is within 6° of target bearing and 6° of target elevation. In addition, for the blip to be visible on the B-scope, the range mark must be within 1000 yards of the target blip. As soon as the target blip appears on the E-scope, the radar operator slews the range mark to bring the blip within the B-scope. When the radar tracker sees the target in the B-scope, he turns the range crank to bring the blip up or down to the range line, and simultaneously turns the bearing crank to bring the blip right or left to the director bearing line.

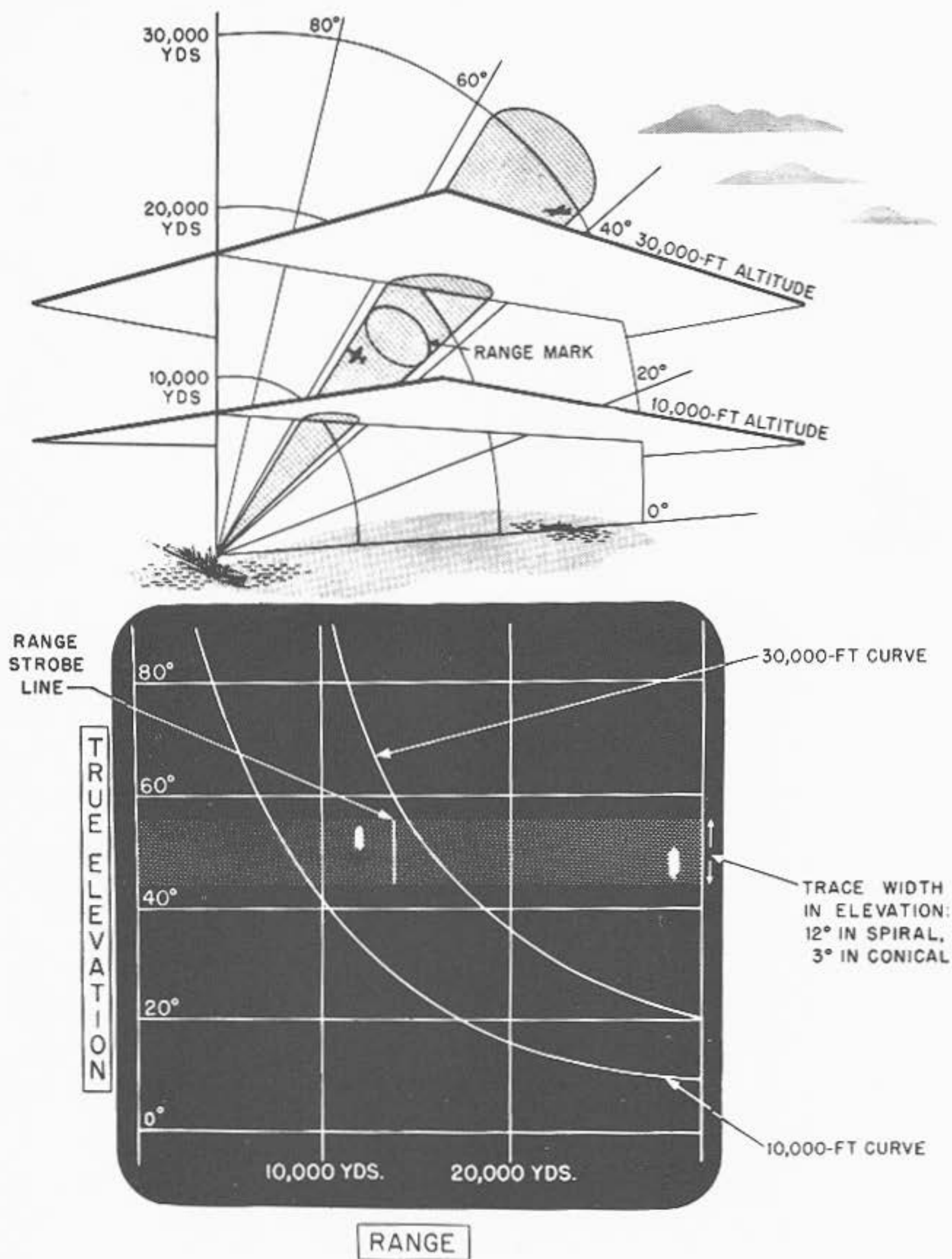
Figure 7-12 shows the appearance of all three radar scopes for different positions of the target. The equipment is on target C; therefore the blip from target C is against the range notch on the A sweep, at the step on the R sweep, at the center of the trace in the E-scope, and at the center of the B-scope. All targets covered by the 12-degree spiral scan appear on the A sweep and E-scope. Target E does not appear on any scope because it is more than 6° from the antenna axis. Target A does not appear on the B-scope because it is more than 1000 yards from the range mark. Targets A and D do not appear on the R sweep because they are more than 500 yards away from the range step.

When the target selected is gated in the A/R scope, and is (as target C is) on the intersection of the zero lines in the B-scope, the radar operator can by operating a foot switch cause the system to track the target automatically.

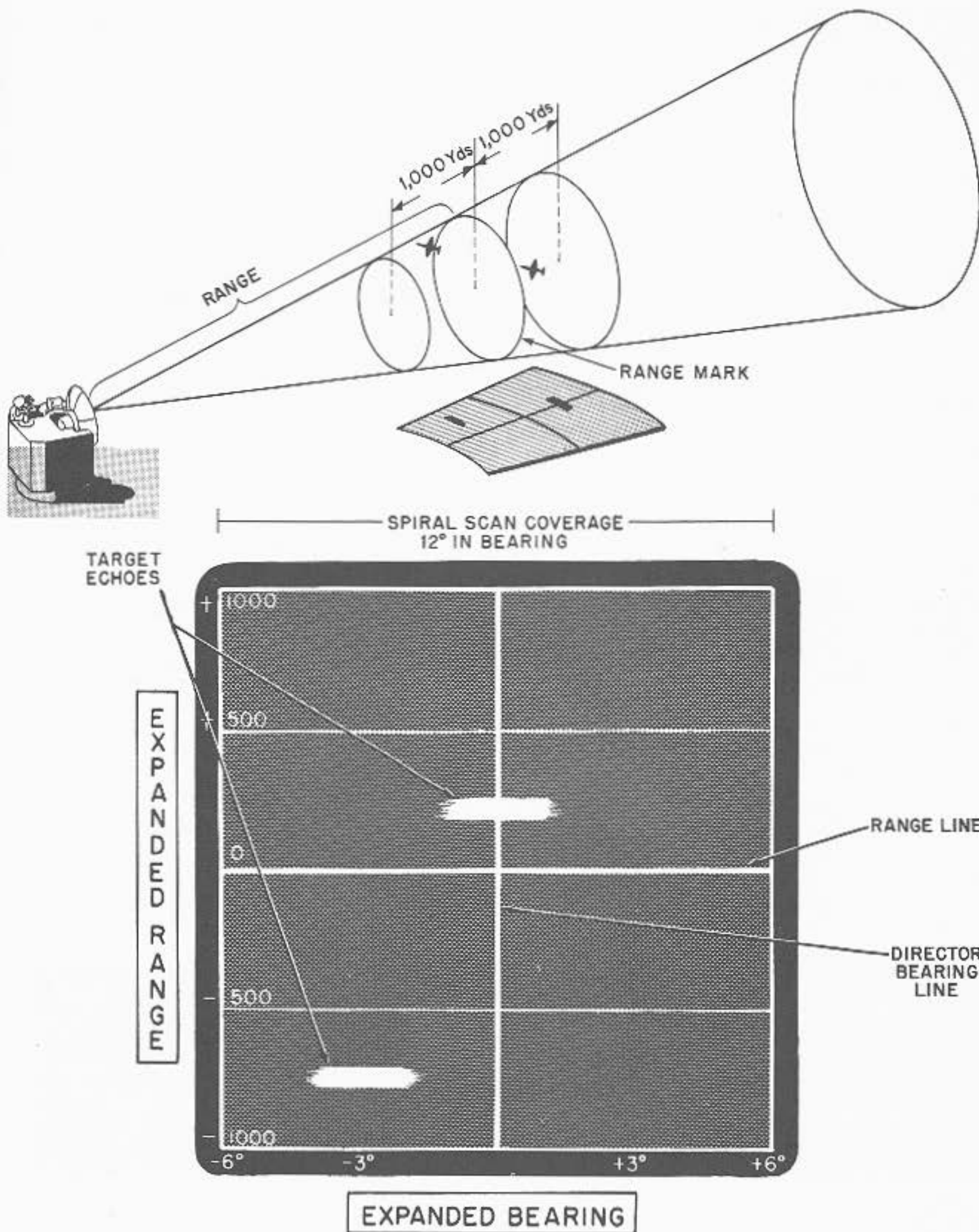


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Figure 7-9. — A/R-scope presentation.

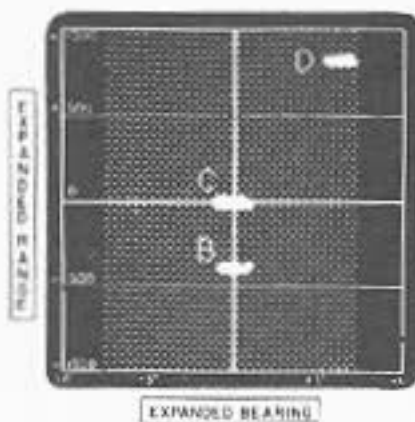
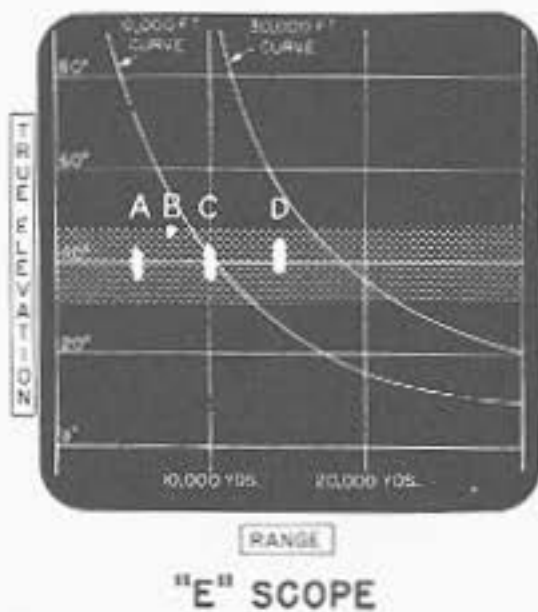
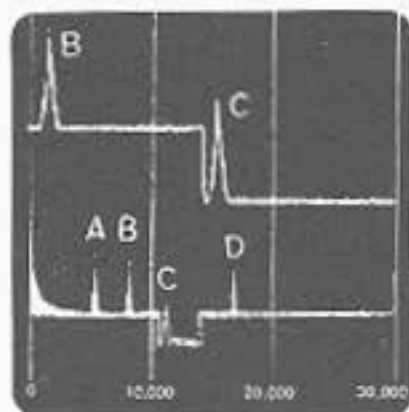
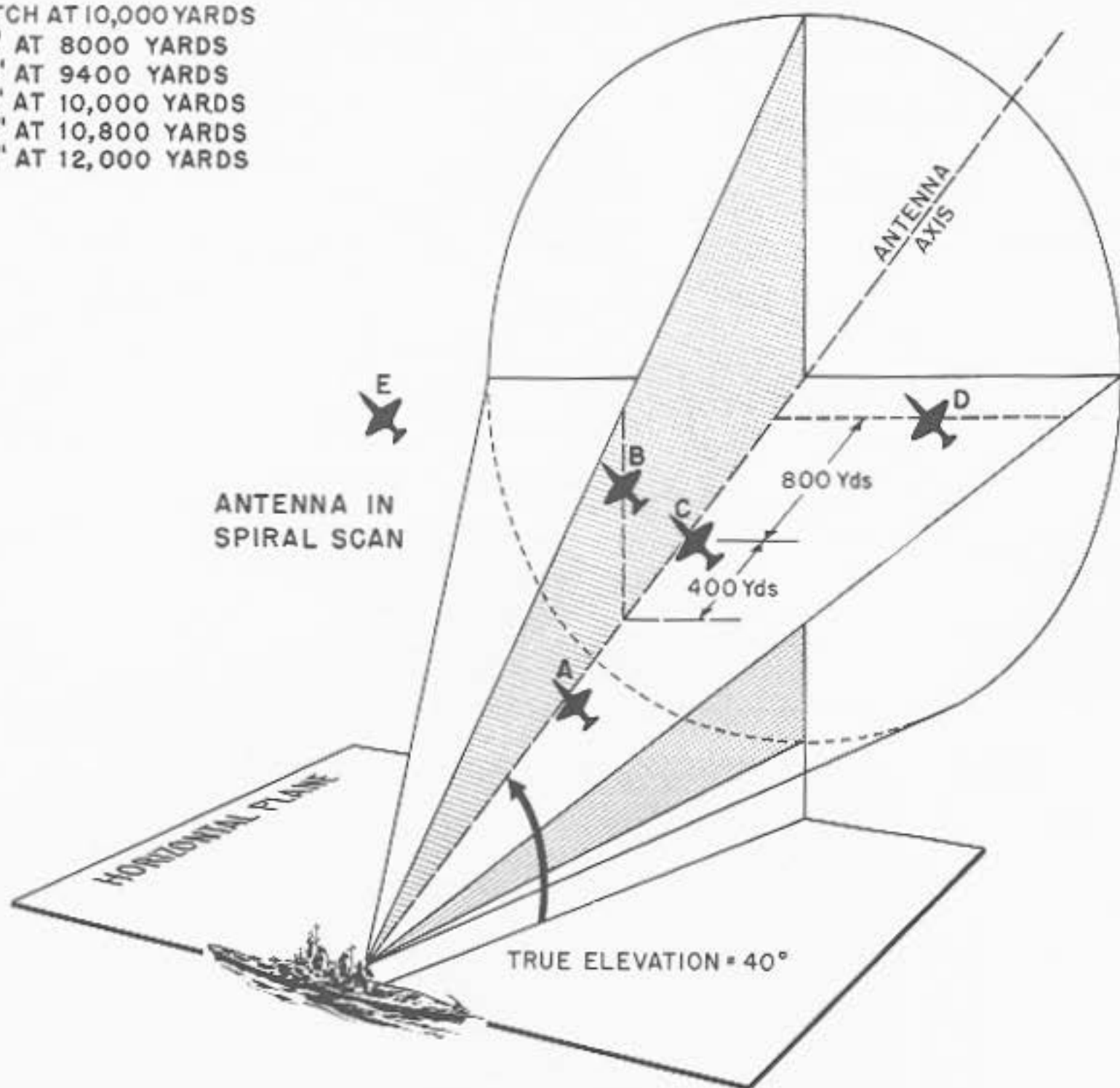


92.32
Figure 7-10.— E-scope presentation.



92.34
Figure 7-11.—B-scope presentation.

RANGE NOTCH AT 10,000 YARDS
 TARGET "A" AT 8000 YARDS
 TARGET "B" AT 9400 YARDS
 TARGET "C" AT 10,000 YARDS
 TARGET "D" AT 10,800 YARDS
 TARGET "E" AT 12,000 YARDS



92.35
 Figure 7-12.—Interpretation of radar traces.

DIFFICULTIES IN DETECTING

Atmospheric conditions will sometimes affect target detection. A moisture-laden cloud might appear to be an air contact on the scope. This false target would soon be discounted by the radar operator since it will have a very low speed. Rain squalls, storms, etc., may temporarily obscure actual air contacts. But if we are hampered by weather, the attackers are also. Extreme adverse weather conditions lend some doubt as to the feasibility of an air attack.

Target detection is made more difficult when the enemy is "jamming" our radar. One form of jamming is more or less semiautomatic and consists of dropping "rope" or "chaff" from an aircraft. This jamming material is made of aluminum foil strips which are cut to resonate at a particular frequency. The effect is similar to what we would see if numerous transmitters were reradiating our air search energy back to us. This type of jamming is easily recognized on the scope because of the almost linear pattern it presents. Its success lies in the aircraft's ability to saturate our scope with false targets, thereby obscuring the real ones.

Some electronic countermeasure equipments can be used for active jamming. We are more concerned with enemy aircraft acting in this capacity than surface units because of the latter's range restrictions at radar frequencies. ECM equipments can automatically find your transmitting frequency and pulse repetition rate, and then transmit "down your throat." On A-type radarscopes this type of interference shows up as "railings" or "fence posts." On B-type scopes it may look like sine waves or "snow."

To be effective, the chaff aircraft must penetrate our entire AAW network. It is doubtful that he can do this since the chaff pinpoints his position to practically every fire control director in the task group. Also, he would be recognized immediately as an enemy, thus eliminating the normal evaluation time. If he chose to drop chaff outside of our defenses, he would be announcing an attack. Moreover, fire control radars have been known to look right through this chaff. Some methods of combating chaff and other jamming are discussed in the next section (countermeasures).

The most pronounced single limiting factor in air searching is the radar's inability to follow the curvature of the earth and detect low altitude targets beyond the horizon. Some radio frequencies (shortwave) will follow the curvature of the earth for great distances provided the waves are

propelled by sufficient power. This is accomplished by bouncing the radio wave between the earth's surface and the ionosphere. Since the ionosphere curves around the earth, the reflected radio waves will curve also.

Shortwaves are in the high frequency range of the spectrum; radar waves are considerably higher in frequency. The higher radar frequencies will penetrate the ionosphere with little or no reflection occurring. They penetrate primarily because of their shorter wavelength. We will not get involved in a discussion concerning the "whys" of this penetration. We are more interested in the end result, which is a desirable straight line of sight transmission.

You may have decided at this point that a low frequency radar, making use of the ionosphere reflection phenomenon, could provide adequate coverage of the blind area beyond the horizon. Perhaps it could. The technical problems encountered in this attempt however, would be staggering. We would have to know the height at which reflection of the wave occurs, and the primary factor in this determination is the ionospheric density. Density of ionization at different altitudes makes the ionosphere appear to have layers. Actually there is no sharp dividing line between the layers of ionization. Suppose we could predict how much density is required to reflect the wave, could we then predict with accuracy at what height reflection would occur? Even with an educated guess, we would be further victimized by sporadic ionizations which occur at varying density in each layer.

If we were to suspend ourselves in the ionosphere and look down to the earth's surface with magnified vision, we might be able to see an aircraft standing out in bas-relief against the water. Electronically speaking this is not the case. It would be difficult indeed to detect a target, say, 50 feet above such a massive reflecting surface.

If we did not have a line of sight transmission in radar, the time factor would be in error. Errors in time mean errors in range. Errors in elevation and bearing would also be noted. To sum it up, current knowledge and the need for accuracy forces us to use higher frequencies, thereby making the blind area something with which we'll just have to live.

A straight line extending from the air and surface search antennas and tangent to the horizon, represents the maximum detectable range of zero altitude targets. This range is proportionally increased by an increase in the target's

altitude. Detection range could also be extended by raising our antennas' heights. Unfortunately we cannot depend on the targets accommodating us by flying at high altitudes, nor can we raise the heights of the transmitting antennas beyond the restrictions imposed by the ship's designers. We must make another tack.

Instead of considering the AAW unit and its 'low flyer' detecting limitations, let's look at the unit as an integral part of a whole. The whole in this case is a task group. Tactically speaking, it is our mission to protect the vital area of the task group and not the units comprising it. Protecting the vital area is easier than protecting a single ship when we discuss the problem in terms of target detection.

The task group is deployed so that some of the units are operating many miles from task group center. These outer perimeter units extend greatly the task group's radar surveillance. They can be used to destroy a target with their ship's armament or to vector CAP. Still other units with the same capability are strategically placed between the outer perimeter and the task group center.

AEW aircraft are stationed above the task group as insurance against the penetration of the surface units' radar network. This aircraft represents a great increase in radar antenna height; consequently, its radar range capability is limited only by altitude and the design characteristics of its radar. The AEW is a flying station; and by utilizing the NTDS, rapidly and accurately it can be used to vector the combat air patrol plane.

Let us next discuss some countermeasures against jamming.

