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Chapter 9

AUTOMATIC WEAPONS

A. Introduction

9A1. General

Automatic guns are case guns in which part of the energy of explosion is used to eject the empty cases and to activate a device which reloads and continues to fire the gun as long as the trigger is operated and the ammunition supply is maintained. All short-range (3,000 yards) AA guns aboard ship are automatic weapons.

The short-range automatic weapons used by the Navy include 20-mm and 40-mm guns, both of which were used in destroying the enemy's air power in World War II.

The United States Navy's medium-range (8,000 yards) AA weapon is the semiautomatic 3″/50 gun, with a separately powered automatic loader making it in effect an automatic gun. This weapon has been developed from the old semiautomatic 3-inch gun which was still used in World War II.

This chapter takes up the 20-mm aircraft gun, the 40-mm AA gun, and the new 3″/50 gun, as representative of present aircraft and AA machine guns. It does not take up the 20-mm AA gun or the old 3″/50 without automatic loader.

B. 20-mm Aircraft Gun

9B1. The general problem of aviation gunnery

Because aircraft speeds are high and constantly tend to become higher, actual firing time in any attack is limited to seconds. For this reason it is essential that rate of fire be rapid, so that there is reasonable probability of scoring enough hits to do effective damage. High projectile velocity is also desirable, to reduce time of flight and thereby minimize the effect of many variables which tend to detract from accuracy. It must also be remembered that performance of the airplane itself is a factor in the effective employment of the plane's guns.

Recognition of targets is one of the most critical items in air combat, because it is the key to making initial estimates of range, speed, and mission. A common error in aerial gunnery is to open fire before the target comes within range, and to continue fire when the target is beyond effective range.

In fact, the general problems of aircraft gunnery can be reduced to questions of *who, where,* and *when.* "Who" refers to the problem of whether a potential target is friend or foe, and if foe, what the type of plane may be. "Where" is the problem of target location relative to the gun, which in modern installations may be solved or largely solved by automatic means. "When" is the problem of when to open and cease fire to provide maximum probability of obtaining hits, yet maintain necessary conservation of a limited ammunition supply.

9B2. Types of aircraft guns and installations

Aircraft guns incorporate certain modifications of conventional gun structures to reduce weight and length, and generally to make them adaptable to aircraft installation. Guns as small as caliber .30 machine guns, and as large as 75-mm guns, have been installed in military planes. The aviation gun in current Navy use is the 20-mm automatic gun, but the caliber .50 machine gun was the one most extensively used in Navy planes throughout World War II. However, the latter weapon seems destined to have little potential significance in future aircraft installations.

Aircraft guns may be installed on either *fixed* or *free* mounts. Fixed guns are rigidly attached in the forward part of the plane, including leading wing edges, and may be trained or elevated only by maneuvering the plane. They are, of course, forward-firing guns. Free mounts, on the other hand, provide for train and elevation in limited arcs.

The British first used airplane *turrets* mounting

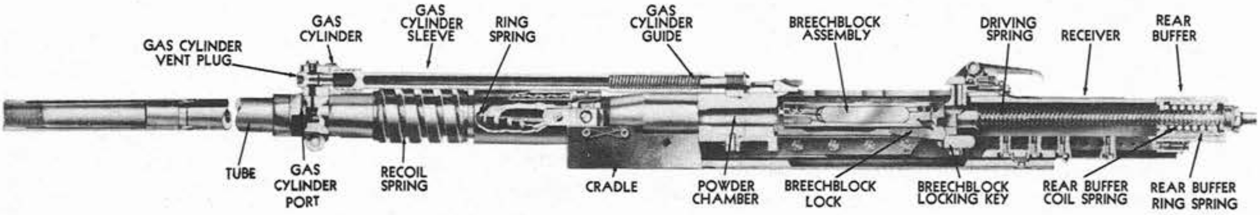

FIGURE 9B1.—20-mm Automatic Gun M3.

flexible guns in battle during World War II. The modern aircraft turret is a self-contained mechanized unit, consisting of an enclosure housing the gunner, guns, ammunition, power drives in train and elevation, armor plate, and other accessories. Such an installation provides many advantages: the angle of fire is increased; movement of guns in elevation and train against the force of the slipstream is facilitated; larger guns can be utilized more readily; the gunner is protected; and, in general, a more adequate defense can be realized in the case of larger, slower aircraft. In addition, a fire control system may be installed to provide local and remote control.

9B3. Development of the 20-mm Gun M3

During the interim between World War I and World War II, both the Germans and the Japanese developed 20-mm guns for aircraft installation, and during World War II the Germans installed as many as six of these guns in some planes. Our own development of a 20-mm gun was initiated in 1937, and speeded up when the European conflict began.

Since its inception this gun has undergone two major changes, each incorporating some improvement in design and operating characteristics. The end product of this technological advance is the 20-mm Aircraft Gun M3. Figures 9B1 and 9B2 show this gun.

9B4. General description

The 20-mm Aircraft Automatic Gun M3 is an air-cooled weapon weighing approximately 100 pounds, and is capable of firing up to 800 rounds of ammunition per minute at an initial velocity of 2,730 feet per second.