DETECTION COUNTERMEASURES

Many anti-jam circuits have been incorporated in our modern radars to combat active jamming. Frequency control power devices change transmitting frequencies at the touch of a switch on some radars. Electronic differentiating circuits change the 'fence posts' into narrow spikes before they are displayed on the scope. Manually operated pulse repetition controls vary the repetition rate of our radars. Some radars have an automatic pulse repetition variance that operates at a random rate, making it virtually impossible for countermeasure gear to lock on. The fence posts would then wander across the scope but the target's movement would be consistent in direction and therefore easily discernible from the

wandering fence posts. Circuits such as fast-time constant (FTC), instantaneous automatic gain control (IAGC), and sensitivity time control can all be used to reduce abnormal signals while processing normal signals without appreciable loss. A relatively new development in electronic counter-countermeasures for gun fire control radars is the radar signal processing equipment (RSPE), which is explained in the following paragraphs.

RADAR SIGNAL PROCESSING EQUIPMENT

As stated above, RSPE is a relatively new development in the field of electronic counter-countermeasures (ECCM). It is added to existing gun fire control radars used for the automatic control of antiaircraft guns. RSPE consists of a cabinet containing its circuitry (fig. 7-13), a range operator's control unit (fig. 7-14), and a trainer's control unit (identical to the range operator's control unit). RSPE can be disconnected from the fire control radar with a single pushbutton.

The main purposes of RSPE are to give faster, more accurate target acquisition and provide continuous target track through high level interference. Each received echo of a transmitted pulse is digitally processed, and the results are stored in a memory to provide the radar with the following:

1. Complete automatic target acquisition within the spiral scan of the radar beam.
2. Virtually instantaneous range tracking of targets.
3. Automatic passive track against almost all forms of noise and jamming.
4. Logarithmically processed video and suppression of most forms of jamming signals for improved scope display.
5. Automatic transmitter frequency slew when active jamming is sensed.

The automatic acquisition capability, which is a necessary function of rapid reaction to various jamming environments, also enables faster fire control action in a clear environment. Using automatic acquisition, the radar will acquire the nearest target within the spiral scan beam (e.g. target A in figure 7-12); lock on in range, bearing, and elevation; and shift to conical scan, all within about one second. If, after about 3 seconds of tracking, the target is determined to be opening or closing at a speed less than 100

This brief look at the RSPE is intended only to give you an overall picture of what the equipment does. Additional information on its description and operation can be found in Fire Control Technician G 1/C, NavPers 10208.

DIRECTOR ASSIGNMENT WITH A TDS

Perhaps the term "target designation" evolved from the designation, or target numbering process in CIC. Or, perhaps designation is related to assigning ships to formation stations; such assignments are often prefixed by "desig." But in weaponry, designation means assigning or directing a fire control system to a specific target. A target designation system (TDS) or a weapon direction system (WDS) does this job. A TDS directs gun fire control systems and will be discussed in this section. A WDS directs gun fire and missile fire control systems, and it will be covered in the next section of this chapter.

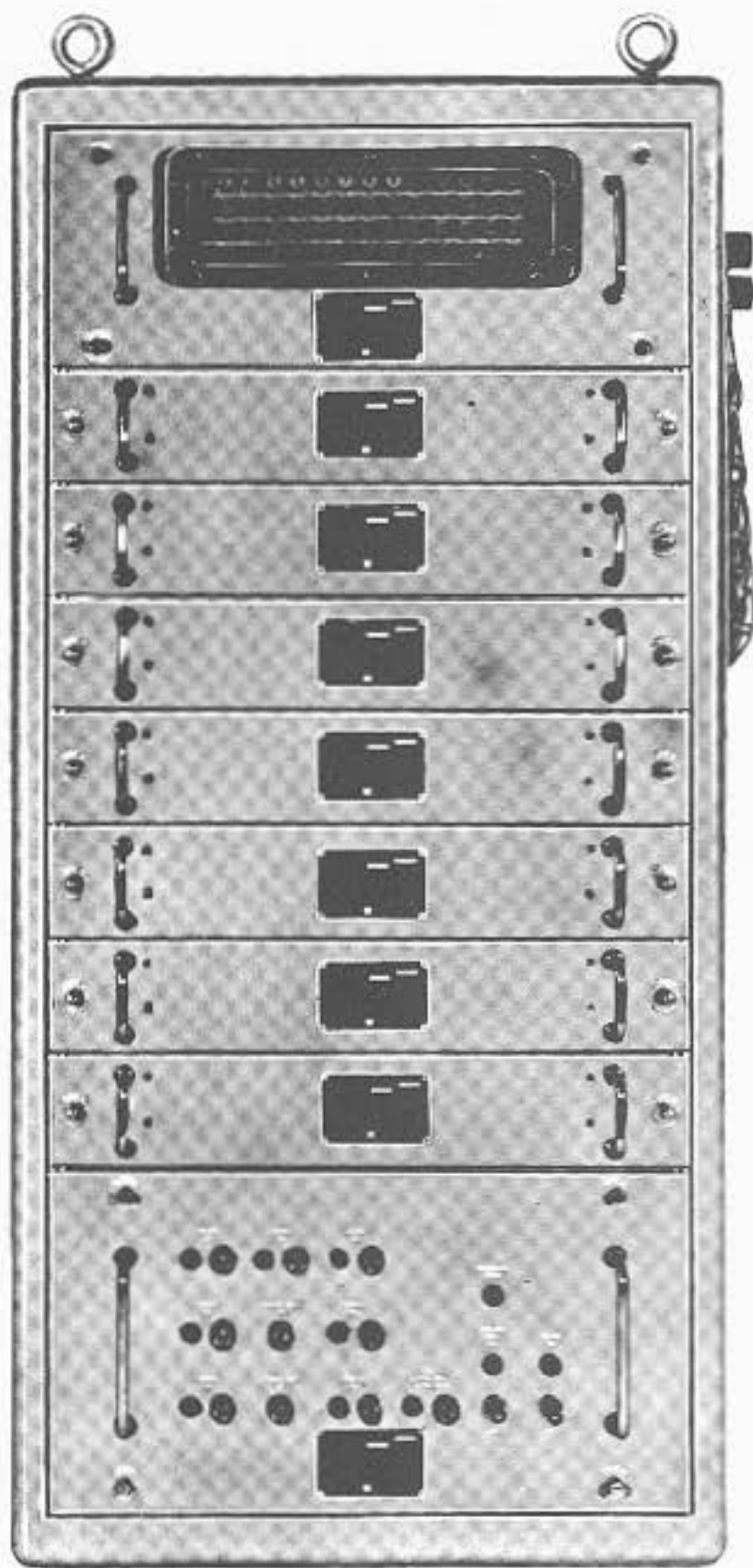
The Naval tactical data system is used to supply information to the TDS and WDS by a communications link (fig. 7-15), as explained earlier in this chapter.

Toward the close of World War II, the usual method of designating a target was by sound-powered telephone. Usually the designation originated with CIC, which plotted target range, bearing, and approximate elevation from information provided by search radar. The WLO (then the GLO) stationed in CIC would call the selected director and give it the target coordinates. The director would then slew in manual control to the coordinates specified, search in that vicinity, and begin tracking the target when it was located. Once a director tracks a target (then and now) the designation process is complete. Fire control system mechanisms and personnel then control all matters prior to target destruction.

Earlier in the chapter, we did not list target designation as a separate step in the ship's defense process because it broadly falls within the "disseminating" category. The same is true for "target acquisition," which is the term used to describe the actions of directors in acquiring targets. Because of their interrelation the actions for designation and acquisition will be covered together in the following sections.

FUNCTION OF A TARGET DESIGNATION SYSTEM

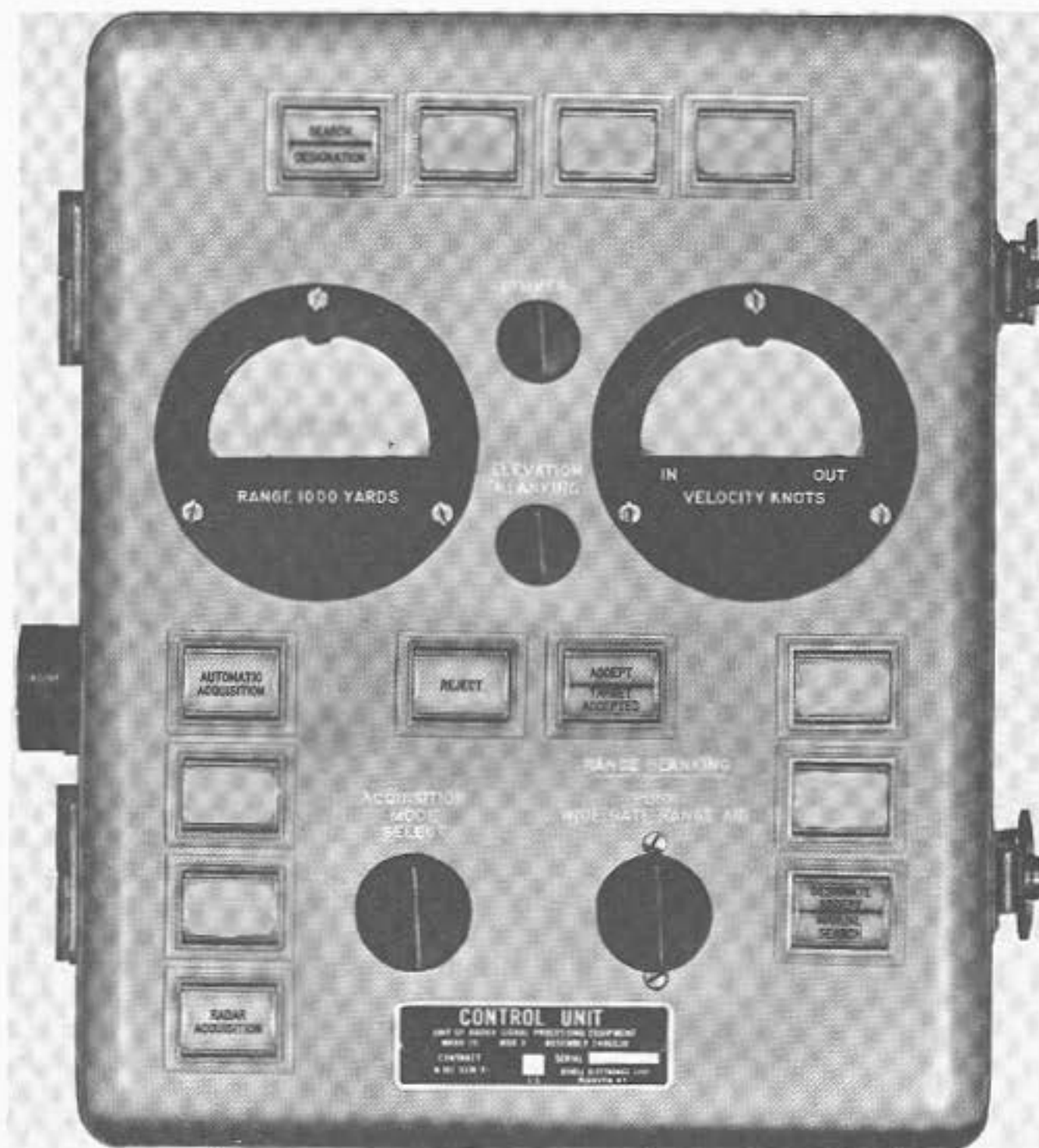
As you may recall from chapter 6, the acquisition part of this sequence of operations



170.46

Figure 7-13.— Electronic equipment cabinet for RSPE Mk 1.

knots, the RSPE will reject it, return to the acquisition mode, and search for the next closest target (e.g. target B in figure 7-12). The operator may override the RSPE and continue to track a stationary or slow-moving target if desired.



170.47
Figure 7-14.—Control unit for RSPE Mk 1.

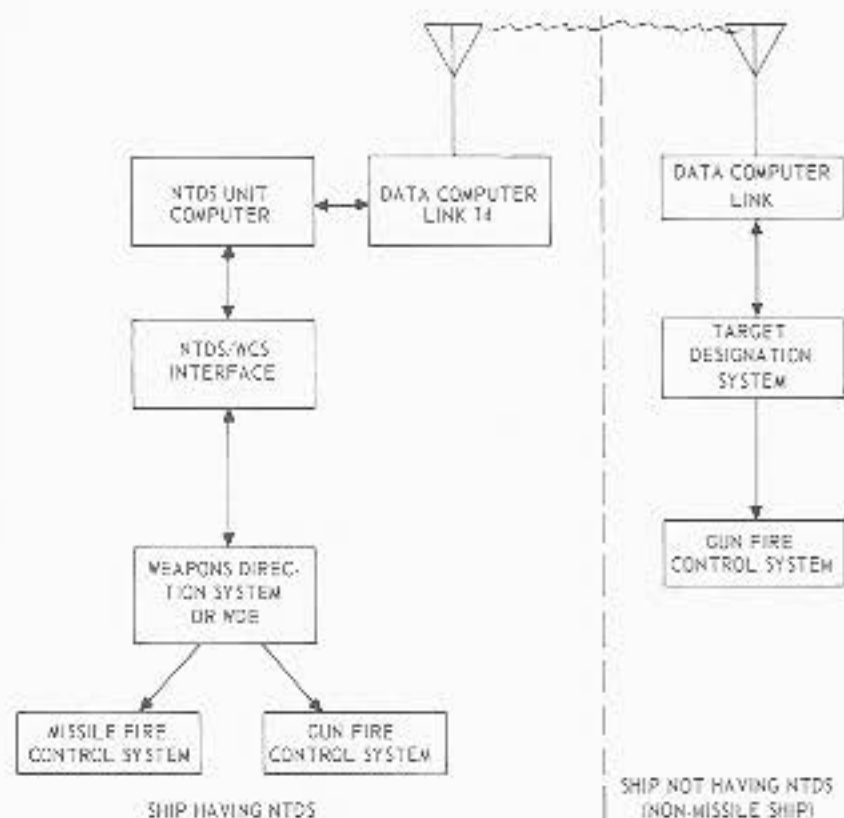
could, in such systems as the Mk 56 GFCS, require no more than a very few seconds. With the increasing speed of air targets, it became necessary to shorten the time required for the WLO to communicate target coordinates to the director, and for the director to find and track the target.

In most cases this in effect means transferring target data from one radar system (viz, the broad-beamed search radar) to another (viz, the relatively narrow-focus fire control radar on a specific director). Several systems were soon devised for performing this function. These

systems also provide for target designation based on target data derived from visual sightings.

The target designation system doesn't eliminate the necessity for the decisions that must be made in target assignments. What it does (along with the NTDS) is to:

1. Present a complete picture of the AAW situation on which the decisions can be based.
2. Enable target assignment to be made with a minimum of delay, with a maximum of accuracy, and with a positive indication that the director has engaged the designated target.



110.139

Figure 7-15.—NTDS data link between ships having NTDS and ships not having NTDS.

Thus any target designation system is essentially a special-purpose high-speed communications and display system, specially designed to perform these functions.

Since there is more than one fire control system and there may be more than one target, deciding which director should track which target can be a difficult decision to make. The officer making these decisions must be quick and responsive to the battle situation. He must keep foremost in his mind the kill capability of the fire control system so designated. He must divide the tracking load between systems as much as possible, and he must have some idea as to which is the more critical target. When (as in a saturation raid) the number of targets is greater than the number of directors and gun mounts, assignment of targets becomes a matter requiring quick, accurate judgment of relative threat from each target and of the ability of each director and gun mount to deal with the targets. In protracted air attack, as in a major strike, such decisions must be made almost continuously.

In the preceeding paragraph, we mentioned "the officer making these decisions" without naming his title. This is because control doctrine varies with the ship's weapons installation, depending on whether the target is detected optically

or by radar. On ships equipped with a TDS, radar-detected targets are designated to the fire control systems by the WLO and the CIC evaluator who works as a team. The weapons officer in the AAW station topside may intercede in radar designations if he deems it necessary to do so. Most optical designations will come from the weapons officer, but this does not mean that director officers or even mount captains have their hands tied in weapon control matters. In wartime emergencies (as outlined by ship's doctrine) they may even commence firing on their own initiative.

GENERAL DESCRIPTION OF A TYPICAL TDS

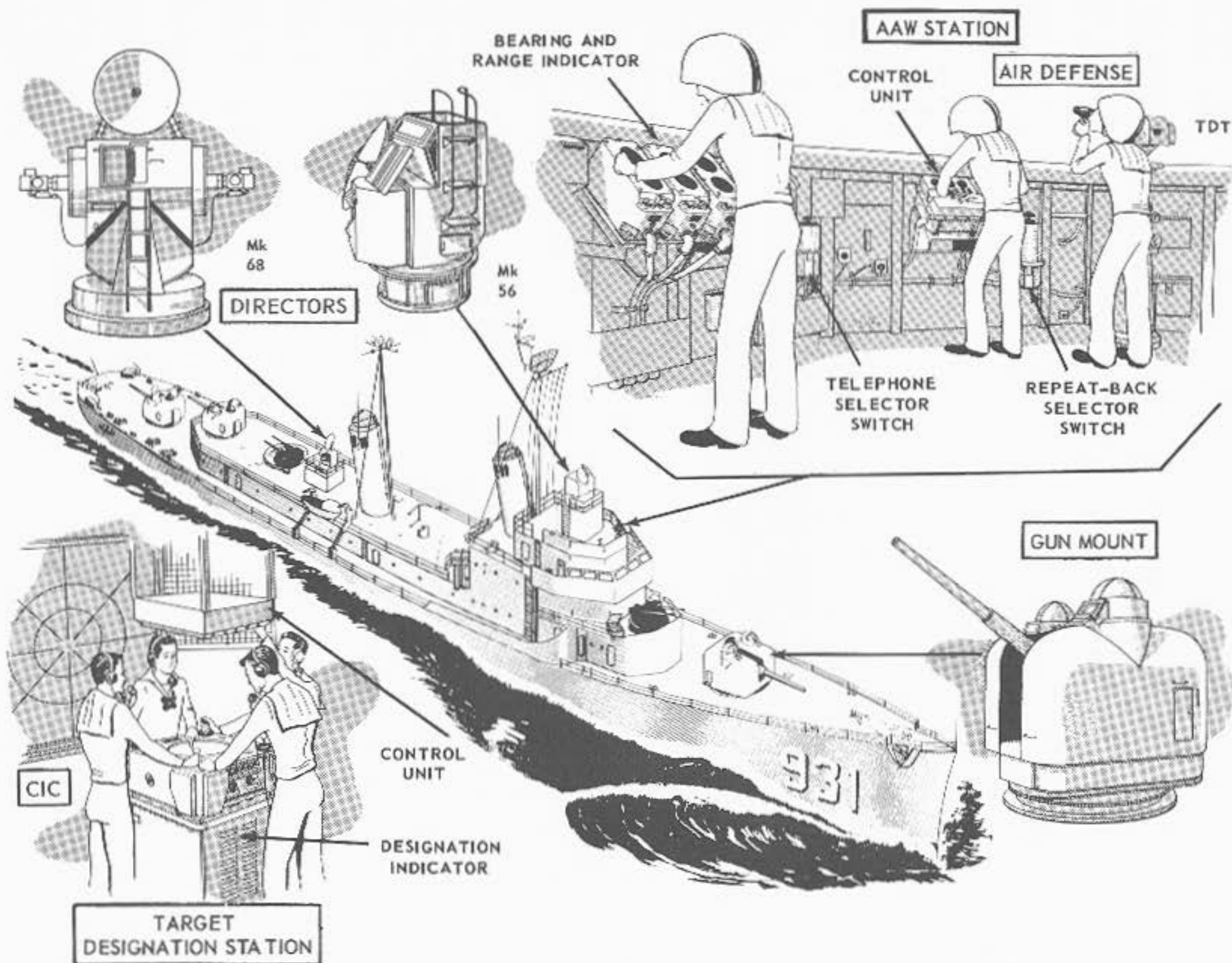
Because the Mk 5 TDS shows the steps required for manual or automatic target designation, it will be the equipment discussed in this section. In the Mk 5 TDS, target information (other than NTDS inputs) put into the system originates in CIC (where the target designation station for radar-originated designations is located) and at the AAW station topside (where optical designations originate). The AAW station topside is called Air Defense on destroyers and may be called Sky One or Sky Two on cruisers. Figure 7-16 shows graphically the key points of the system aboard a 931-class destroyer.

The system is controlled from the AAW station and from the target designation station in CIC. Figure 7-17 illustrates the flow of signals through the system. Optical designations are transmitted from the target designation transmitter (TDT) and control unit, through a target designation switchboard to the gun director; radar designations (from local radars or NTDS link) are transmitted from a search radar display on the designation indicator, through a coordinate converter, and through the target designation switchboard to the gun director.

Operators at the designation indicator display (a PPI display) in the target designation station, or operators at the TDT and control unit in the AAW station, track the target and select directors to receive designation.

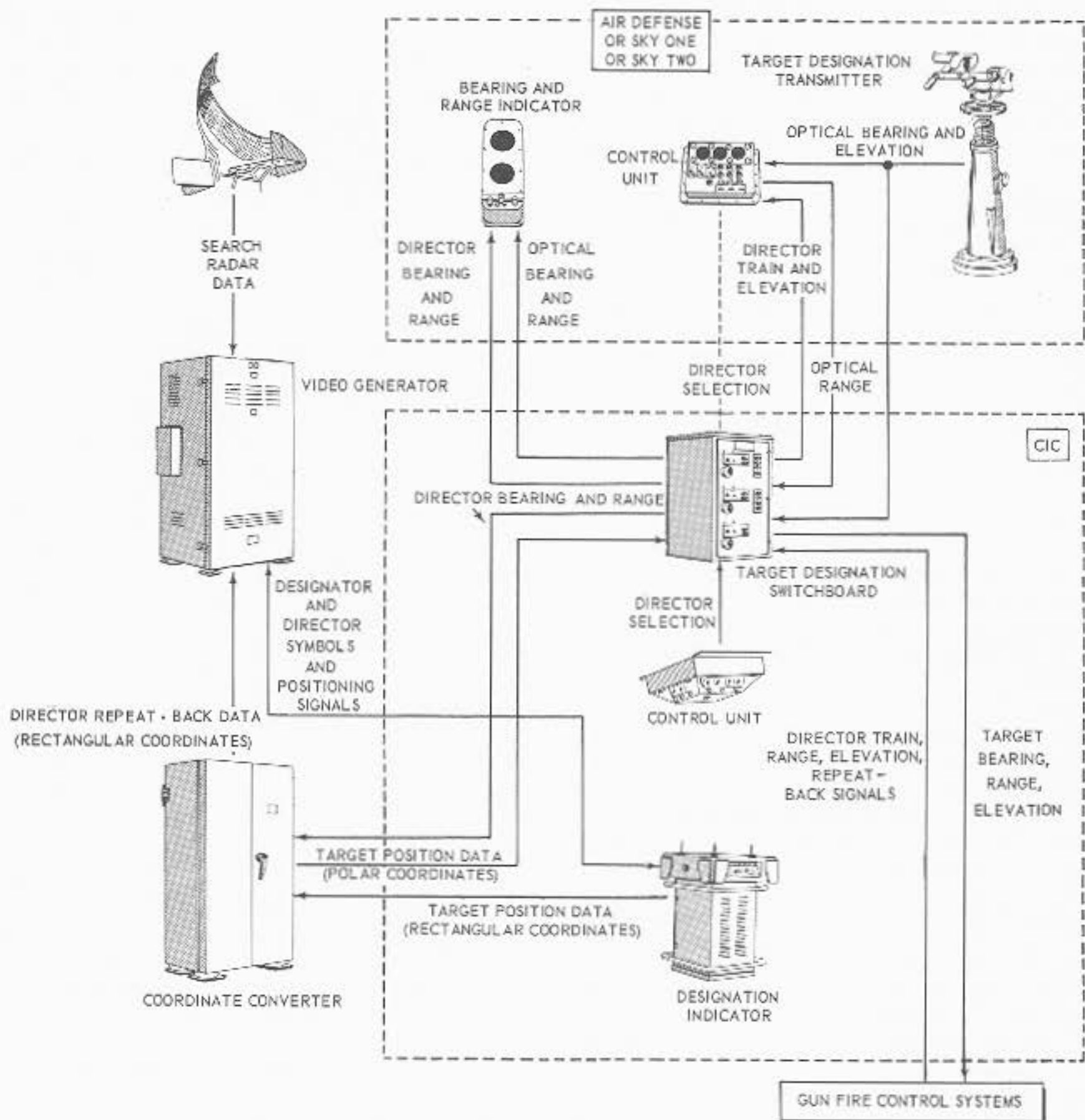
Each operator at the designation indicator views the search radar and tactical data on the plan position indicator (PPI) display and controls a "joystick" which transmits signals to the video generator and the coordinate converter.

At the converter signals are changed from rectangular coordinates to polar coordinates, and then transmitted through the target designation switchboard to the gun directors.



110.74

Figure 7-16. — Target designation system Mk 5 Mod 7, DD 931 class destroyer.



110.75

Figure 7-17.—TDS Data Flow (schematic).

Repeat-back data follow a reverse path from gun directors, through the target designation switchboard, coordinate converter, and video generator, to the designation indicator.

SPECIAL FEATURES OF THE SYSTEM.—The system is a flexible one. Each designation

operator may transmit the same target information to one or more gun fire control systems. This allows a maximum concentration of ship fire power. Interdirector transfer is also possible. This can be used to provide increased fire power on a target already being tracked, or

to transfer a target from a director approaching its training limit to a director better able to track on the target.

The system furnishes director repeat-back information on a PPI scope and on indicators that inform designators how long their assistance is required after designations have been made. Luminous semicircles (repeat-back hooks) representing director tracking coordinates are projected on the PPI display. The position of the repeat-back hooks indicates bearing and range from the director.

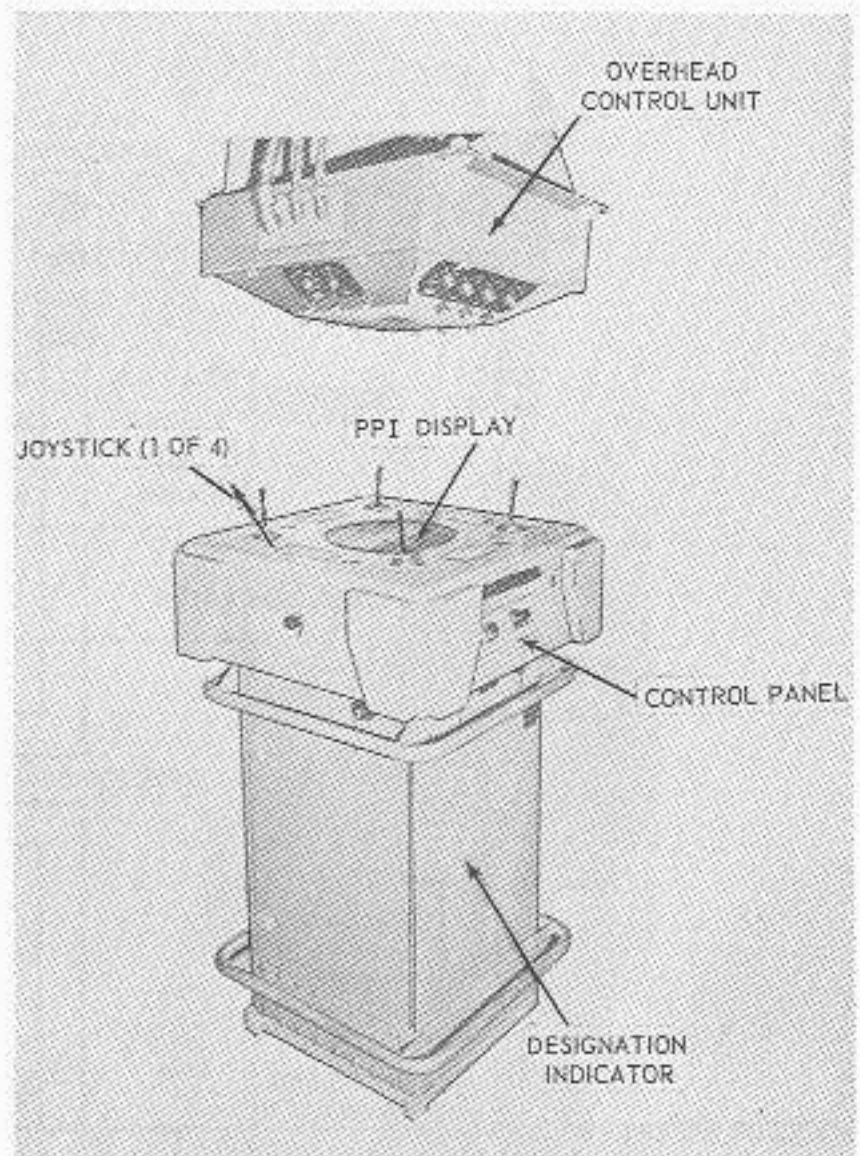
To avoid duplication of designations, optical designations have priority over radar designations; and optical designations from the starboard side have priority over optical designations from the port side. This permits only one designation to any specific director at any one time.

TDS EQUIPMENT IN CIC

Two of the main units of the target designation system, the designation indicator and the overhead control unit, are located in CIC. These units (fig. 7-18) serve as the display and control center of the CIC TDS station, which is manned by four men—a supervisor and three designators.

The designation indicator has a PPI display and four joysticks (one in each corner) on its top surface and a control panel on one side (fig. 7-18). (The supervisor stands at the control panel.) The PPI display (shown schematically in figure 7-19) includes the following:

1. Bearing dial (calibrated in degrees) and three concentric range markers, permanently marked above and around the PPI tube face.
2. The PPI image originating with the search radar, and including the evolving radar beam, target blips, and other features of the original radar display.
3. Four designate hooks. Each consists of semicircle with a dot at its center. The position of each hook on the display can be controlled by manipulating one of the joysticks.
4. Four repeat-back hooks. These are like the designate hooks, but lack the center dot. The positions of the repeat-back hooks on the display are controlled by selected gun fire control directors.
5. The ship heading marker, which indicates the true bearing of the ship's centerline. As the ship turns, the line revolves around the display.

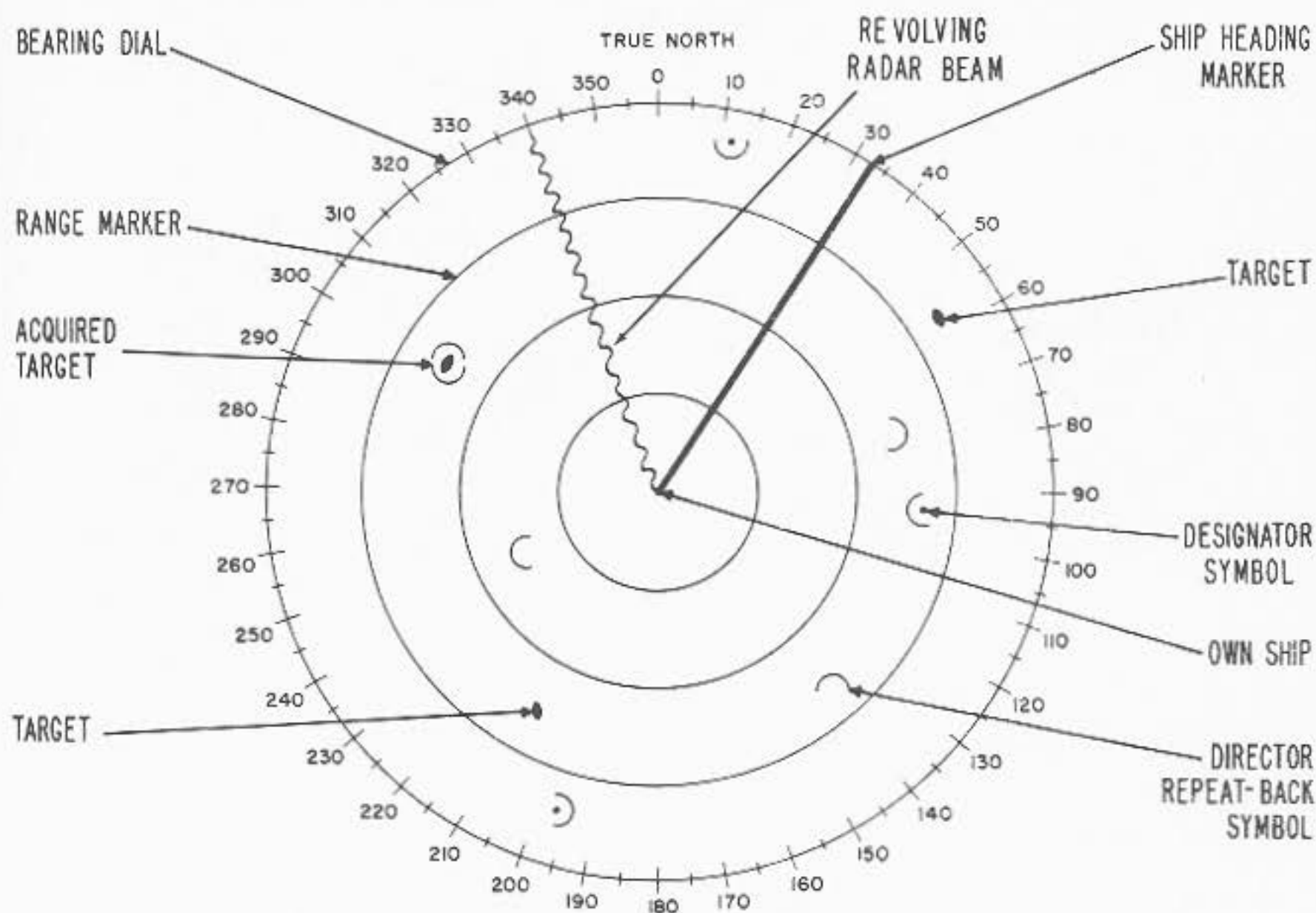


110.76

Figure 7-18.—TDS target designation station.

6. Data manually plotted by the supervisor with grease pencil for use by the designators. The markings are made on a reflection plotter assembly mounted over the face of the PPI scope. This assembly is a nonparallax, concave, partially mirrored surface, so designed that any marks placed on its surface are reflected to the face of the PPI display. The marks reflected downward appear at the same point regardless of the viewing angle.

The overhead control unit is located directly above the designation indicator. It consists of three designator panels and one supervisor panel. It enables director selections and interdirector designations to be controlled from this location. The panels are equipped with director status lamps that indicate the method of designation being used and director selector switches and estimated elevation switches for designating the approximate elevation of the target. (Target elevation is not transmitted automatically.)



92.16

Figure 7-19.—TDS Designation Indicator PPI presentation (schematic).

TDS EQUIPMENT AT THE AAW STATION

All TDS equipment at the AAW station is used for designating targets acquired optically or for indicating the status of the directors (fig. 7-20).

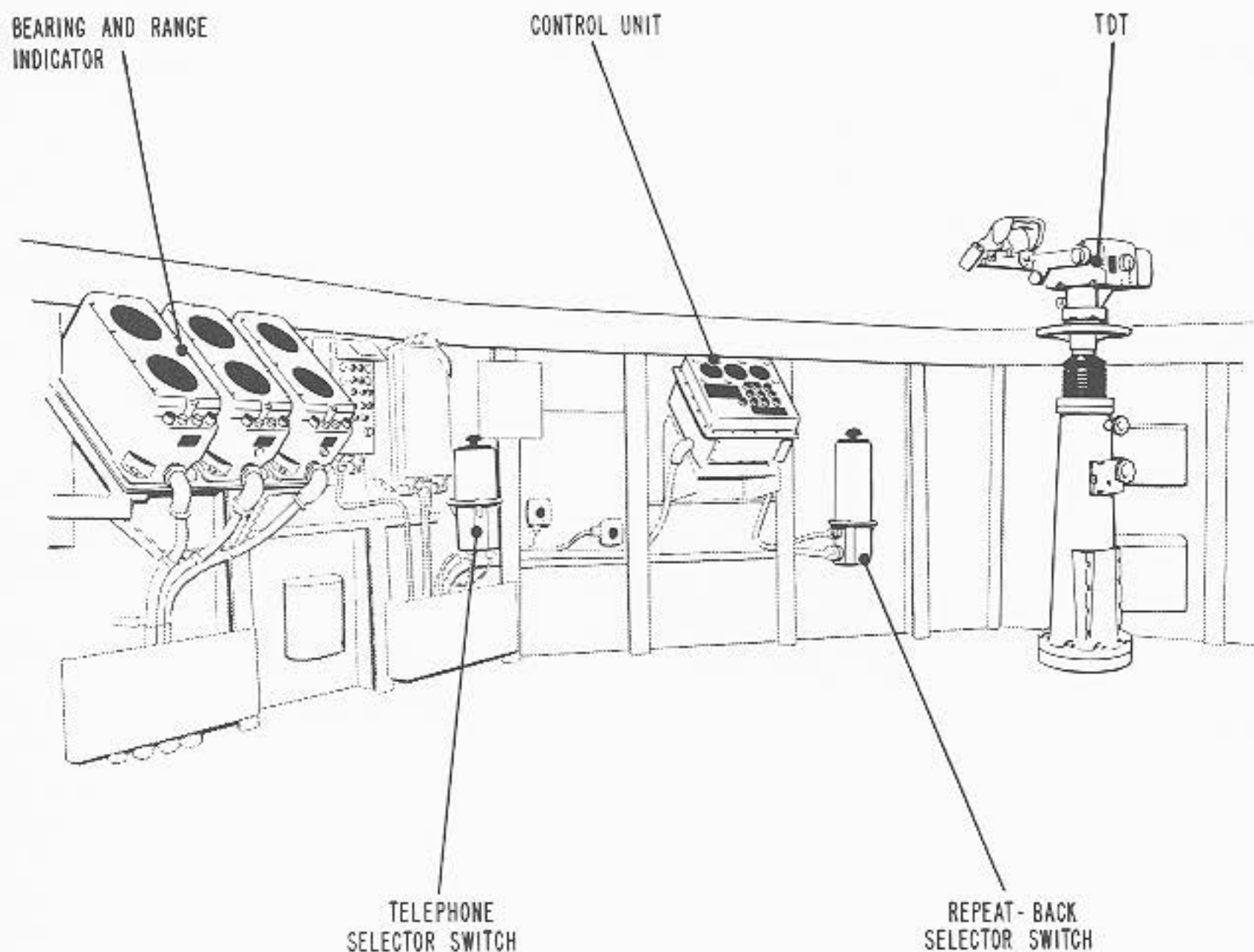
Target Designation Transmitter

The target designation transmitter (TDT) transmits target bearing and elevation data by synchro to the control unit and the target designation switchboard. The TDT is essentially a weather-protected pedestal on which a pair of binoculars can be quickly mounted or dismounted. As the operator manually trains and elevates the TDT to put the binocular line of sight on target and track the target, synchro transmitters inside the TDT pedestal continuously register the position of the line of sight. A pushbutton on

one of the TDT's handgrips can be used to signal the target designation station in CIC when the TDT has its line of sight on target. The TDT does not provide for direct transmission of range data; range estimates are normally transmitted from the AAW station's control unit. Two TDT's are installed at the AAW station, one on the starboard side and the other on the port side.

Bearing and Range Indicator

The bearing and range indicator is a multiple-indicating device, consisting of a group of several similar units—one for each director that can receive designations from the TDT's. Each unit has dials which display own-ship course; director bearing and range; the designated values of target position; and an indicator lamp to show whether the director is tracking the target. The indicator



110.77
Figure 7-20.—TDS AAW station.

group is located in front of the AAW officer's station, thus enabling him to monitor the status of the directors.

Control Unit

The control unit is a three dial unit; one unit is associated with each TDT. It displays bearing and elevation information for the TDT and a selected director (one of three may be selected). Signal lights indicate director status. A selector switch can be set to indicate estimated range; this indication is transmitted to the director to which the control unit is switched.

Director Repeat-Back Selector Switch

This switch selects the director to which the control unit is to be connected.

OTHER UNITS ASSOCIATED WITH THE TDS

Other units associated with the TDS include bearing, range, and elevation indicators located in the fire control system directors; indicator panels; a video generator unit; a coordinate converter unit; and a target designation switchboard.