Operating with the gun is a feed mechanism mounted on top of the gun proper. Rounds of ammunition are fed into the gun from a disintegrating link belt. A charger retracts the breechblock initially and cocks the gun, or can remove a round from the chamber. Firing is done by an electric trigger, which fires the 20-mm Automatic Gun M3 by remote control. Each of these units will be discussed below.

9B5. Principles of functioning

Power to keep the gun operating automatically comes from the energy released each time a round is fired. This energy is utilized in three ways:

1. When the round is fired, some of the ammunition propellent gas goes through a small hole drilled in the gun barrel to act on the gun components and unlock the breech block. This is called *gas operation.*

2. The expanding gas remaining in the gun barrel pushes the breech locking and closing components to the rear. This is called *blowback.*

3. Firing the gun causes some of the gun components to *recoil.* The energy of recoil compresses springs of some of the gun components. The expansion of these springs causes these components to counterrecoil and return the gun to battery. Recoil and counterrecoil activate the feed mechanism which supplies ammunition to the gun.

Since the 20-mm M3 gun utilizes all these sources of power, it is classified as a combination gas-operated, blowback, and recoil weapon.

The functioning of the main parts of the gun in the entire automatic action is described under the following heads:

1. Recoil mechanism.
2. Receiver.

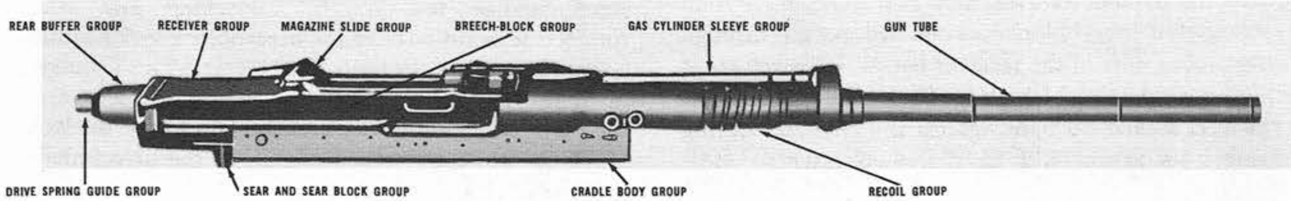

FIGURE 9B2.—Subassemblies of the 20-mm Automatic Gun M3.

3. Breechblock.
4. Driving-spring assembly.
5. Gas mechanism.

9B6. Recoil mechanism

The function of the recoil mechanism is to cushion the impact of recoil and return the gun to battery.

The recoil mechanism consists of a recoil spring and a recoil housing assembly.

Recoil spring. The recoil spring is a heavy, flat, helical (or coil) spring which surrounds a portion of the gun barrel slightly forward of the chamber. The front end of the recoil spring seats against a bracket which is directly attached to the gun barrel and recoils with it. The after end of the recoil spring rests against the recoil housing assembly, a nonrecoiling part.

Recoil housing assembly. The recoil housing assembly consists of two main parts: a hollow tube, or sleeve, and a separate spring called the ring spring, which fits inside the sleeve. The sleeve is a cylindrical steel tube that surrounds the gun barrel abaft the recoil spring. It is secured to the stationary mounting assembly of the gun and does not recoil.

As the gun recoils, the gun barrel moves rearward, attempting to carry the recoil spring with it. The recoil spring bears against the ring spring inside the sleeve of the recoil housing assembly. The stationary sleeve forces both springs to compress, stopping the recoil movement. Recovery of the springs initiates counterrecoil and returns the gun to the battery position.

9B7. Receiver

The receiver is the component of the gun assembly that mounts the barrel and houses the breechblock and driving-spring assembly. It consists of three main components: the receiver body, the breechblock-locking key, and the receiver slides.

Receiver body. The receiver body is a hollow rectangle, partially open at the top and bottom and fully open at the rear. A large opening in the front end of the receiver body is threaded to receive the gun barrel. Since the gun barrel is directly attached to the receiver, the receiver is a recoiling part.

Breechblock-locking key. In approximately the midpoint of the receiver, near the bottom, a solid rectangular breechblock-locking key passes through slots on the sides of the receiver body. This key keeps the breechblock, which slides back and forth in the receiver, locked up tight against the chamber during firing. Its action will be described later in more detail.

Receiver slides. The two receiver slides are metal strips bolted inside the front of the receiver body, one on each side. They support the breechblock when it is in the front of the receiver body, and aid in locking the breechblock in firing position. Cam surfaces at the rear of the slides engage corresponding cam surfaces on the breechblock lock (a hinged arm) of the breechblock mechanism as it moves forward in the receiver. The resulting action forces the lock downward into a notch in the breechblock-locking key and locks the breechblock in firing position.

9B8. Breechblock

The breechblock moves forward and backward inside the receiver body. On the forward movement it takes the ammunition cartridge from the mouth of the feed mechanism, carries it into the chamber, and fires the round. On its return stroke, the breechblock carries the empty cartridge case to the ejector. Figure 9B3 is a sectional view of the breechblock.

The breechblock consists of the bolt, the breechblock lock, two breechblock slides, a firing pin, and an extractor. See figure 9B3.

Bolt. The bolt is the main component of the breechblock. It helps carry the cartridge to the gun-barrel chamber and closes the breech end of the barrel. It also houses the firing pin and supports the breechblock slides, the extractor, and the breechblock lock.