BEARING, RANGE, AND ELEVATION INDICATORS (not illustrated) — located in the gun fire control directors — display designated range, bearing, elevation, and own ship's course. Signal lamps indicate whether the designation is originating with a radar or an optical source.

INDICATOR PANELS (not illustrated) are located in fire control directors; they are used to indicate, by flashing lamps, the source of target designation, and they provide an audible

signal that alerts director personnel to designations.

The VIDEO GENERATOR and COORDINATE CONVERTER (fig. 7-17) are unattended units located in an equipment room near CIC. The video generator provides target information and director data, which are displayed on the PPI scope of the target designation indicator. The coordinate converter has four channels—one per director. Each channel has two sections—an input section and a repeat-back section. The converter receives target information in the form of rectangular coordinates and converts them to polar coordinates, which are transmitted to the directors through the target designation switchboard (fig. 7-17). It also converts director data in polar coordinates to rectangular coordinates which are transmitted to the video operator for presentation on the PPI display.

The TARGET DESIGNATION SWITCHBOARD has automatic rotary switches that provide rapid, remotely controlled, flexible switching of target designation and repeat-back circuits. The switches may be operated automatically from the CIC or the AAW station or manually from the switchboard.

FROM TARGET DETECTION TO TARGET DESTRUCTION

Let us now trace the entire process from the moment the target is detected until it is destroyed. Bear in mind that there are many details omitted, and that many steps will be different with different ships and equipment. We are assuming for the sake of illustration that the target designation system is being used with a Mk 56 GFCS and the target information originates with CIC. The entire process is shown graphically in 20 steps in figures 7-21 through 7-31.

If the target information originates in the AAW station, the procedure differs slightly.

The target is assigned to a port or starboard TDT operator to track (fig. 7-32). The TDT operator tracks the target and presses the TDT on-target pushbutton when the target is centered in the binocular. This illuminates the on-target lamp on the associated control unit. The TDT operator keeps this pushbutton depressed during the entire time he is tracking.

The operator at the control unit selects the director to receive the designation and turns the director set-up switch on. This sounds a buzzer to inform director personnel of impending designations. The control unit's "busy" indicator lamp for the selected director flashes.

The control unit operator positions the "estimated range" switch to the approximate target range, and sets the director repeat-back selector switch to cause director information to appear on the repeat-back dials.

The director officer accepts designation by pressing the target designation pushbutton, which allows the director to slew to the designated coordinates (fig. 7-33).

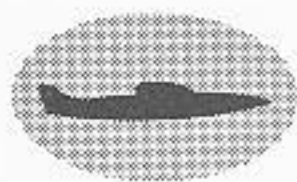
When the radar operator at the radar console has gated the target he presses the footswitch. This shifts the director to automatic tracking, and causes the "tracking" lamp on the control unit to go on.

EMERGENCY OPERATION. If equipment or circuit failure in the radars make normal operation impossible, the TDS can still function to coordinate the target designation operation. By setting a test switch on the video generator so that it develops a "synthetic" trigger pulse (which is normally used in checking and aligning the equipment), the designate and repeat-back hooks can be made to appear on the PPI display. With all hooks properly indicated, even though search radar information is not available, inter-director designation is possible.

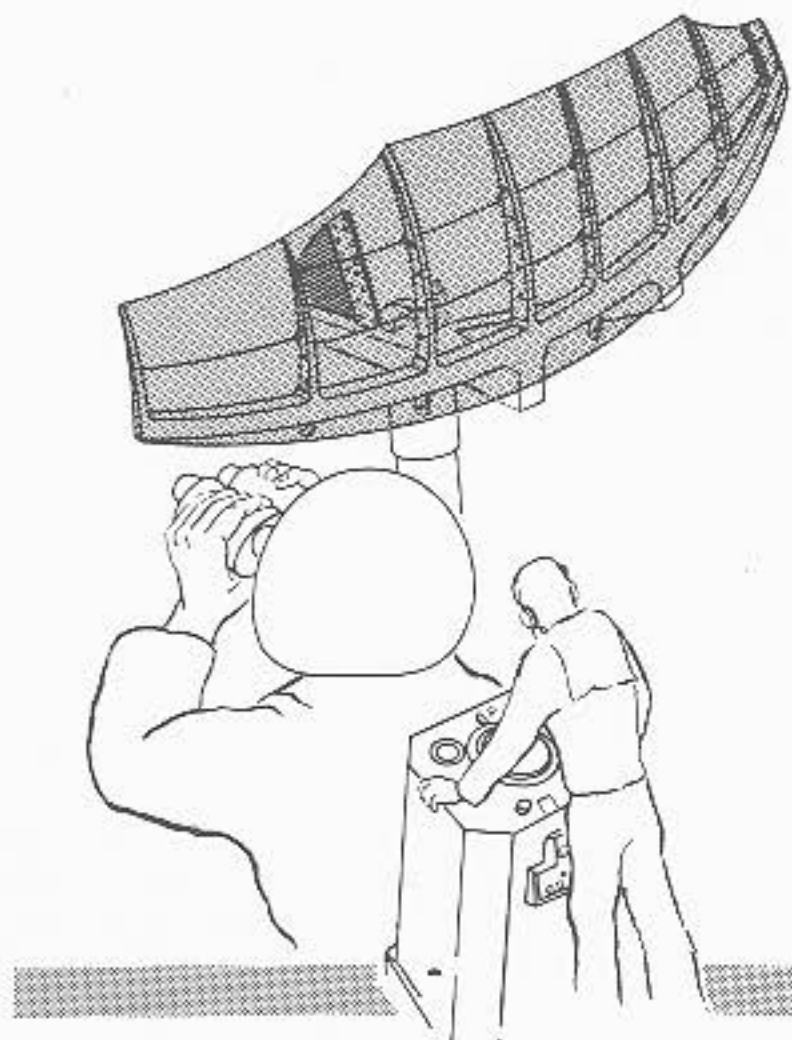
DIRECTOR ASSIGNMENT WITH A WDS

A WDS is basically a TDS. However, it is more sophisticated since more stations and electronic components are involved, and since a WDS controls both missile and gun fire control systems. You'll notice major refinements, particularly in the areas of director assignment and CIC tracking prior to director assignment. One PPI scope did these jobs in the TDS; approximately four separate consoles are used in the WDS. Three of these consoles (those used to track targets prior to director assignment) are called Target Selection and Tracking Consoles (TSTC). The other console is used to make director assignments and is appropriately named the Director Assignment Console (DAC).

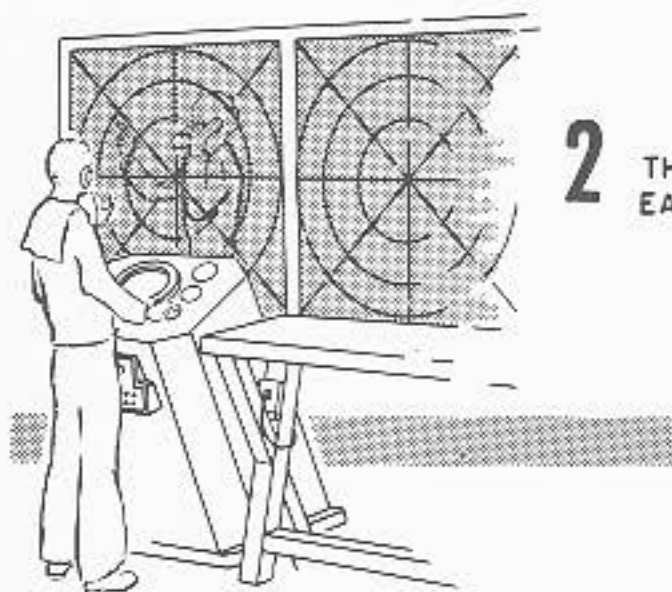
A WDS includes all electronic and optical devices used in designating targets. The optical devices are TDTs in the AAW station(s) whose operation we have previously discussed. The electronic devices are all part of a sub-equipment called the Weapons Direction Equipment (WDE). A WDE has as its major units the four consoles mentioned above and another console called the Weapon Assignment Console (WAC). The WAC has no designating function. Its purpose is to provide a means for assigning the missile



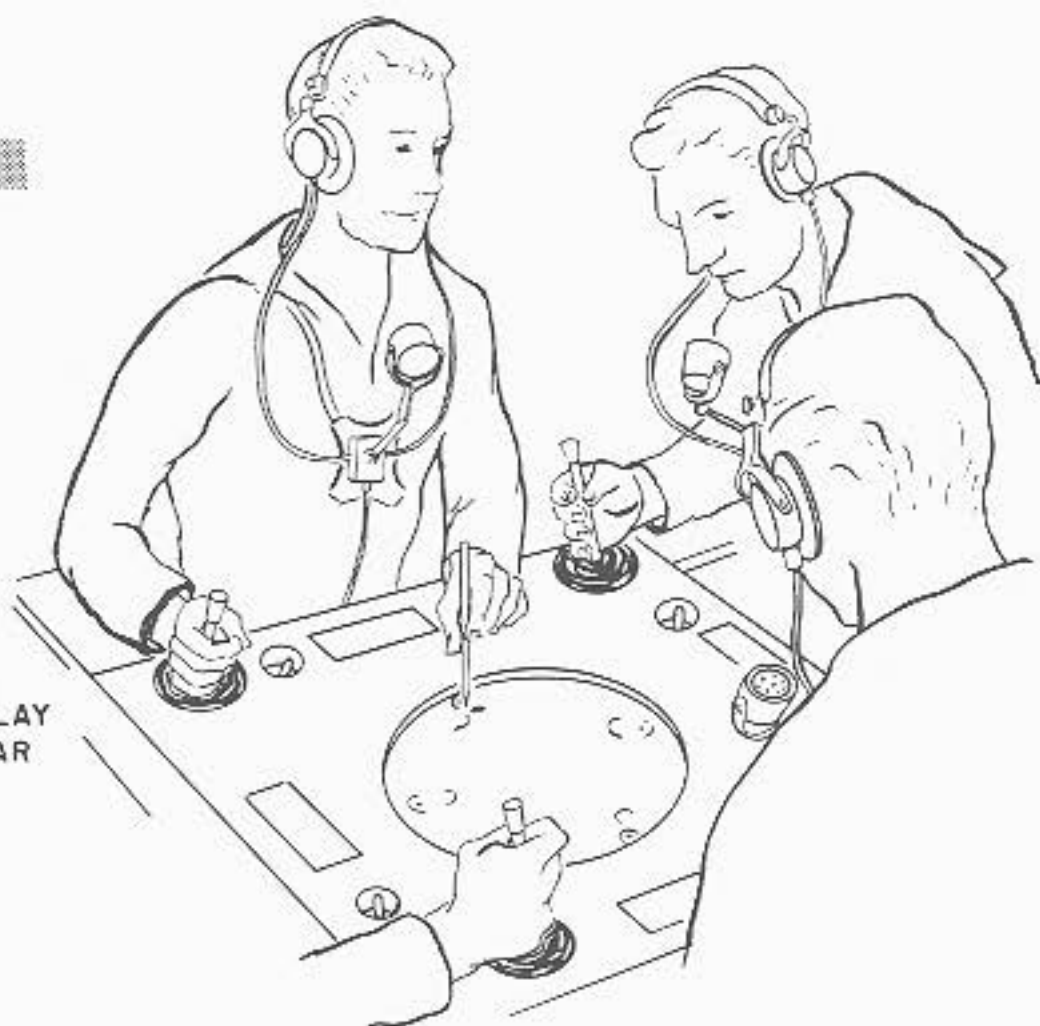
1 THE TARGET IS DETECTED BY RADAR OR OPTICS



2 THE TARGET DESIGNATION SUPERVISOR RECEIVES EARLY WARNING TARGET INFORMATION FROM CIG.



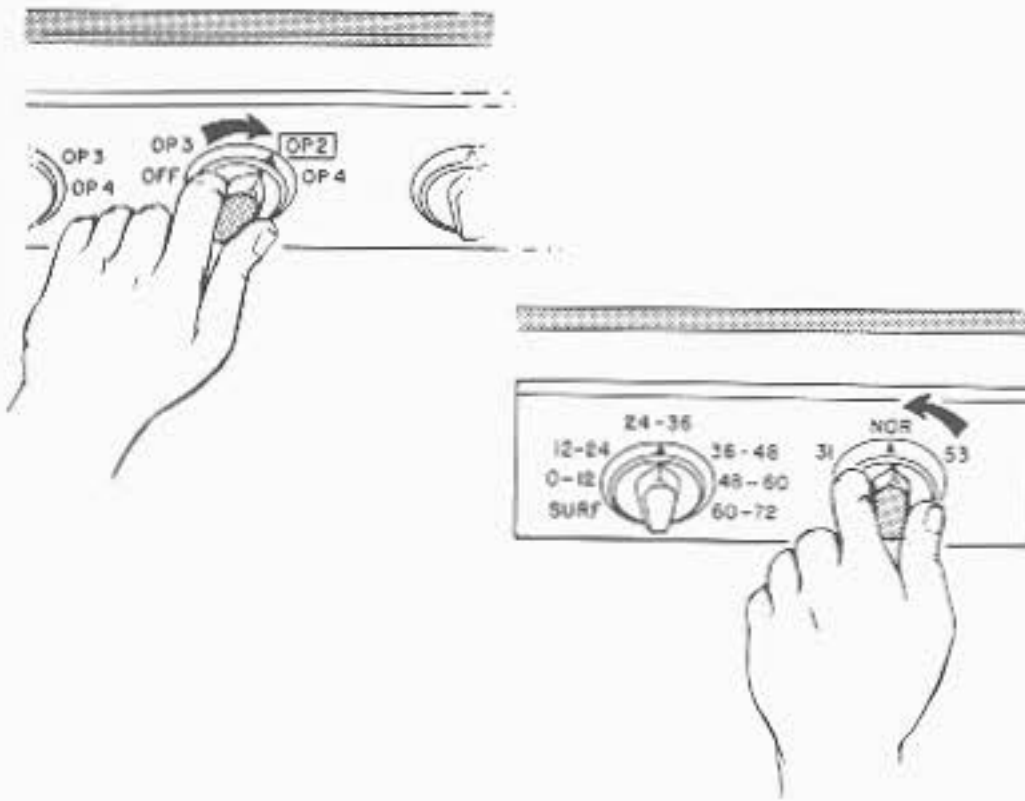
3 HE INDICATES ON THE PPI DISPLAY WHERE THE TARGET WILL APPEAR



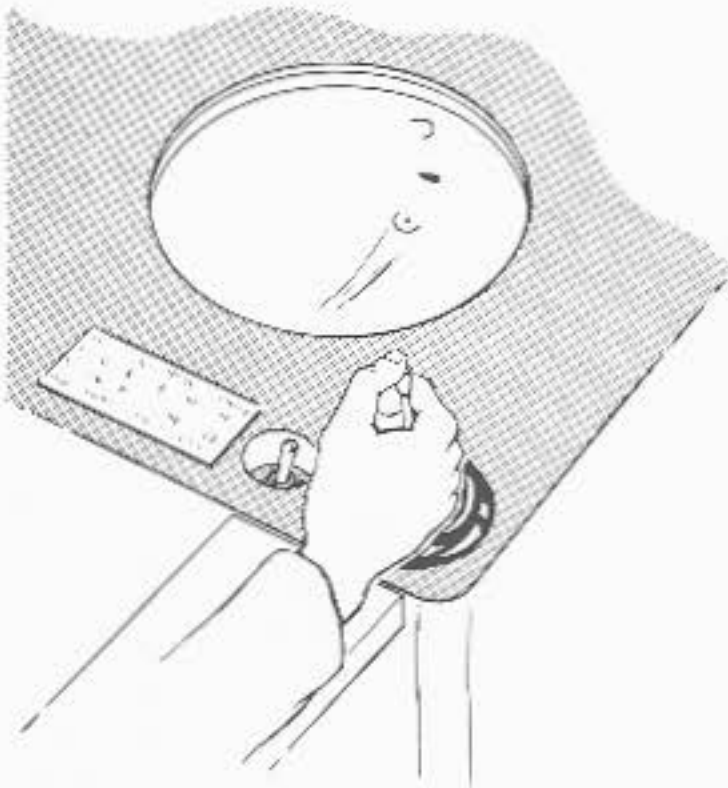
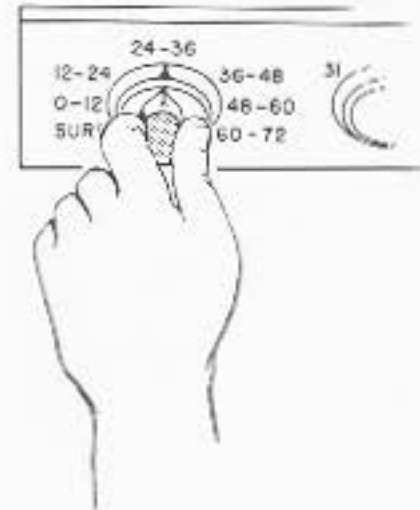
110.78.1
Figure 7-21.—Steps in target designation, acquisition, tracking, and attack procedure.

4

THE OPERATOR AND SUPERVISOR POSITION THEIR DIRECTOR SELECTOR SWITCHES.....



...THE DESIGNATING OPERATOR ALSO POSITIONS THE
SIMULATED ELEVATION SWITCH TO THE APPROXIMATE
TARGET ELEVATION



5

THE OPERATOR, BY MOVEMENT OF THE JOYSTICK,
SLEWS THE DESIGNATE SYMBOL TO THE TARGET
AND COMMENCES TRACKING.

...HE THEN POSITIONS THE CALL SWITCH.

110.78.2

Figure 7-22.—Steps in target designation, acquisition, tracking, and attack procedure—Continued.