The firing pin and driving spring are inside the longitudinal tunnel of the bolt. The tip of the firing pin protrudes through a small tapered hole in the front of the bolt. The bolt's front face is recessed to accommodate the base of the cartridge case.

Flanges along the lower edges of the bolt guide the breechblock slides. The bottom of the bolt is recessed at the rear to receive the breechblock lock, and at the front to accommodate the extractor. The extractor is attached to the bolt by the extractor pin and a cylindrical strut-type spring which forces the forward end of the extractor toward the face of the bolt.

Breechblock lock. The breechblock lock seats on the breechblock-locking key. It locks the breechblock in battery while the round is fired.

The breechblock lock is a flat plate with cams projecting from each side of its top surface. When the breechblock moves forward, these cams engage the receiver slides and force the breechblock lock downward against the breechblock-locking key. The rounded forward edge of the breechblock lock fits into a mating recess in the breechblock bolt. This arrangement provides a hinge action between the lock and the bolt. The protruding shoulders on top of the lock move up into the notched section of the breechblock slides when the slides are retracted.

Breechblock slides. Two breechblock slides serve

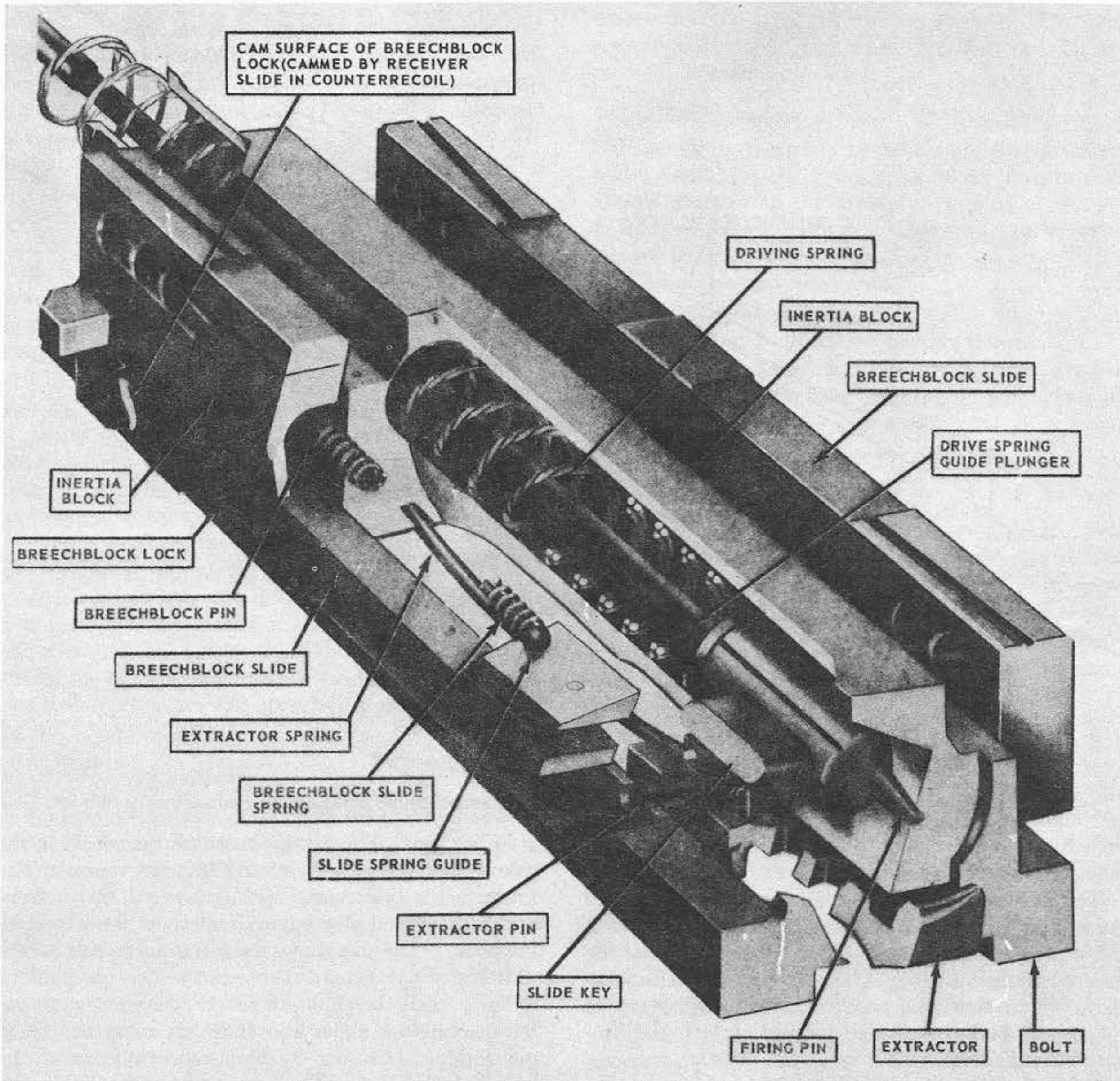

FIGURE 9B3.—20-mm Automatic Gun M3. Breechblock, cut-away view.

to guide and support the bolt in the receiver. These slides are shorter than the bolt, and slide forward and backward on the flanges along the lower edge of the bolt.

The 2 slides, 1 on each side of the bolt, are keyed together by the slide key, a flat, rectangular piece of metal with rounded edges, which extends through a slot in the bolt. This slot is elongated to allow the slide key to move forward and backward during the locking and unlocking action of the breechblock. The slide key also mates with a recess in the firing pin, so that the breechblock slides and firing pin operate together.

The bottom edges, near the rear of the breechblock slides, have notched recesses cut in them to accommodate the raised shoulders of the breechblock lock when the breechblock is unlocked. It will be remembered that the breechblock lock, hinged to the bolt, is cammed down by the receiver slides and engages with the breechblock-locking key as the breechblock moves forward just prior to firing. At this time the breechblock is in its full forward position in the receiver, and the

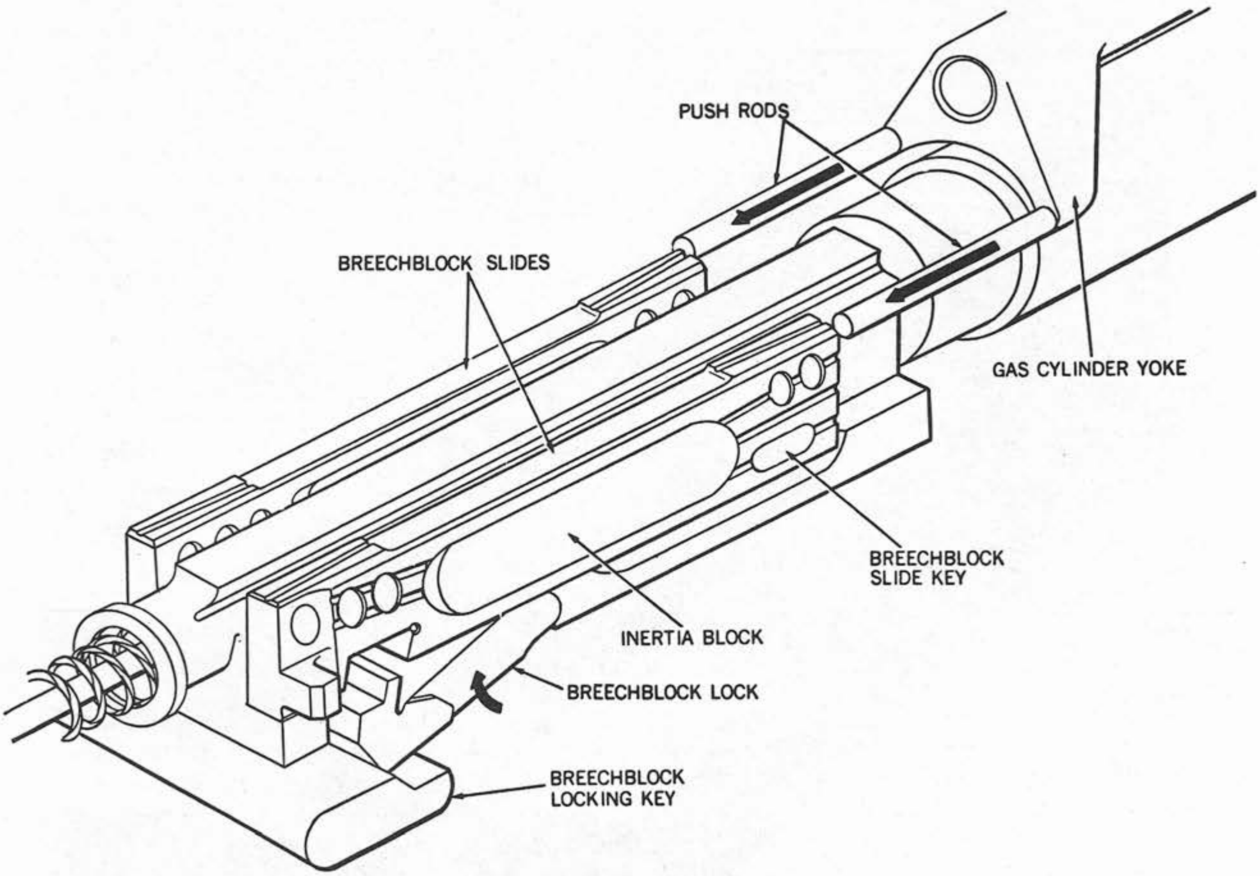

FIGURE 9B4.—20-mm Automatic Gun M3. Breech unlocking action; slides being forced rearward by push rods.

breech end of the gun barrel is closed and locked. This is the firing position.

The breechblock lock cannot move back up into the notched recesses in the breechblock slides, because the slides continue to travel forward slightly after the lock is cammed down. The rear ends of the breechblock slides, abaft the notched recess, rest on top of the raised shoulders of the breechblock lock and prevent it from rising.

When the breechblock is unlocked by the gas mechanism after firing, the breechblock slides are pushed backward by push rods, which also compress springs inside the slides. See figure 9B4. The forward inner notched surface of the slides catches the raised shoulders of the breechblock lock and forces it up and free from the breechblock-locking key. The breechblock lock moves back up into the recess in the slides and prevents the slides from moving with respect to the bolt. The slides, however, have stored energy in the compressed springs located inside them. When the breechblock lock is cammed down, freeing the slides to move, the springs expand and push the slides forward.