6 RADAR TRACKER PRESSES TARGET DESIGNATION BUTTON TO ACCEPT DESIGNATION.

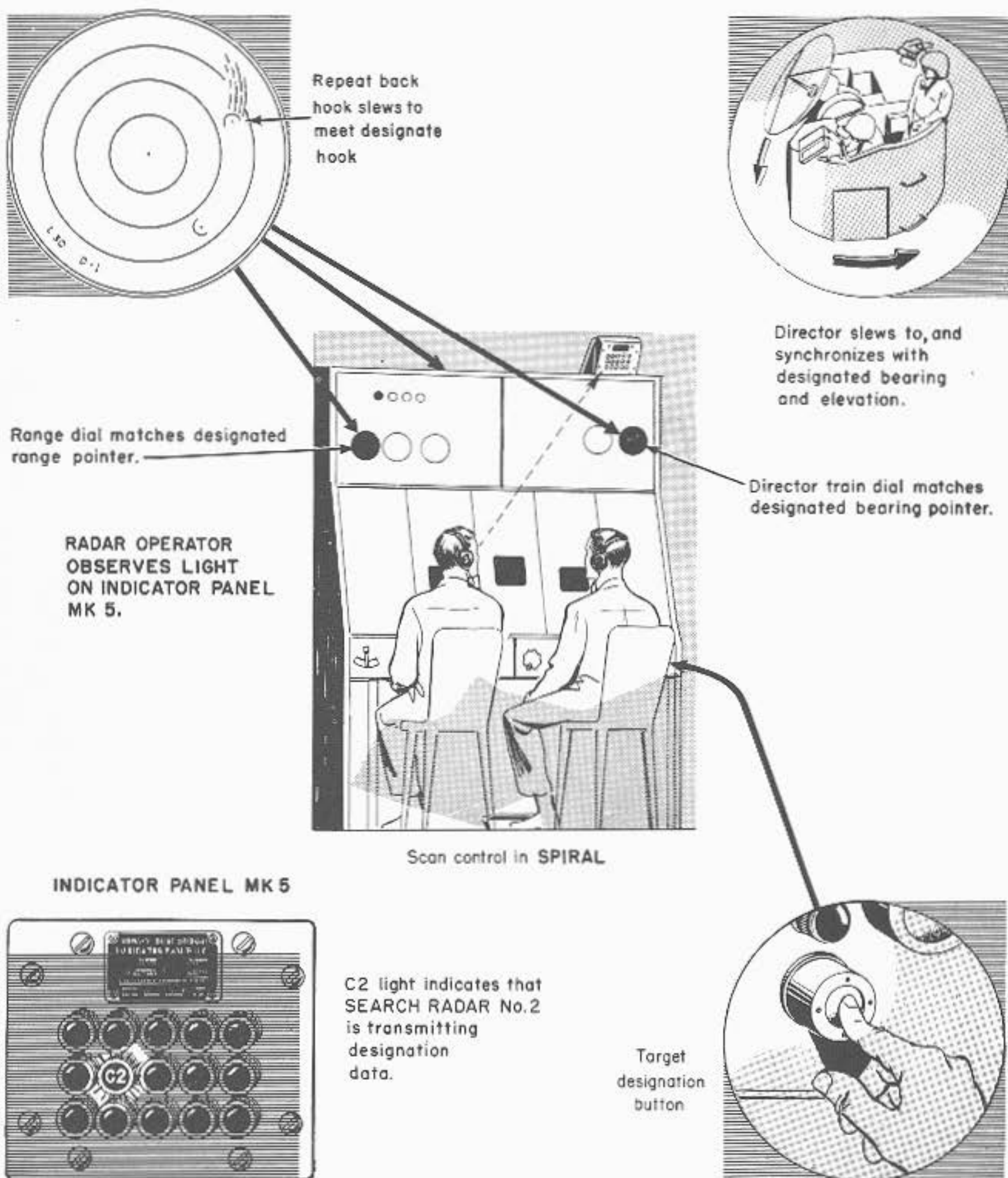
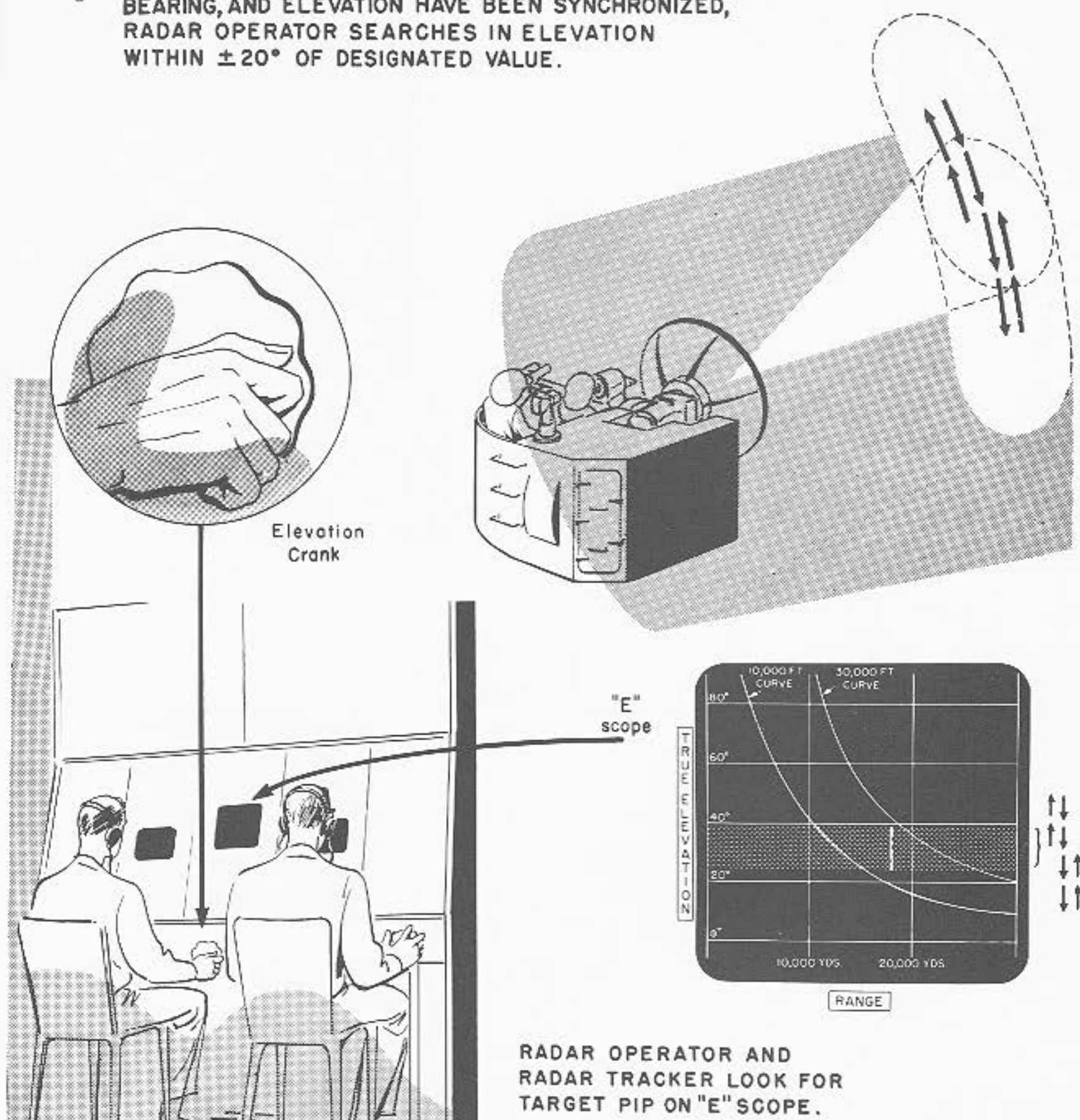


Figure 7-23. — Steps in target designation, acquisition, tracking, and attack procedure — Continued.

110.78.3

- 7** IF PIP DOES NOT APPEAR WHEN RANGE, BEARING, AND ELEVATION HAVE BEEN SYNCHRONIZED, RADAR OPERATOR SEARCHES IN ELEVATION WITHIN $\pm 20^\circ$ OF DESIGNATED VALUE.



RADAR OPERATOR AND RADAR TRACKER LOOK FOR TARGET PIP ON "E" SCOPE.

- 8** IF PIP DOES NOT APPEAR DURING ELEVATION SEARCH, RADAR TRACKER SEARCHES WITHIN $\pm 20^\circ$ OF DESIGNATED BEARING.

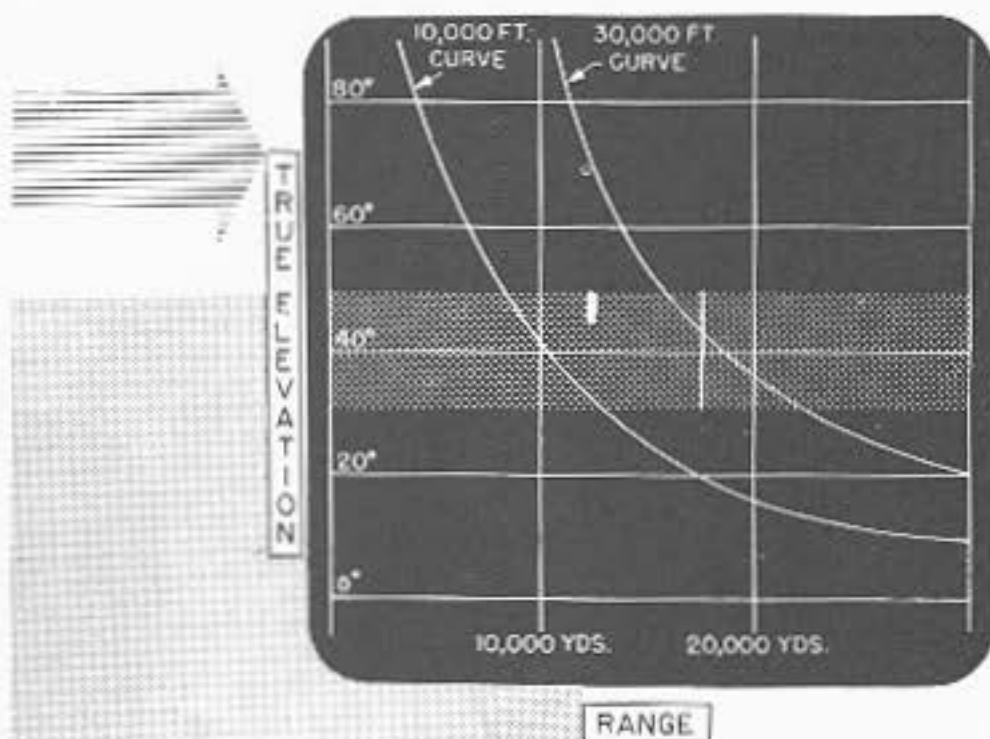
- 9** IF PIP DOES NOT APPEAR DURING BEARING SEARCH, RADAR TRACKER PRESSES "SEARCH ERASE" BUTTON TO RE-SYNCHRONIZE SYSTEM. THEN BOTH OPERATORS REPEAT ELEVATION AND BEARING SEARCHES.

110.78.4

Figure 7-24.—Steps in target designation, acquisition, tracking, and attack procedure—Continued.

10 WHEN TARGET PIP IS
VISIBLE ON "E" SCOPE ...

... OPERATORS
STOP SEARCHING; THEN ...



11 ... RADAR OPERATOR ...

A ... SLEWS RANGE MARK
CLOSE TO TARGET PIP, AND ...

B ... CRANKS ELEVATION TO
CENTER PIP ON TRACE.

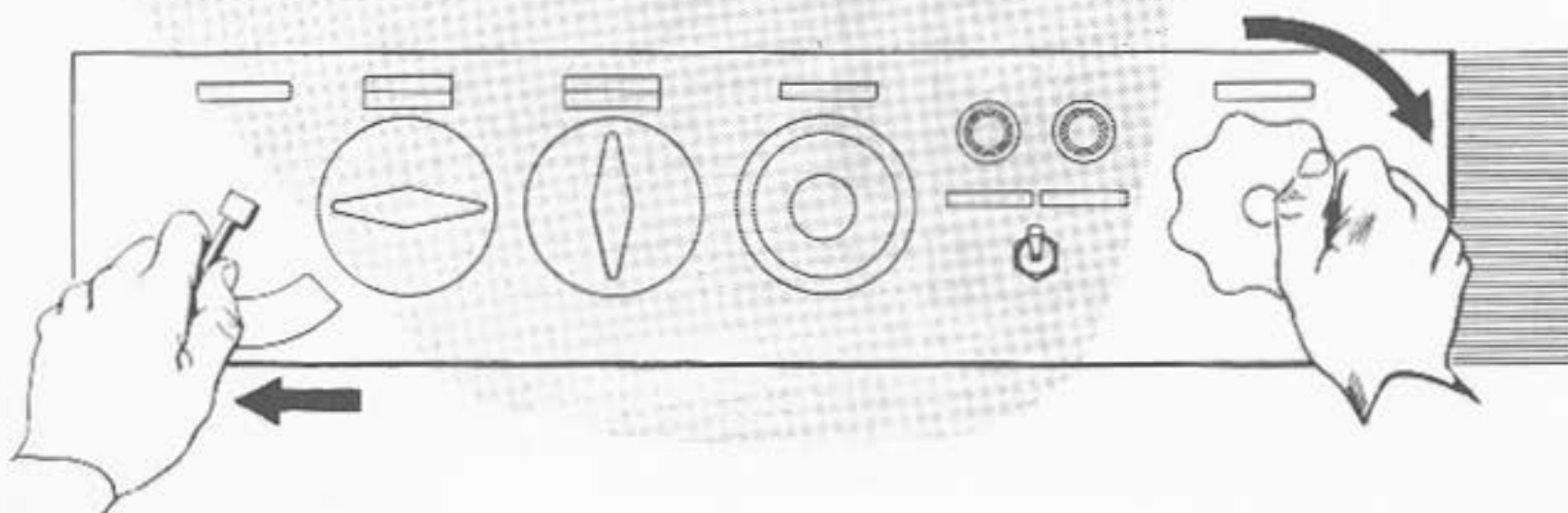
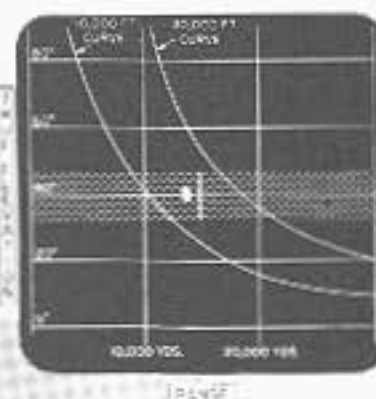
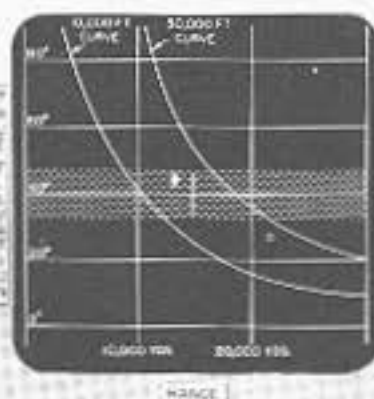
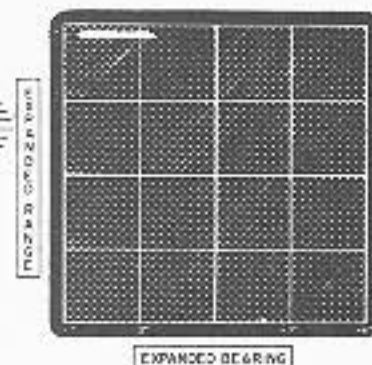


Figure 7-25.—Steps in target designation, acquisition, tracking, and attack procedure—Continued.

110.78.5

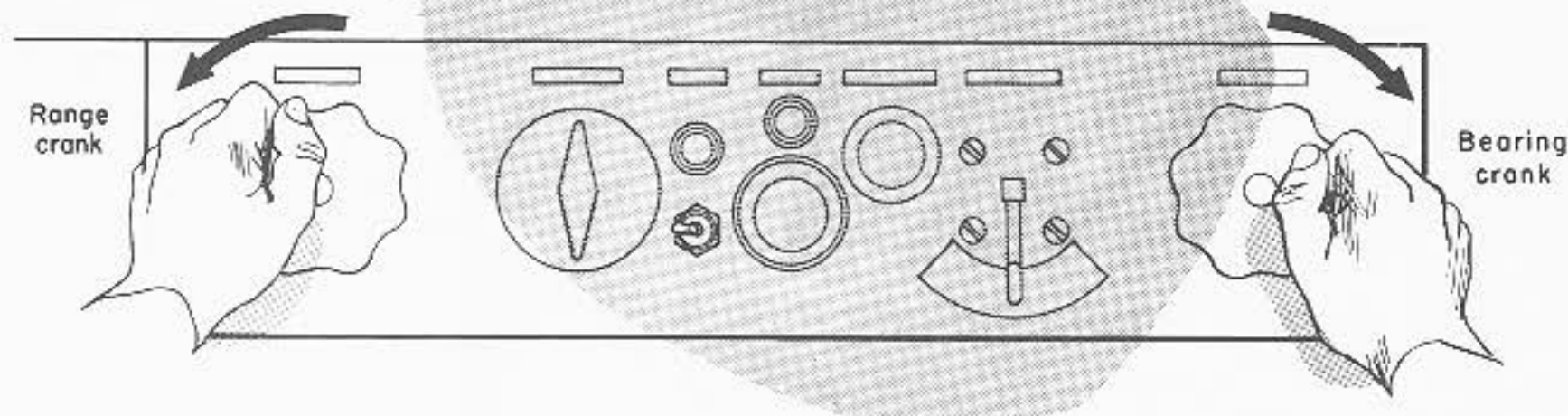
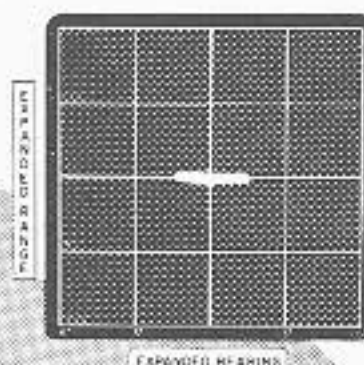
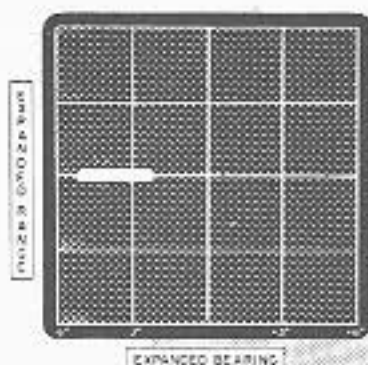
12 AS SOON AS PIP IS VISIBLE ON "B" SCOPE ...



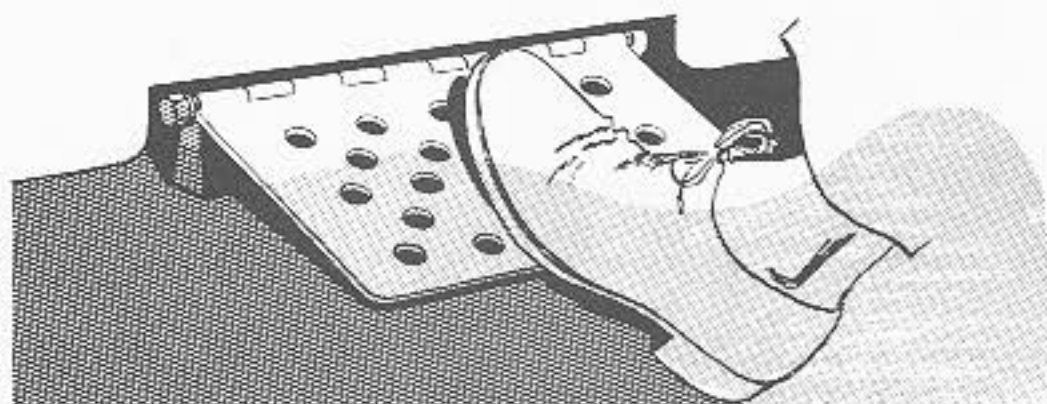
... RADAR TRACKER ...

A ... CRANKS RANGE TO CENTER PIP VERTICALLY, AND ...

B ... CRANKS BEARING TO CENTER PIP HORIZONTALLY; THEN ...



13 ... PRESSES SCAN CONTROL FOOT SWITCH TO SHIFT TO CONICAL SCAN FOR AUTOMATIC RADAR TRACKING



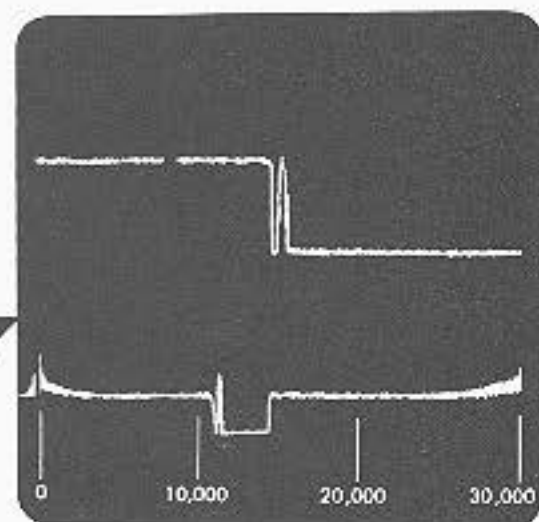
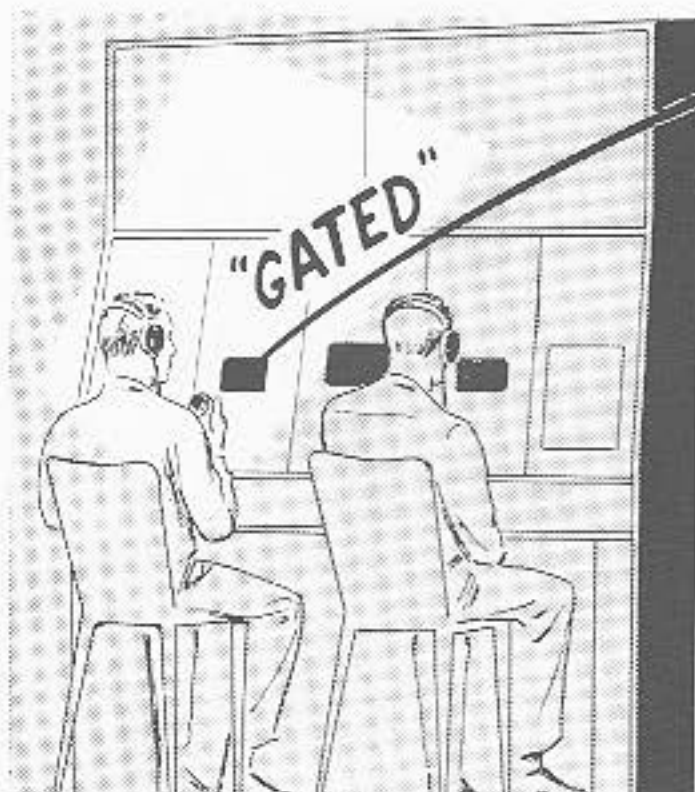
110.78.6

Figure 7-26.—Steps in target designation, acquisition, tracking, and attack procedure—Continued.