Firing pin. The firing pin strikes the round in the chamber of the gun barrel and fires the round. The firing pin is cylindrical, with a tapered tip in front and a machined slot approximately in the center of the body. The slot allows the firing pin to ride on the slide key which extends between the two breechblock slides. As the breechblock moves to battery position, the breechblock slides and slide key carry the firing pin forward, causing its tip to protrude from the breechblock bolt and fire the round. After firing, the breechblock slides and slide key move rearward and retract the firing pin.

Extractor. The extractor grips the round as it enters the chamber, holds the round during firing, and draws the empty case rearward as the breechblock is blown back by the expanding gases after firing. Ejector prongs fastened to a nonrecoiling part of the gun assembly strike the top of the cartridge case as it moves rearward. The extractor and empty case are pivoted downward, and the case drops through a hole in the bottom of the receiver and out of the gun. The extractor spring forces the extractor upward to the position where it grips the next round.

9B9. Driving-spring assembly

When initial recoil movement begins, the barrel, receiver, and breechblock all move rearward together. Shortly after recoil begins, however, the breechblock is unlocked from the receiver. The expanding gases in the chamber, acting against the face of the breechblock, blow it back faster than the receiver and barrel are recoiling. The recoil mechanism, discussed earlier, absorbs the force of recoil and initiates counterrecoil.

The receiver will not carry the breechblock forward with it in counterrecoil, since the two are not locked together as at the moment of firing. It is the function of the driving-spring assembly to make the breechblock counterrecoil and return to battery position.

The main parts of the driving-spring assembly are the driving-spring plunger and the driving spring.

Driving-spring plunger. The forward end of the driving-spring plunger is attached to the base of the firing pin. The after end is attached to the rearmost component of the gun assembly, the rear buffer, which in turn is attached to the rear of the receiver. The plunger telescopes as the breechblock is blown back.

Driving spring. The driving spring surrounds the plunger and is compressed as the breechblock moves to the rear. It is the recovery of the driving spring that drives the breechblock forward to strip a round out of the feed mechanism and chamber it ready to be fired by the firing pin.

9B10. Gas mechanism

The gas mechanism unlocks the breechblock and retracts the firing pin when the gun has fired. The gas mechanism consists of a cylinder which mounts on top of the gun, covering a small hole drilled in the top of the barrel; a piston and rod which move rearward in the cylinder against spring pressure; and two push rods which are forced rearward by an extension of the piston rod, called the yoke (fig. 9B4).

As the gun is fired, the projectile moves forward, uncovering the small hole, or port, in the top of the barrel. Some of the expanding propellent gas escapes through the port into the cylinder, where it exerts pressure on a piston and rod, forcing the rod rearward against spring pressure. The yoke on the piston rod pushes the two push rods, which are free to move back and forth in longitudinal holes drilled in the front of the receiver body. In turn, the two push rods, when forced rearward by the yoke, force the breechblock slides back, retracting the firing pin and unlocking the breechblock.

The propellent gases, still inside the barrel, force the breechblock rapidly to the rear. (This is blowback.) As the gas pressure lessens in the gun barrel and the gas cylinder, spring pressure in the cylinder gradually forces the piston rod and yoke forward to the position where they are ready for another cycle. The push rods slide forward freely when struck by the counter-recoiling breechblock slides.

9B11. Cyclic action

In an automatic gun like the 20-mm Aircraft Automatic Gun M3, the firing of a round furnishes the energy to carry on the cyclic functioning of the gun to fire succeeding rounds. The sequence of cyclic actions is:

1. Gun fires and recoils.
2. Breechblock unlocks.
3. Breech opens and fired case is ejected.
4. Gun counterrecoils and driving spring drives breechblock forward (picking up a new round).
5. Breechblock locks.
6. Gun fires and recoils.

9B12. Gun fires and recoils

When the round is fired, the gun barrel, receiver, and breechblock recoil. The gun barrel carries rearward the recoil spring which surrounds it. The recoil spring contacts the ring spring inside the stationary sleeve of the recoil housing assembly, compressing both springs and stopping recoil movement.

9B13. Breechblock unlocks

At the moment of firing, the breechblock is held against the breech of the gun barrel by the breechblock lock resting against the breechblock-locking key. The breechblock lock slides prevent the breechblock lock from disengaging until after firing.

The action of the gas mechanism unlocks the breech as shown in figure 9B4. Propellent gases enter the gas cylinder through the small hole in the gun barrel. Gas pressure forces the piston rod and yoke aft. The yoke, through the two push rods, forces the breechblock slides rearward. The breechblock slides are connected by the breechblock-slide key, which actuates the firing pin. The firing pin is notched to fit over the breechblock-slide key. Therefore, as the breechblock slides move rearward, the breechblock-slide key retracts the firing pin. The notched sections at the rear of the breechblock slides engage the protruding shoulders of the breechblock lock, forcing the lock clear of the breechblock-locking key, and unlocking the breechblock.

9B14. Breech opens and fired case is ejected

After unlocking, blowback starts the breechblock to the rear. As gas pressure in the gun barrel drops, spring action in the gas cylinder returns the gas mechanism components to their original position. The breechblock and extractor move backward until the

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tip of the fired case strikes the stationary ejector prongs, pivoting the empty case out of a hole in the bottom of the receiver and out of the gun.