14

WHEN TRACKING CIRCUITS "LOCK ON" PIP...

...RADAR OPERATOR REPORTS...



"A/R" scope

... TO CONTROL OFFICER.

15

CONTROL OFFICER ORDERS...



**... "MOUNT 52 ... MATCH POINTERS
AND SHIFT TO AUTOMATIC"**

HAND MICROPHONE

16

DIRECTOR OPERATOR RELAYS MOUNT CAPTAIN'S REPORT OF "MOUNT 52 IN AUTO" TO CONTROL OFFICER THROUGH VOICE TUBE.

Figure 7-27.—Steps in target designation, acquisition, tracking, and attack procedure — Continued.

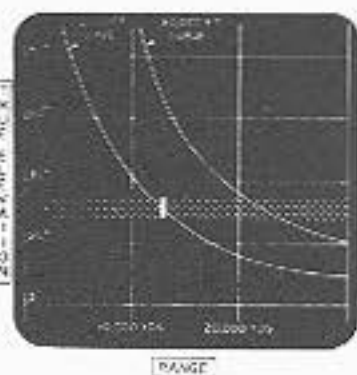
110.78.7

17 AUTOMATIC RADAR TRACKING—



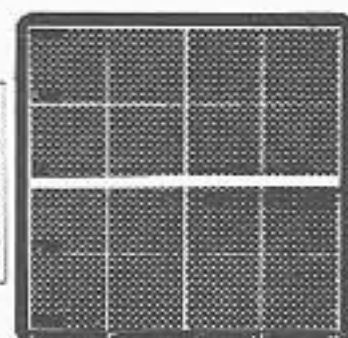
CONTROL OFFICER:
WATCHES RANGE DIAL.

DIRECTOR OPERATOR:
LOOKS FOR TARGET
IN TELESCOPE.



"E" scope

AUTOMATIC TRACKING CIRCUITS
KEEP DIRECTOR ON TARGET
AND PIP GATED;
CREW ONLY OBSERVES
PROGRESS OF TRACKING.



"B" scope

RADAR OPERATOR:
WATCHES PROGRESS
OF TRACKING ON "E" SCOPE
AND "A/R" SCOPE.



RADAR TRACKER:
WATCHES PROGRESS OF
TRACKING ON "B" SCOPE.

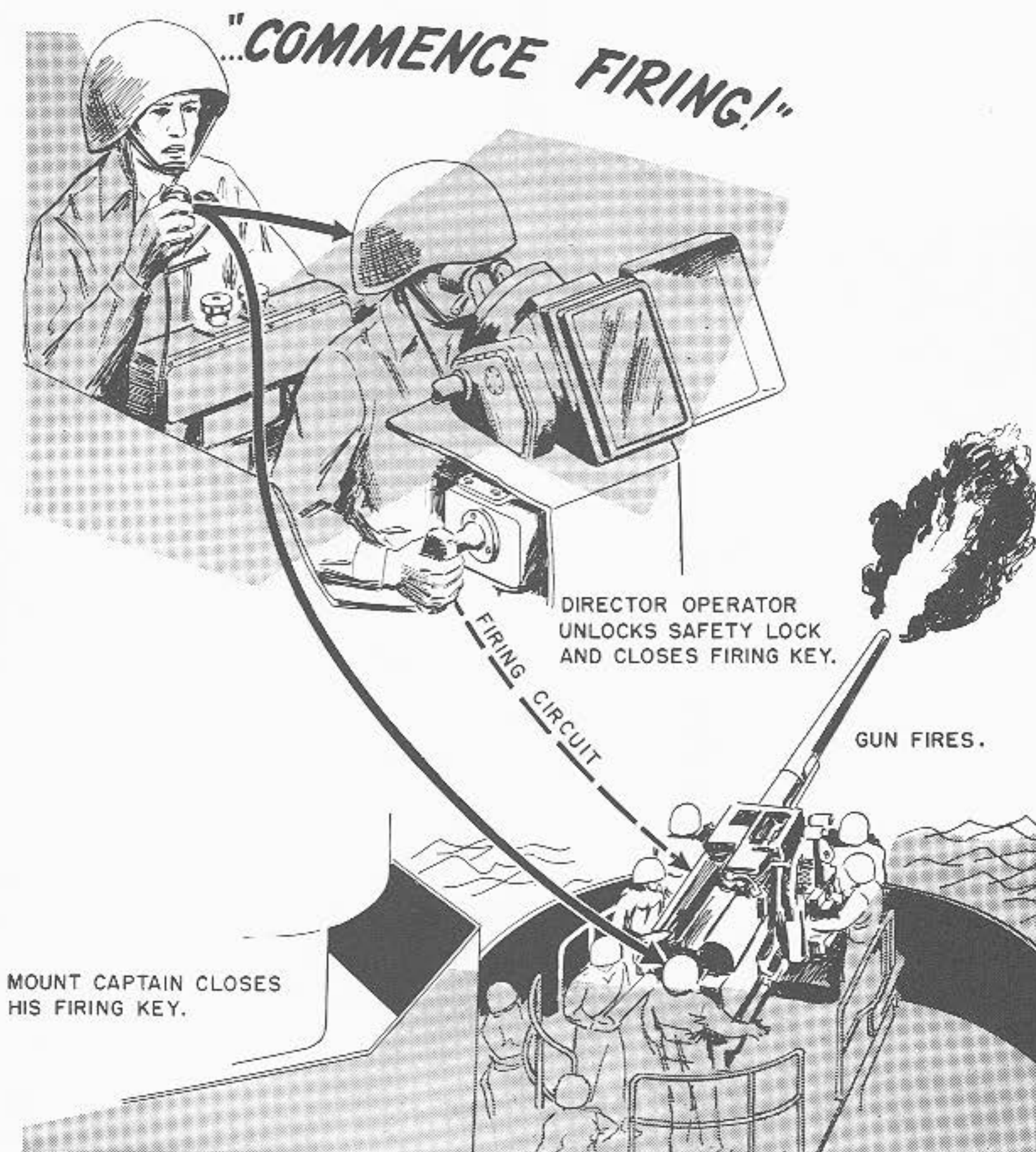
Scan control in CONICAL

110.78.8

Figure 7-28.—Steps in target designation, acquisition, tracking, and attack procedure—Continued.

18

WHEN "OPEN FIRE" RANGE IS REACHED, CONTROL OFFICER ORDERS...

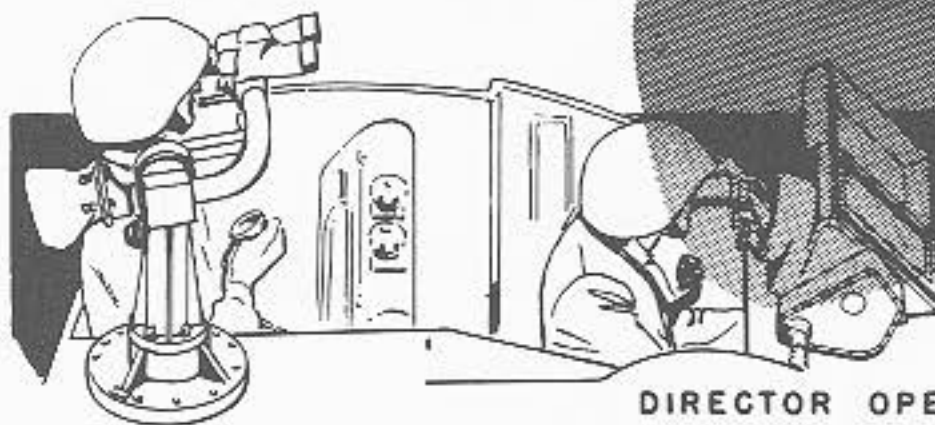


110.78.9

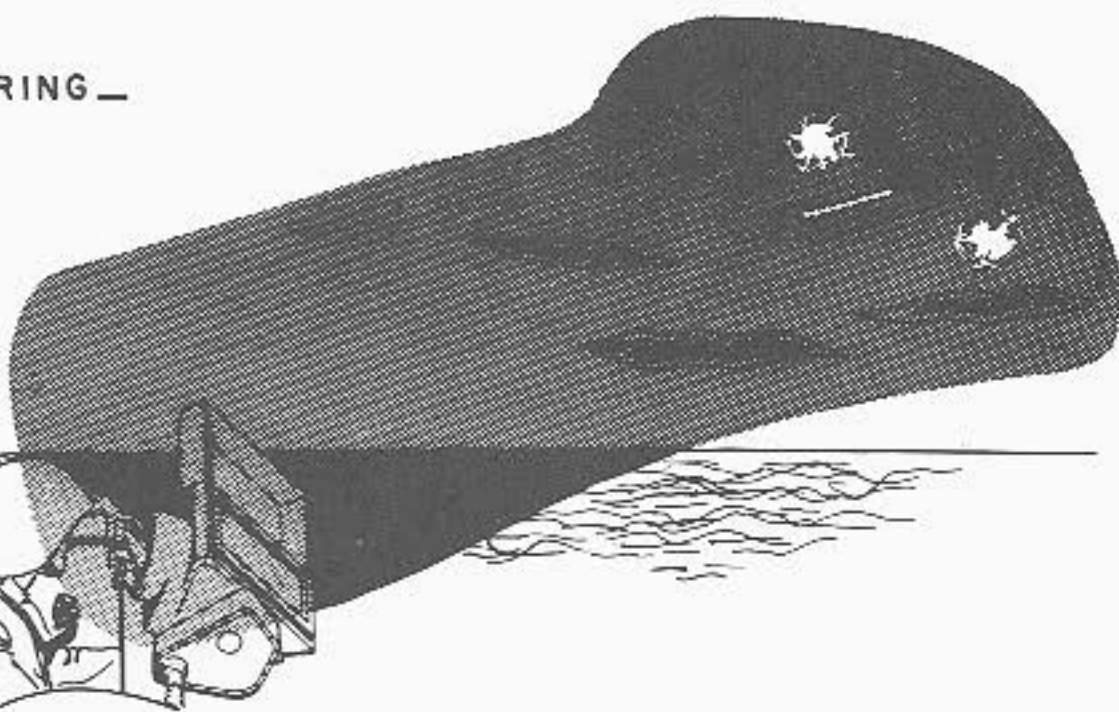
Figure 7-29.—Steps in target designation, acquisition, tracking, and attack procedure—Continued.

19 DUTIES DURING FIRING_

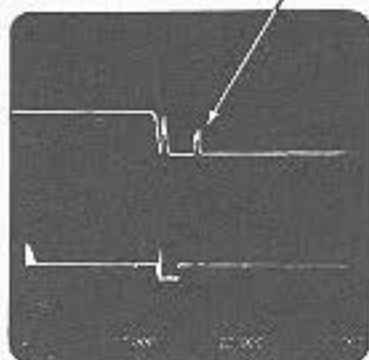
**CONTROL OFFICER:
OBSERVES FIRING.**



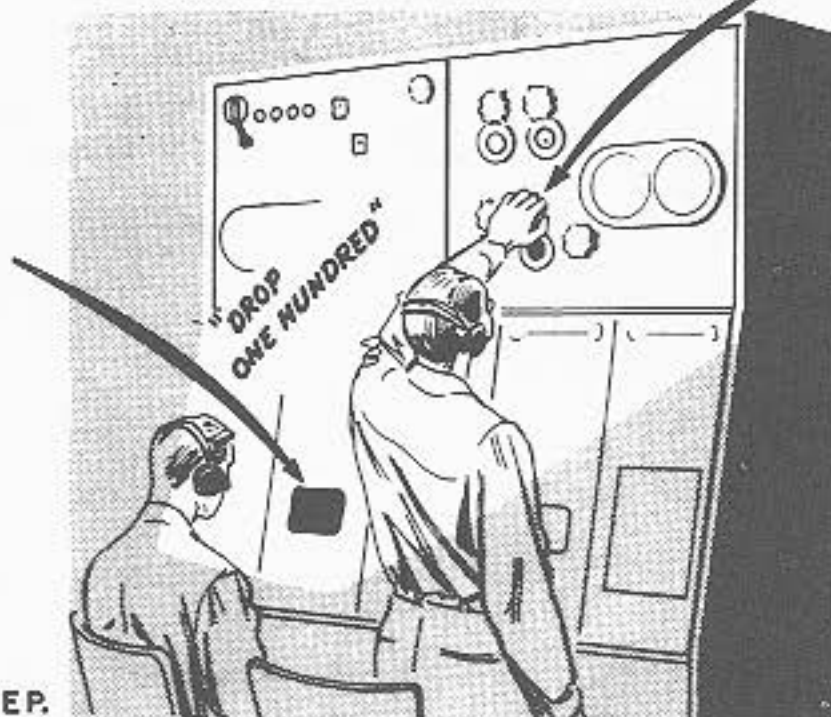
**DIRECTOR OPERATOR:
HOLDS FIRING KEY CLOSED.**



Pip from burst



**RADAR OPERATOR:
ESTIMATES RANGE
SPOTS FROM "R" SWEEP.**



**RADAR TRACKER:
SETS RANGE SPOTS
ON FUZE SPOT DIAL.**



**ELEVATION AND DEFLECTION SPOTS MAY BE ESTIMATED FROM "E" AND "B" SCOPES
AND INTRODUCED ON ANGLE SPOT TRANSMITTER.**

ALL SPOTTING SUBJECT TO SHIP'S DOCTRINE.

110.78.10

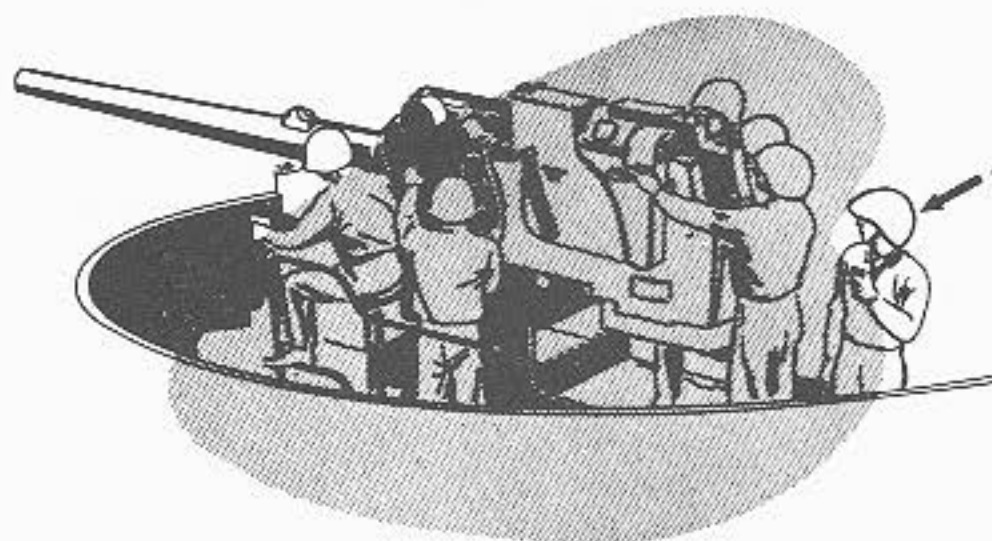
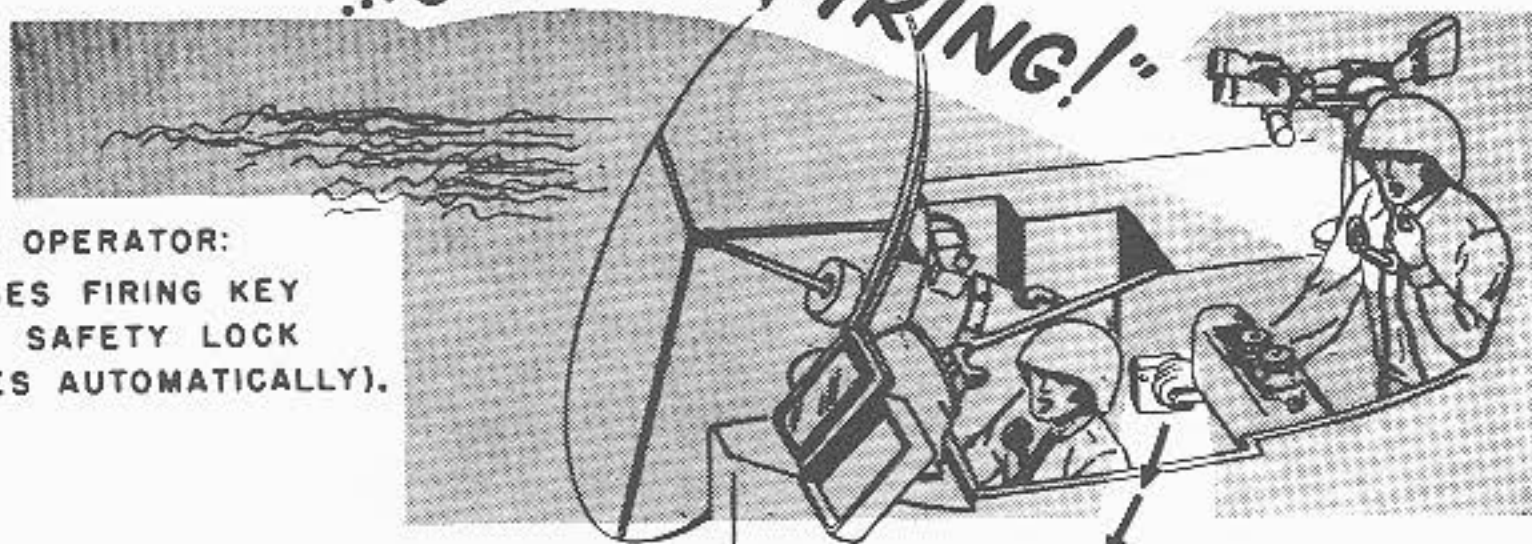
Figure 7-30. — Steps in target designation, acquisition, tracking, and attack procedure — Continued.

20

WHEN CONTROL OFFICER OBSERVES THAT TARGET IS DESTROYED OR HAS PASSED BEYOND EFFECTIVE FIRING RANGE, HE PULLS CEASE FIRING HANDLE AND ORDERS...

...**"CEASE FIRING!"**

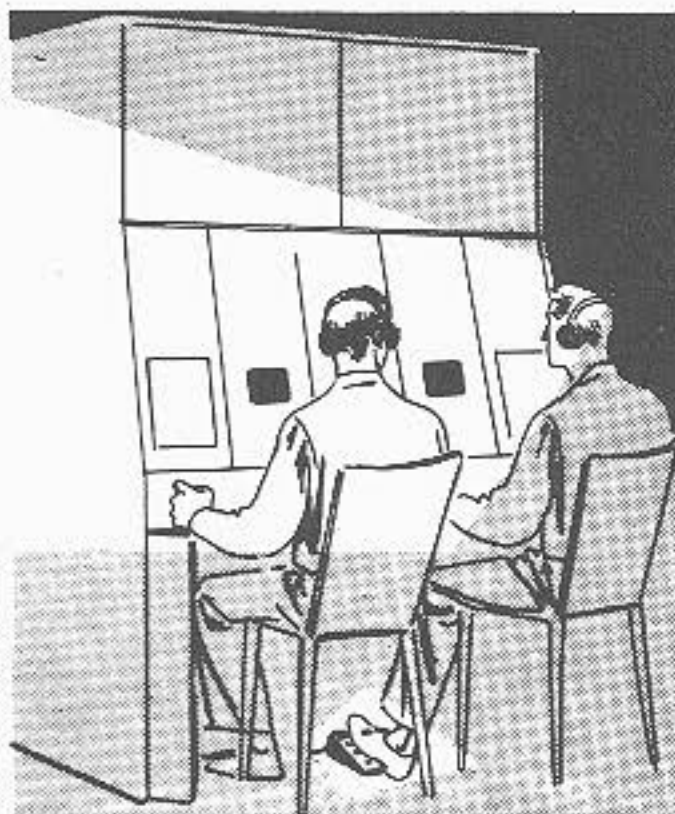
DIRECTOR OPERATOR:
RELEASES FIRING KEY
(FIRING SAFETY LOCK
ENGAGES AUTOMATICALLY).