9B15. Gun counterrecoils and driving spring drives breechblock forward

The recoil spring and ring spring, which were compressed during recoil, now expand and start the receiver and gun barrel forward in counterrecoil.

The breechblock, when it was blown back in the receiver, compressed the driving spring in the bolt. Recovery of the driving spring sends the breechblock forward toward firing position, where it picks up a new round of ammunition from the feed mechanism.

9B16. Breechblock locks

As the breechblock moves forward in the receiver, projecting cams on the breechblock lock engage camming surfaces on the receiver slides, forcing the lock to rotate downward. The breechblock lock seats against the breechblock-locking key in the receiver, and is held by the rear lower surface of the breechblock slides. Simultaneously, the breechblock bolt reaches the end of its forward motion and chambers the cartridge. The slide springs, combined with the momentum of the driving spring, cause the breechblock slides and breechblocks slide key to continue forward after the bolt has stopped.

9B17. Gun fires and recoils

The firing pin is carried forward by the breechblock-slide key, and by the expanding driving spring. The firing pin strikes the cartridge primer and fires the round. This cycle repeats until the trigger is released or the ammunition is expended.

9B18. Feed mechanism

The feed mechanism used with the 20-mm Aircraft Automatic Gun M3 is designated the AN–M2 feed mechanism. It is designed to feed up to 800 rounds of ammunition per minute into the gun. The linear movement of gun components in recoil and counterrecoil is transformed to rotary motion by mechanical means in the feed mechanism. This rotary motion winds coil springs which drive a set of starwheels. The starwheels are 9-toothed sprockets contoured to fit between the cartridge cases in the ammunition belt. As the starwheel housing rotates, the two starwheels engage the incoming rounds, drawing them into the feed mechanism. Once inside, stripper cams strip off the detachable links which hold the rounds together in belts. The cartridge is then aligned with the mouth of the feed mechanism. The extractor grips it and rams it into the gun chamber.

9B19. Charger

A charger is used to retract the breechblock and cock the gun, or to remove a round from the chamber. A lug on the breechblock slide extends through a long slot in the receiver. This lug is engaged by the charger, which draws the entire breechblock assembly to the rear until it reaches the cocked position. The breechblock is held in this position by the trigger mechanism. Charges may be either manually, hydraulically, or pneumatically operated.

9B20. Electric trigger

The trigger in the pilot's compartment and the mechanism which actuates firing at the gun are connected electrically. The mechanism that holds the breechblock in the rear of the receiver and prevents firing is the sear. The sear mechanism is fastened to the underside of the receiver. The sear itself is a hooked arm which engages with a recess in the bottom of the breechblock lock, preventing it from moving forward. The other main part of the sear mechanism is a solenoid assembly. Pressing the trigger causes the solenoid assembly to draw the sear out of the path of the breechblock. When the circuit is opened, a spring forces the sear upward again, where it engages the breechblock lock.

C. 40-mm Guns and Mounts

9C1. General

The 40-mm gun is a recoil-operated, heavy machine gun designed primarily for AA fire. Its distinctive features include (1) a vertical sliding-wedge *breech mechanism,* (2) a hand-fed *automatic loader,* (3) a spring-operated *rammer,* and (4) a *trigger mechanism* that controls the rammer operation only.

Once put in operation and the ramming cycle started, this gun loads and fires without further attention. It can be operated in either fully automatic or single fire. The maximum cyclic rate of automatic fire is about 160 rounds per minute.

For naval use, these guns are usually water-cooled and assembled in pairs, 1 pair making up a twin mount, 2 pairs a quad mount. The individual gun mechanisms are alike except for the changes necessary to make them right and left guns. Both twin and quad mounts are used on destroyer escorts, destroyers, and many classes of larger naval ships. Air-cooled single guns are used on some small craft.

The conventional mounts for twins and quads have

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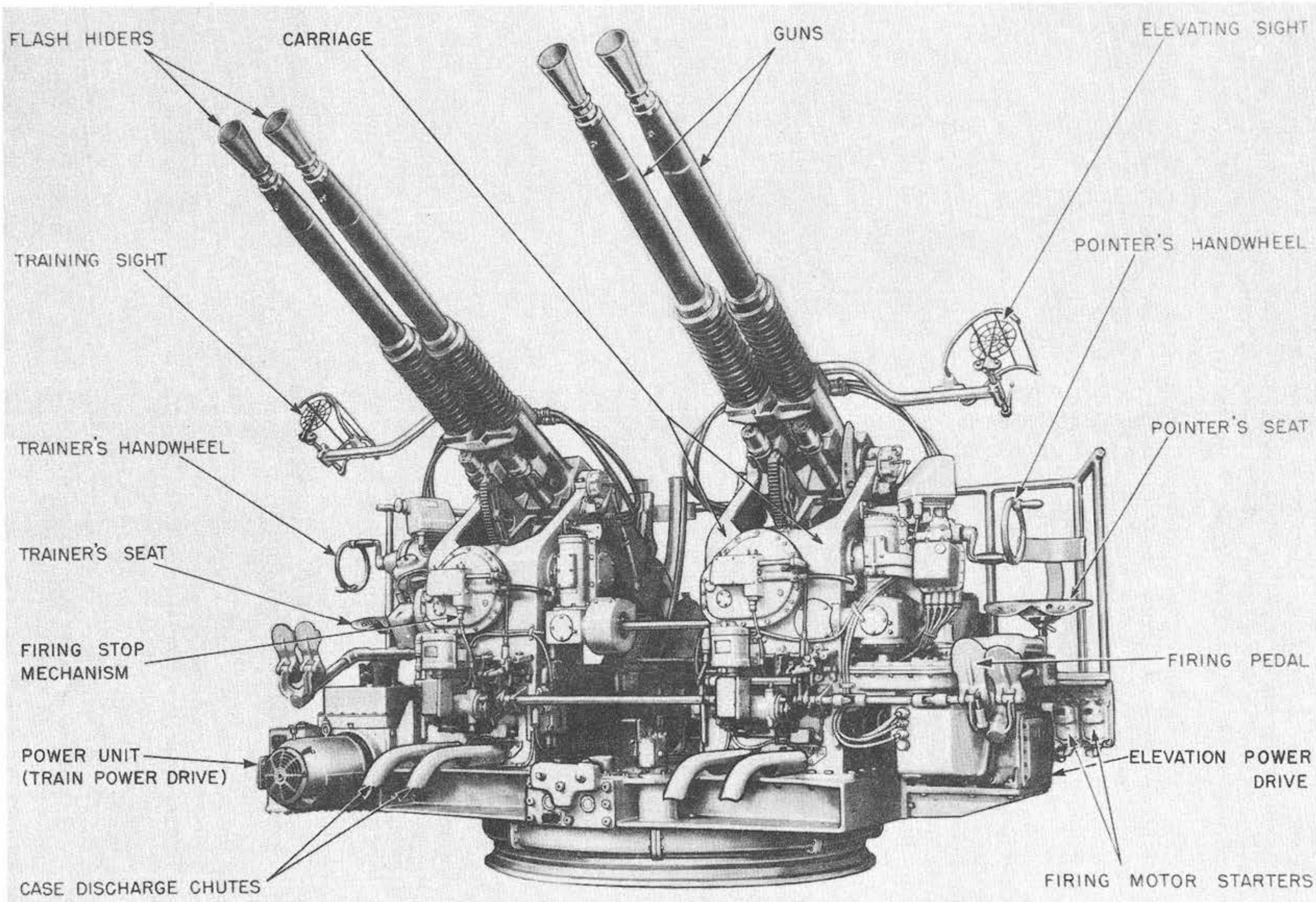

FIGURE 9C1.—40-mm quad mount assembly.

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power-operated elevating and training gear to position the guns as a unit. Power drives may be controlled at the mount by the pointer and trainer, or from the director through an electrical control system. The mounts can also be trained and the guns elevated manually by handwheels.

Ammunition is of the fixed type, loaded into clips containing four rounds each. The usual AA projectile is provided with a tracer and a nose-type impact fuze armed by the rotation of the projectile in flight. A complete round weighs about 5 pounds, the projectile about 2. The tracer is effective for from 7½ to 8 seconds, after which it destroys the projectile by detonating the burster charge. Non-self-destructive AA and AP projectiles are also available. The service charge produces an initial velocity of about 2,800 feet per second. The maximum horizontal range obtained before self-destructive action, is about 5,000 yards; without self-destructive action, the range is increased to about 11,000 yards.

See figure 9C1 for the general arrangement of 40-mm quad assemblies.

The gun mechanism consists of the following five major components:

1. *Barrel assembly.* This consists of the gun barrel, its water jacket, the recoil spring, and the flash hider. The barrel is a single-piece forging 56 calibers long. It is rifled with 16 grooves having a right-hand increasing twist of 1 turn in 45 calibers at the origin to 1 turn in 30 calibers at the muzzle. The barrel passes through the cylindrical fore part of the slide and is attached to the housing within by means of a bayonet-type joint.

2. *Slide. assembly.* This has a box-shaped rear section and a cylindrical forward section, which serve to support and provide working surfaces for the other parts of the gun mechanism.

3. *Breech-mechanism assembly.* This consists of a housing assembly, a breechblock assembly, and associated operating parts. It is a recoiling part of the gun mechanism.

4. *Loader assembly.* The loader feeds cartridges to the rammer tray and catapults them into the firing chamber. The main operating parts are the loader, rammer tray, and rammer.

5. *Recoil-counterrecoil system.* Each gun has its own recoil-counterrecoil assembly, which consists of a recoil spring fitted over the after end of the barrel assembly and a hydraulic recoil unit secured to the under-side of the slide, with the piston rod attached to the housing. The spring is compressed during recoil and returns the gun to battery as the recoil piston moves back and forth in the hydraulic cylinder. At the same time a fluid mixture of glycerin and water is forced through a series of orifices. Both recoil braking and counterrecoil buffing are accomplished in this single cylinder unit. A needle valve adjusts orifice size, and its setting determines the time required for counterrecoil. The length of recoil is governed by the quantity, specific gravity, and temperature of the recoil fluid, and to a slight extent by the elevation of the gun. The setting of the needle valve in the recoil cylinder has no appreciable effect on the length of recoil, but does control the velocity of counterrecoil and, as a result, the rate of fire.