"Cease-Firing"
Signal

**MOUNT CAPTAIN OPENS
HIS FIRING KEY.**

CONSOLE OPERATORS:
SWITCH TO SPIRAL SCAN AND RESTORE OTHER
PRELIMINARY SETTINGS IN PREPARATION FOR
NEW TARGET.



110.78.11

Figure 7-31.— Steps in target designation, acquisition, tracking, and attack procedure— Continued.

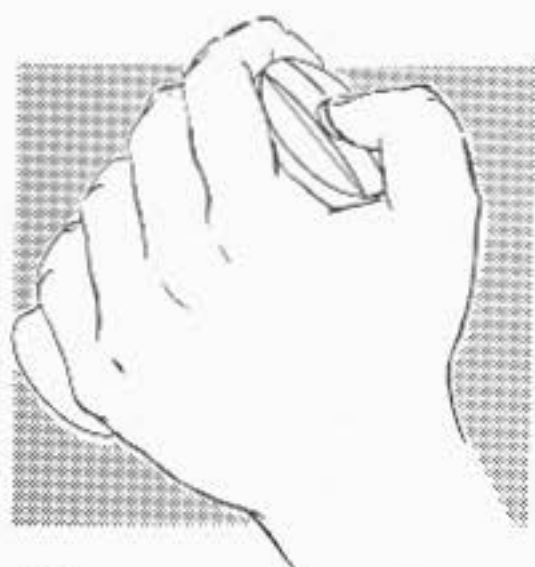
1

THE TARGET IS DETECTED BY PERSONNEL IN THE AAW STATION AND ASSIGNED TO A TDT OPERATOR TO TRACK.



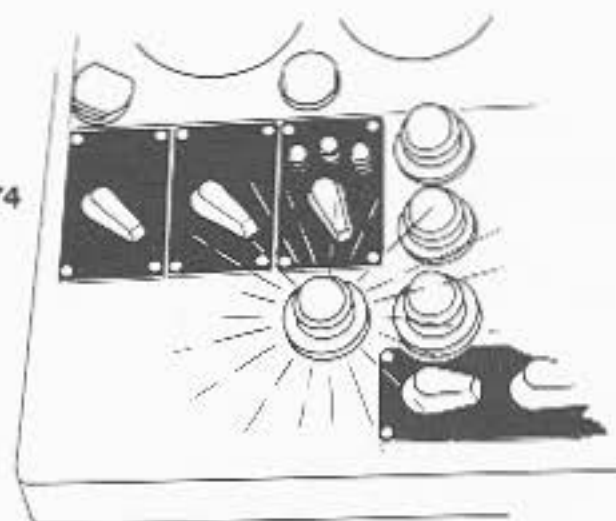
2

THE TDT OPERATOR TRACKS THE TARGET AND PRESSES THE TDT ON-TARGET PUSHBUTTON WHEN THE TARGET IS CENTERED IN THE BINOCULARS.



... WHICH

ILLUMINATES THE ON-TARGET LAMP ON CONTROL UNIT MK 74



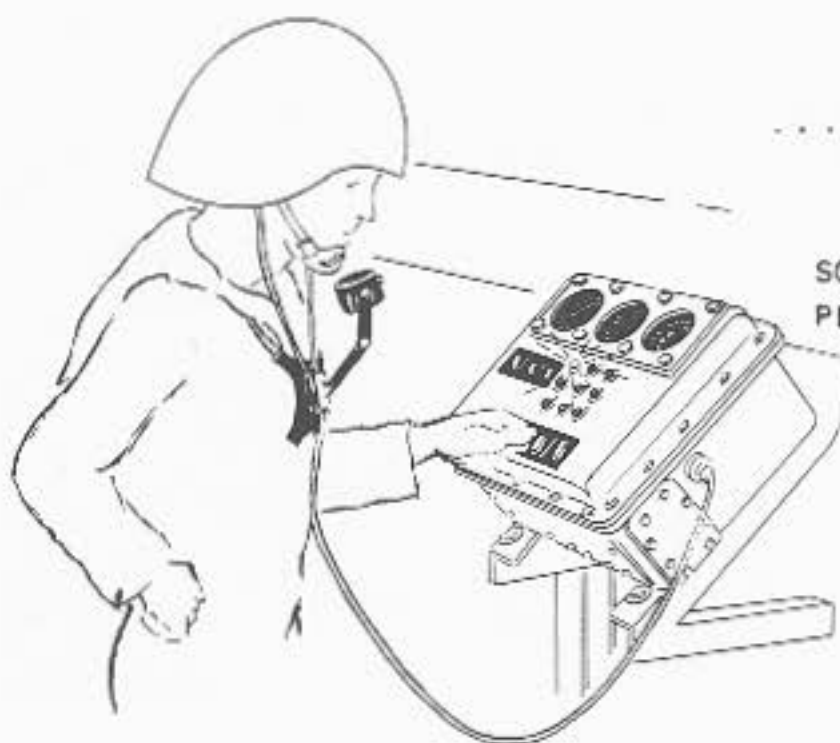
3

THE OPERATOR AT THE CONTROL SELECTS THE DIRECTOR TO RECEIVE THE DESIGNATION AND POSITIONS THE DIRECTOR SET-UP SWITCH TO ON

... THIS

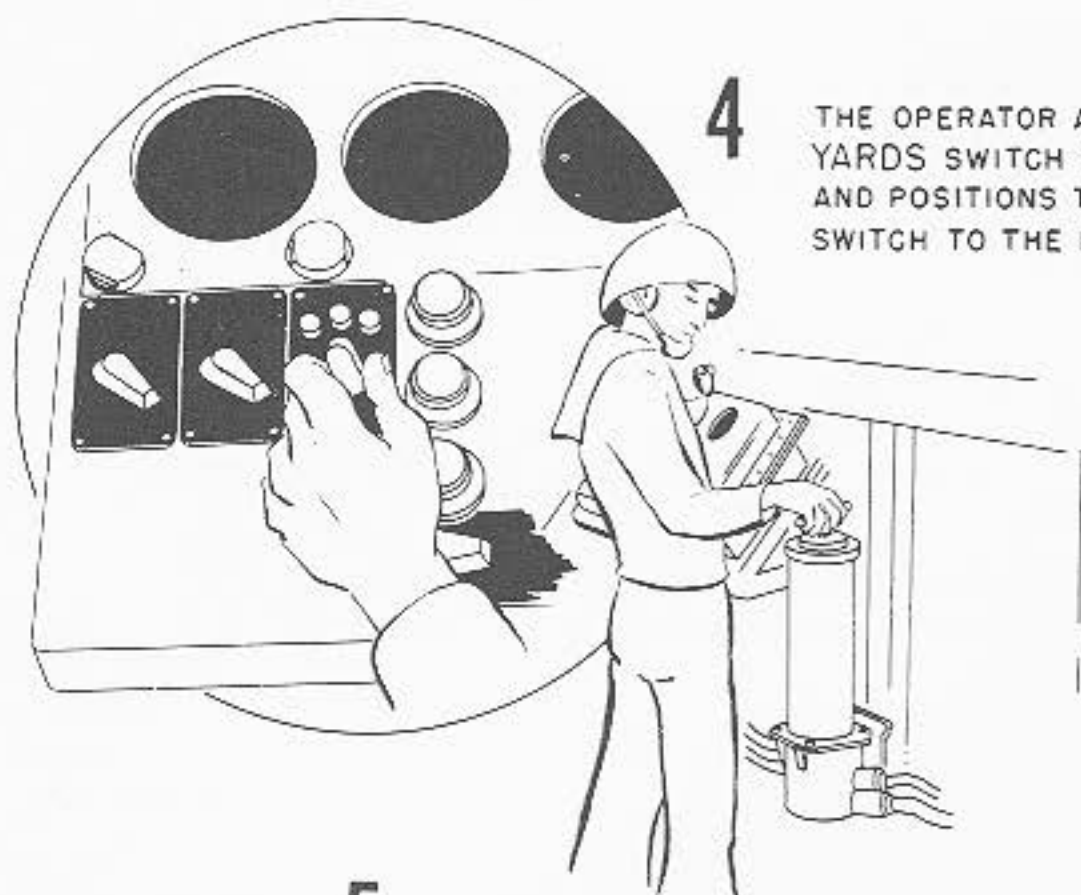
SOUNDS A BUZZER INFORMING GUN FIRE CONTROL SYSTEM PERSONNEL OF IMPENDING DESIGNATIONS.

... THE BUSY OR OWN CONT. LAMP OF THE SELECTED DIRECTOR FLASHES



110.79.1

Figure 7-32. — TDS steps in target designation procedure (AAW station).



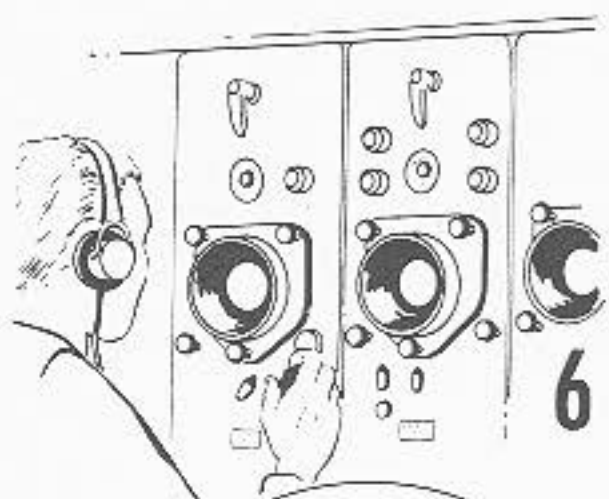
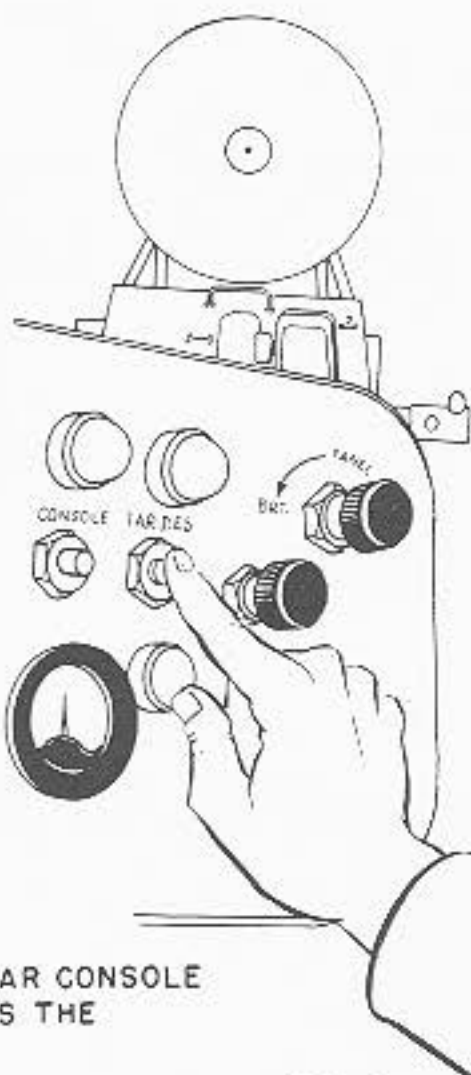
4

THE OPERATOR ALSO POSITIONS THE ESTIMATED RANGE YARDS SWITCH TO THE APPROXIMATE TARGET RANGE AND POSITIONS THE DIRECTOR REPEAT-BACK SELECTOR SWITCH TO THE DIRECTOR RECEIVING THE DESIGNATION.

5

THE DIRECTOR OFFICER ACCEPTS DESIGNATION BY PRESSING THE TAR. DES. PUSHBUTTON

...THE DIRECTOR SLEWS TO THE DESIGNATE COORDINATES



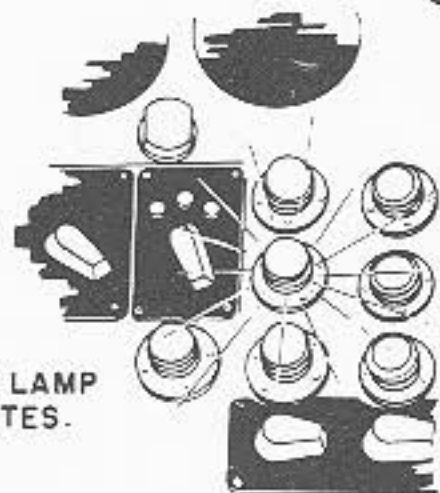
6

THE RADAR OPERATOR AT THE RADAR CONSOLE GATES IN THE TARGET AND PRESSES THE FOOTSWITCH.



...THE DIRECTOR SHIFTS TO AUTOMATIC TRACKING

...AND THE DIRECTOR TRACKING LAMP ON THE CONTROL UNIT ILLUMINATES.



110.79.2

Figure 7-33.—TDS steps in target designation procedure (AAW station).—Continued.

launcher (an act which is similar to putting guns into automatic) and to fire the missile at the optimum time.

Keep in mind that many weapon direction systems are linked to naval tactical data systems. Therefore, they may receive designations from external sources (fig. 7-15).

GENERAL DESCRIPTION OF A WDS

Don't be dismayed by the abbreviations in the preceding article. They will become commonplace if you are assigned to the weapons department of a missile ship where these terms (and their abbreviations) are used.

Figure 7-34 shows the major units in a WDS that are used in radar designations (some were eliminated for simplicity). Notice that a missile fire control director and its computer, and gun fire control director and its computer, are depicted along with their respective delivery devices; i.e., a missile launcher and a gun. You'll recall that once a target is acquired by a fire control system, the system functions independently of the WDS in tracking the target, and in computing the launcher or gun orders. The function of the WDS, then, is to direct the fire control system to the target initially.

An air search radar detects targets and sends the video data simultaneously to three TSTCs. The TSTC in CIC selects the targets to be tracked by the other two TSTCs in the weapons control station. This is done by assigning electronic tracking channels to the targets. A tracking channel is assigned to a target based on evaluation by the CIC evaluator and the WLO. Each TSTC operator in the weapons control station has a prearranged responsibility for establishing a track in one-half of the total number of channels—a division of the tracking load results. A target movement rate is electronically available within a channel after a few seconds of manual operation by a TSTC operator. The established rate enables the TSTC to track the target automatically as long as relative motion factors are constant. Additional minor corrections are required by the operator if the relative motion factors vary. Tracking channel data are sent automatically to the director assignment console. These data include range, bearing, course, speed, altitude, and estimated weapon release range for as many targets as are being tracked. The system can track as many targets as the number of tracking channels permits.

It is from the director assignment console (where all target data are collected and displayed)

that a specific director or fire control system is selected to destroy the target. The selected director slews (i.e., moves at an accelerated rate) to the target's present position in range, bearing, and elevation. If all equipment is aligned and functioning properly, the target echo is now visible on the fire control system's radarscopes. The crew refines director position and causes the fire control system to shift into automatic radar track. When a system shifts into automatic track, its associated computer starts computing precise gun or launcher orders. Synchronizing a gun to its ordered position, and its subsequent loading and firing are processes that are controlled by the system's director officer. Loading a launcher, synchronizing it, and firing the missile are steps that are supervised by the WAC operator (nominally, the missile officer). Control doctrine normally requires these officers to receive orders from the ship's weapons officer before firing ordnance.

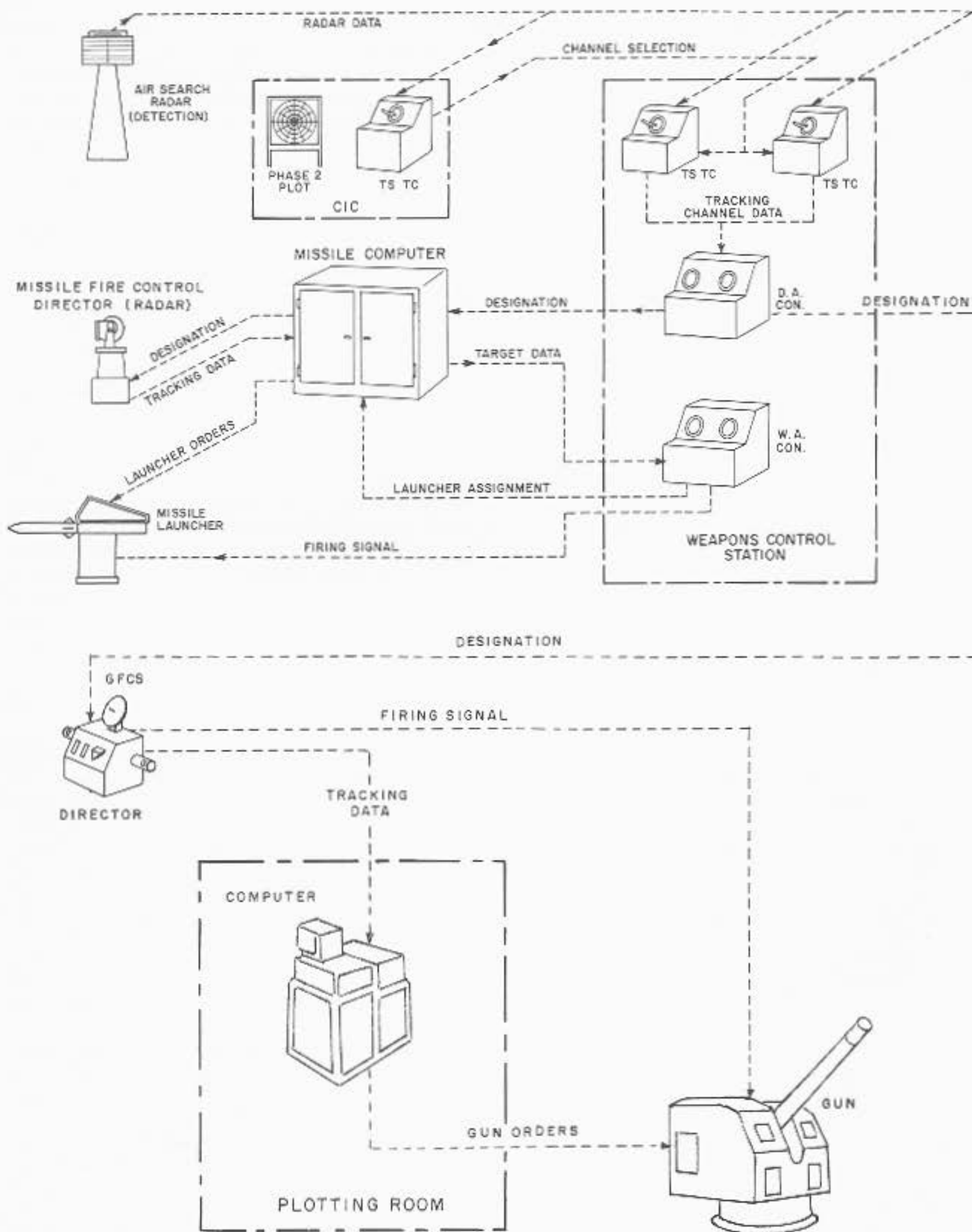
We'll now take a closer look at the operation of a TSTC, and in the following section, a DAC. The WAC will be covered in the second volume of this series. Even though figure 7-34 is representative, it does not show the exact number of WDS units installed on all missile ships. The number (and the location) of these units depends on the ship's armament.

THE TARGET SELECTION AND TRACKING CONSOLE

There is a typical TSTC and its PPI display in figure 7-35. If this were the one in CIC, it would be controlled by an assigned operator who is under the direct supervision of the WLO. The console displays targets on PPI presentation which can be shifted to monitor various radar search displays. Shifting of the radar display permits system flexibility in the event of malfunction or poor reception of any one search radar. If the air search radars are equally receptive, the console operator will select one that has a height-finding capability and the narrowest radar beam.

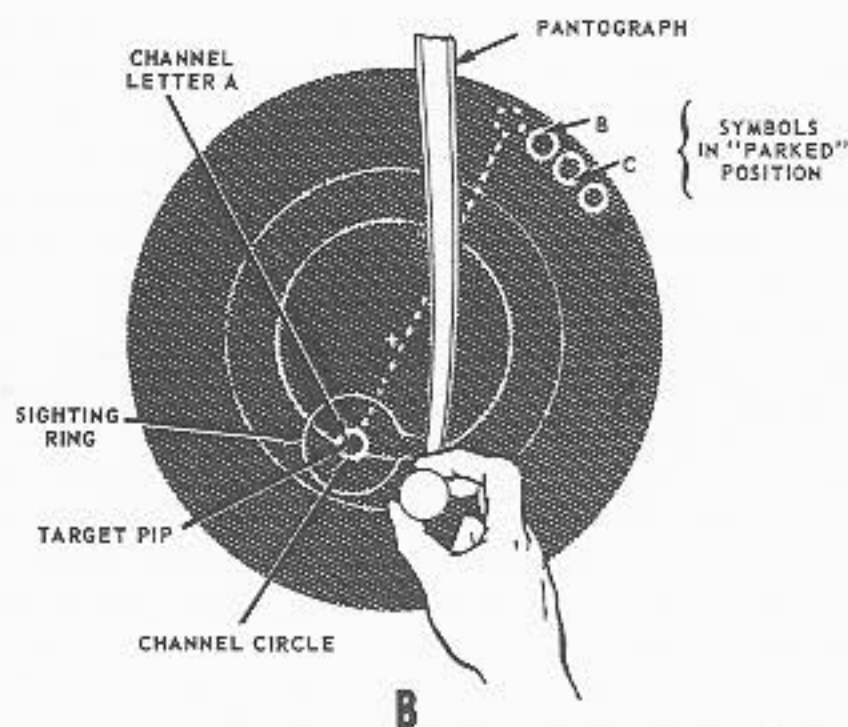
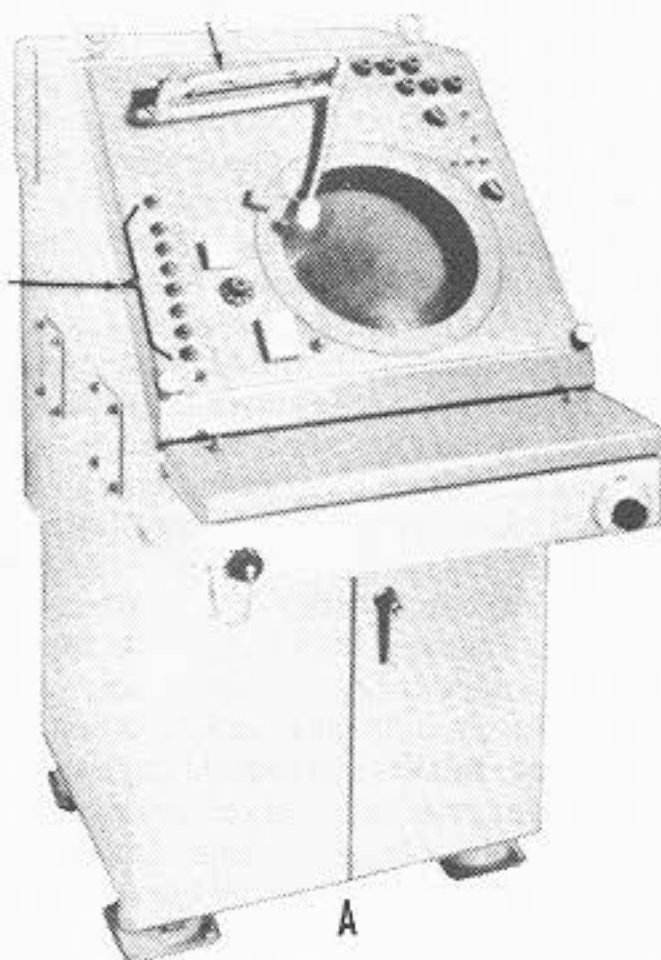
As mentioned previously, the target height quantity is eventually converted into an angle of true target elevation for use by the directors. We observed that this eliminated large sector searching in elevation by the directors and therefore greatly reduced target acquisition time.

Using the search radar that has the narrowest beam further reduces target acquisition time in that it more definitively pinpoints the target's position. Search radars have a much larger beam width than fire control radars. This means that



63.19
Figure 7-34.—WDS simplified data flow.

PANTOGRAPH ARM

CHANNEL
PUSHBUTTONS

12.42

Figure 7-35.—A. Typical target selection and tracking console; B. TSTC display.

a certain amount of refining or searching by the fire control director is required after it has been designated to a target by a relatively broad

beam search radar. Correct radar alignment reduces the searching requirement.

Any one of the three consoles can be used to send target data to the DAC. In practice the WLO's TSTC is used to alert the other two to the threat of an attack. That is, the WLO's console will select the target to be tracked and the other two consoles will do the actual tracking.

Target selection is accomplished by placing the pantograph arm on the console directly over the target video on the radarscope. A small illuminated dot, which represents the position of the pantograph arm, will then be superimposed on the target video. If evaluation indicates that the contact is a threat, the WLO will order his console operator to assign a tracking channel to the target.

There are a number of tracking channels in this equipment. Several tracking channels are necessary in order to separate the movement data of one target from another when the console is used to track multiple targets. Buttons which activate the tracking channels are located on the left of the console and identified by single letters such as A, B, C, etc. To activate a tracking channel for a particular bogey, the operator presses a channel button which is not in use. A small illuminated circle with the channel letter designator within will then appear in the same position on the radarscope as the dot from the pantograph arm.

The two target selection and tracking consoles in the weapons control station have more or less the same radarscope picture as the console in CIC. Tracking channel C for example, shows up in exactly the same position on all three consoles provided the individual console controls are set alike. Disparities in console presentations occur when different range scales or radars are selected by the console operators. However, the true position of both the symbols and targets is unaffected by the console controls.

To reiterate, the presence of a tracking channel symbol superimposed on target video will cause the tracking operators to commence tracking that particular target. Upon assigning a channel to a target, the console operator in CIC parallels visible information via sound-powered telephones. It is in this way that the WLO can select the target to be tracked by weapons control.

The evaluator or WLO estimates the target's weapon release range and the console operator manually inserts it into the system. Insertion of EWRR (estimated weapon release range) is

accomplished at the WLO's console by pressing the appropriate channel button and simultaneously making the input at an attached panel. This channel circuit activating prerequisite permits each tracking channel to have its own EWRR. Knowing the target's EWRR aids weapons control in making a director-to-target assignment. This is particularly true if multiple targets have been detected.

Pre-battle intelligence relating to the enemy's aircraft types and weapon capabilities should be available to the evaluator. Studies will have to be made, based on all available information, to provide EWRRs for different aircraft types. Standards will have to be developed for use in the absence of target amplifying data. The evaluator, who is a very busy individual, may delegate the determination of EWRR to the WLO. In any event, the WLO is responsible for its insertion into the equipment.

WDE designation-accept circuitry has no way of knowing automatically which search radar is being used by the target selection and tracking consoles. This presents a problem when search radars without height-finding capabilities are the source for target designation. Obviously, target height data in this case are unreliable. Some means is then necessary to inform control personnel and increase the limits of the fire control directors' elevation search arcs. A switch, activated by a target selection and tracking console operator, will illuminate "elevation unreliable" lights throughout the system. The same switch triggers computers which then enlarge elevation search in missile directors during the acquisition phase. Throwing this switch is unnecessary on destroyers because the absence of height data automatically activates elevation unreliable circuits.

We mentioned before that the WLO selects the target to be tracked by weapons control. Actually his is a mechanical selection which is an execution of the evaluator's tactical selection. In the heat and confusion of battle, however, these two individuals may often find their responsibilities overlapping. It is mandatory that the evaluator and WLO work together as a team. The WLO will sometimes be required to take control of weapon direction when the evaluator is involved in another facet of this extremely complex battle station. An alert WLO may observe a threat on his radarscope that is not displayed on the phase 2 plot. He can also anticipate the evaluator's

decision and assign inactive tracking channels to suspected threats. This does not mean it is time to start shooting. The WLO is merely establishing a TS and TC track on the contact.

Tracking at the target selection and tracking consoles is rate-aided. That is, a target movement rate is established which subsequently aids the operator in tracking. The rate is generated by repositioning the pantograph arm to coincide with the target's movement. When the pantograph arm is moved, and a rate-aid switch is activated, present target position data are inserted into the tracking channel. Successive changes of pantograph position are electronically compared with previous positions and a target rate is the eventual result. The continuous rate-aided solution will then keep the channel letter designator positioned on target. Three or four pantograph corrections should be all that are needed to establish a fairly accurate rate. Minor corrections are necessary as the track progresses to compensate for changes in target course, attitude, or speed. Rate-aided tracking pays off since multiple targets can be tracked with one tracking console using one pantograph device.

The operators of the two tracking consoles in WCS are responsible for tracking in channels to which they have been assigned. The practice is to assign half of the channels to each operator. It is then up to the selecting console in CIC to split up the tracking load. A tracking operator can insert target data into a channel only if he has access to that channel. We are speaking now of electronic access and not predetermined responsibility. Channel access is electronically indicated by the presence of a small circle around the channel letter designator on the radarscope. A tracking console operator can gain access to a channel through a switch on the pantograph arm or by pressing the desired channel pushbutton.

It is possible to display access circles for a particular channel on more than one console and for more than one operator to make alternate corrections to the channel's rate. It is not possible for more than one operator to make rate corrections simultaneously in that particular channel. In the event simultaneous inputs are attempted, an electrical order of precedence takes over and permits the channel to receive data from one source only. The console with the highest precedence is understandably in CIC. Precedence is also established for the two consoles in WCS.

Target height or altitude graduations are inscribed toward the left on the radarscope of each

target selection and tracking console. These graduations or indices increase from bottom to top on the scope with each increment equal to 5,000 feet. If a 3-coordinate radar has been selected at the console, a video dot representing the target's height will appear adjacent to the height graduations. The video dot moves vertically in response to target height information from the radar. Target height is then visually apparent to the operator when he compares the dot's vertical position to the inscribed indices.

To put height into a channel, the operator gains access, rotates a height cursor knob to align a height measuring spot on the scope to the vertical position of the video dot, and then operates a "height data in" switch that stores height into the channel. If a 3-coordinate radar is unavailable, the equipment can continue to send height data to the WCS provided height has been received in GEOREF report. The known height data are substituted for the vertical position of the video dot. The height cursor knob is rotated until the measuring spot agrees with the reported height and the rest of the operation remains the same. Height data from another ship are not as accurate as that received from our own ship's radar; therefore the console operator throws a switch that energizes the "elevation unreliable" circuits, except for destroyers where this is unnecessary.

THE DIRECTOR ASSIGNMENT CONSOLE

Assigning the proper director in time is very important in AAW. The officer operating the director assignment console must be extremely well qualified. He must be aware of tactical considerations, and be able to comprehend the electronic difficulties which sometimes beset this very complicated equipment. His electronic knowledge must extend to all phases of director assignment and the director's ability to receive designations.

Tracking data from a channel are fed automatically from the tracking console into the director assignment console. Two plots or scopes are provided on this console. They are called the plan and multipurpose plots (fig. 7-36). Target video is not present on these plots, but the plan plot shows target range and bearing by displaying the same channel letter designators we have discussed before. Target course and speed for a particular channel can be approximated on the plan plot by a vector which has its tail attached to the channel letter. The vector's magnitude and direction correspond to target

speed and course. (See channel A in plan plot.)

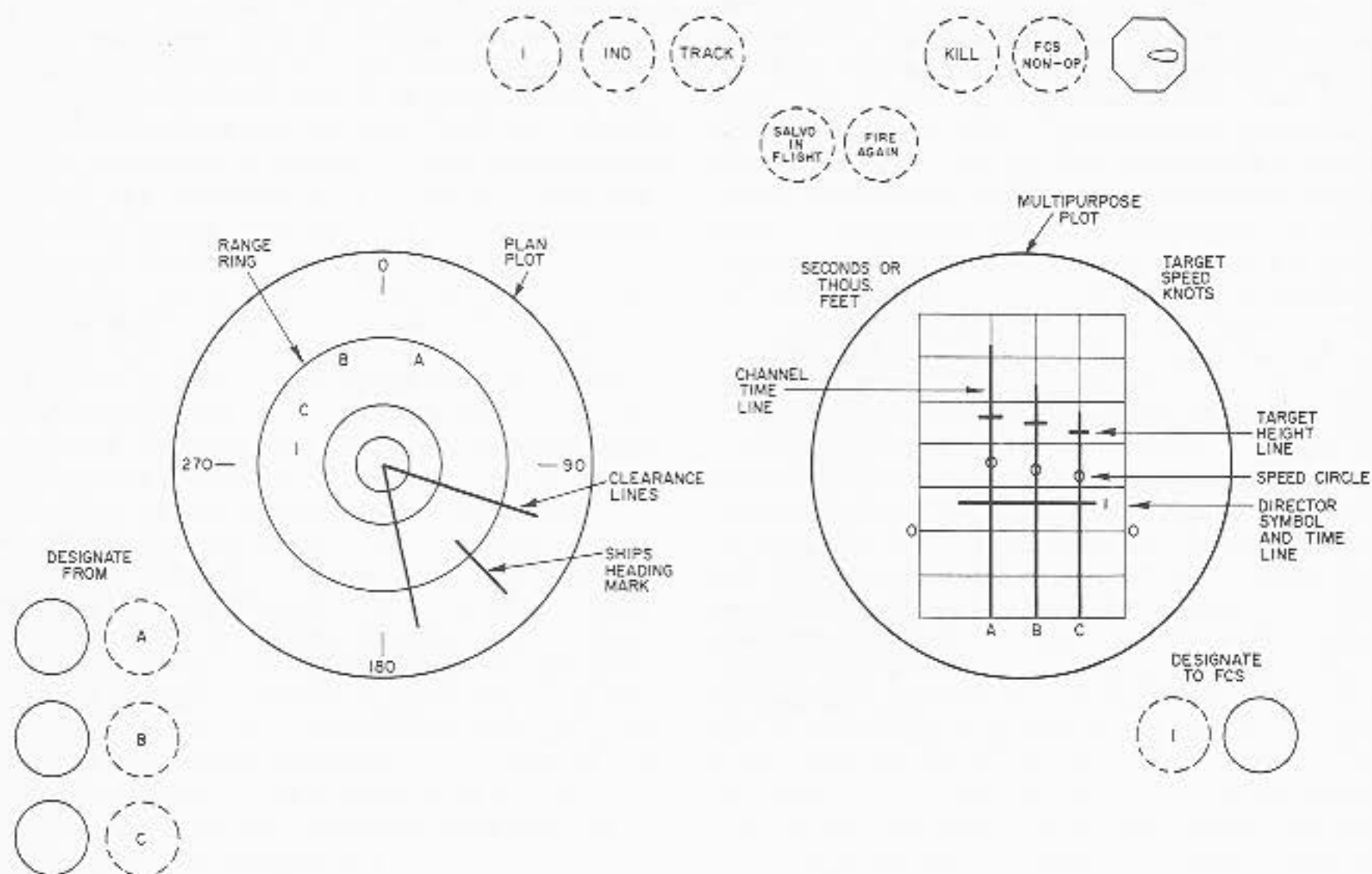
Numbers which show the range and bearing of the directors are also displayed on the plan plot. The director numbers are always present, but a channel letter shows up only when that channel is used to track a target. All of the symbols (numbers and letters) are intensity modulated; that is, they show up on the scope as a video presentation. The directors are numbered in increasing numerical order from forward to aft on the ship. All directors that are used in AAW have their numbers displayed on the director assignment console. The director numbers are also displayed on the target selection and tracking consoles provided the director is tracking. If director 1 is tracking channel B, a 1 would be superimposed on the B.

The plan plot also presents a ship's heading mark, which is a continuous indication of own ship's course. There is a radial line on each side of the heading mark that also moves in response to course changes. The arc described between the radial lines through the ship's head marker represents the missile blind zone for an after launcher installation.

The multipurpose plot is used for making time comparisons which enable the operator to select one of several targets for designation to a director. This plot permits the operator to plan ahead in case the directors are occupied and cannot be assigned immediately. Target height and speed are also displayed on this plot to aid the operator in director assignment.

The multipurpose plot has a vertical video line for each tracking channel. The vertical length or height of the line is compared to inscribed indices on the scope which represent time. The vertical time lines are "programmed" to show when a director must be designated to a particular channel, so that a missile may be fired to intercept before the target reaches his estimated weapon release range. The factors which affect the height of the vertical line are target range and speed, fire control director acquisition time, weapon assignment time, and EWRR. Computations for these lines are based upon their application to missile fire control systems; however, approximations can be made which will apply to gunnery fire control systems as well.

Pushbuttons on the left side of the director assignment console are used to "designate from" a target data source. The source may be any one of the tracking channels, one of the optical target designation transmitters (TDTs), or one of the AAW directors which has previously acquired



12.43

Figure 7-36.—Director assignment console display.

the target. Your ship may have two or four TDTs located at topside AAW station(s). TDTs are used to designate targets which may have escaped radar detection. Designating from a director to another director is called inter-director designation; it is by far the most expeditious method, since the target is more accurately pinpointed by fire control radar.

Pushbuttons on the right side of the console are used to "designate to" a fire control system. There is a pushbutton for each AAW director arranged in numerical order from top to bottom on the console.

To assign a director to a target data source, the console operator merely presses a "designate from" simultaneously with a "designate to" push button. For example, if we wish director 1 to track the target in channel C, we would depress the C in the "designate from" column and the 1 in the "designate to" column simultaneously. If we want director 1 to track director 2's target, we would depress the 2 in "designate from" along with the 1 in "designate to." (The

total number of directors and data sources is not shown in figure 7-36.)

Circuits are then activated which automatically slew the director to the target in range, bearing, and elevation. Remember, the accuracy of the elevation information depends on the reliability of target height data. Range and bearing accuracy depends primarily on the tracking ability of the target selection and tracking console operator. We are assuming that your equipment is aligned and functioning properly.

A director is released from designation when it "sees" the target with its own equipment or when the DAC operator presses a designation "release" pushbutton on the right side of the console. The "release" pushbutton will have to be depressed at the same time as the director's "designation to" pushbutton.

A tracking channel is "dumped" by using more or less the same procedure. Another release button, on the lower left of the console, must be depressed simultaneously with the pushbutton for the channel that is no longer desired.

A tracking channel can also be dumped at the target selection and tracking consoles by using the same procedure; however, a good practice would be to dump channels only from the director assignment console. Undesirable accelerated movement at the director may result if a channel is dumped when the director is attempting to acquire the target. For this reason it seems advisable to dump channels from the DAC, since it is the only console where director acquisition of the target can be viewed. As you will recall, the director's number is not present on the target selection and tracking consoles until the director shifts into the track mode.

An ever-present problem in weaponry is the limitation placed upon firing arcs by the ship's superstructure. For obvious reasons, launchers and guns are electrically cut out if they are aimed at any part of the ship. The cutout area in bearing and elevation is referred to as the blind zone for a specific weapon. An after launcher cannot fire dead ahead and a forward gun is cut out directly aft. The blind zone

problem is still present even when similar weapons are located fore and aft, provided an attack is overloaded in one direction. The director assignment console operator solves this problem by making course recommendations to the pilot house. Maximum fire power will be brought to bear if the ship places her beam to the expected attack, however, this is not always feasible. To recommend a course, the director assignment console operator rotates a "course recommend" knob to the desired course, activates a "course recmd" switch, and an electrical signal positions a course indicator in the pilot house. Course recommendations are paralleled via the JA telephone circuit for general information and to give the officer of the deck an opportunity to intercede if the new course would endanger the ship. In making course recommendations, the DAC operator must consider the dead time before a steering order is given and the time it takes the ship to complete the maneuver. A course is recommended generally as soon as the target's projected track indicates that he will enter the blind zone.