9C2. Mount

The 40-mm twin and quad gun assemblies have open base-ring mounts. The training circle is secured to the stand, and the carriage is supported on radial and thrust roller bearings. A platform on the after end of the carriage is used by the loaders when the gun is in operation. The cooling-system tanks and electrically driven circulating pumps are mounted on the after end of the platform. The firing mechanism is mounted on the forward face of the carriage. The slide trunnions are supported on roller bearings.

Individual power drives, electric-hydraulic or amplidyne, are used for the elevating and training gear. See chapter 10. With late models of twin mounts and with all quads, in local power control the pointer controls both train and elevation. With the electric-hydraulic system, he uses a single control lever or "joy stick"; with the amplidyne system as installed on quad mounts, he uses a pair of handles on a control box. For manual control, the pointer's and trainer's handwheels are geared directly to the elevating and training racks.

The mount can be trained 360° in either direction from the locked position. A training stop is provided to prevent training beyond these limits. A power-drive cut-off switch operates, when the limit is approached, to shut off the driving motor. The elevation limits, unless restricted for specific shipboard installations, are 15° depression and 90° elevation. Elevation and train centering pins lock the gun and mount in place when the gun is secured.

Open peep and ring sights are provided for the pointer and trainer. On some mounts, especially singles, lead-computing sights are also provided; but the normal method of control is by director.

9C3. Personnel

The basic gun crew for the twin or quad mount includes the following: a mount captain, a pointer, a trainer, 1 loader for each gun, and at least 1 ammunition passer for each gun. More handlers will be needed if the ready ammunition is stored at some distance from the mount.

The mount captain is in charge of the gun and crew. In local control, he designates targets and gives orders for firing. In addition to his regular duty of training the mount, the trainer releases the train centering pin and starts the circulating pumps in the cooling system. The pointer releases the elevation centering pin, starts the firing motor, elevates the gun with the handwheels, and operates the foot firing pedal. (Joy-stick control in both elevation and train may be given to the pointer when desirable.) The loaders set the firing-selector lever at the desired position (STOP FIRE, AUTO, or SINGLE), operate the hand operating lever, and place the ammunition in the loader. The ammunition passers bring the clipped cartridges from the ready stowage or magazines and hand them to the loaders on the gun platform.

D. 3″/50 Rapid-Fire Guns and Mounts

9D1. General

The 3″/50 rapid-fire guns are semiautomatic guns with automatic power-driven loaders, installed in dual-purpose open twin or single mounts. They are weapons primarily intended for defense against aircraft, but are so equipped that they may 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. The 40-mm mount, the best rapid-fire gun at that time, was often making hits that were not stopping suicide planes or dive bombers short of their targets. The 3″/50 mount was not completed in time to be used in combat in World War II, but it has proved itself in practice firings to be very effective.

This mount is now replacing 40-mm on all types of combat ships. The twin mount shown in figure 9D1 is dimensionally interchangeable with the 40-mm quad mount. The single 3″/50 rapid-fire mount, which is similar in most respects to the twin, is designed to be substituted for the 40-mm twin mount.

The barrel of the 3″/50 is a one-piece, rifled, chambered tube, with its breech end locked to the housing by a bayonet-type joint.

The housing contains the breech mechanism and is supported in the slide. The breech mechanism is a vertical sliding-wedge breechblock type with several additional features.

The breechblock has two mechanisms for lowering it against the action of a breech-closing spring. One is a hand-operating lever employed only for initial round loading or for servicing or unloading the gun. The other breech-opening arrangement is an automatic recoil-operated cam-and-lever device.

When the breech is open, two mechanisms function, alternately, to hold the block against the action of the closing spring. One is a stiff-leg type of breech hold-down mechanism which serves as a positive lock, holding the block and locking it until the gun is loaded. It prevents breech closing until it is first released and then displaced from its holding position. The other holding mechanism is similar to that used in the 5″/38 gun, in which the two extractors hold the breechblock down by engaging its pallets. However, their arrangement in the 3″/50 is such that, when they complete their empty-case extracting action, the extractors are poised above the pallets in the lowered breechblock, and function to hold the breechblock down only if the other device fails. This arrangement reduces the effort required to trip the extractors when a rammed round of ammunition engages them.

The gun barrel and housing are supported by the slide. When the gun is fired, they move backward and forward on bearings in the slide. A hydraulic recoil cylinder brakes rearward motion. A large counterrecoil spring drives the gun forward into battery.

The slide, gun, and housing are supported by the carriage. The trunnions, which are integral with the slide, rest in roller bearings at the top of the carriage.

A large elevating arc attached to the bottom of the slide is concentric with the trunnions. It meshes with the elevating pinion of the mount elevation power drive system.

The 3″/50 gun assembly stand is a deck-flange ring-shaped design with dimensions identical to those of the 40-mm stand. It includes the training circle and the stationary roller path. The mount is driven in train by a power motor which drives the training pinion and pulls the gun, slide, and carriage around the training circle on the stand.

General characteristics. The 3″/50 gun has the following general characteristics:

Bore	3-inch
Length	50 calibers
Muzzle velocity	2,700 feet per second
Range, horizontal	13,100 yards
Range, ceiling	27,300 feet
Rate of fire (design)	45 rounds per minute
Ammunition type	fixed, electric primed
Fuze type	VT, PDF, BDF
Weight complete weapon	6,230 pounds

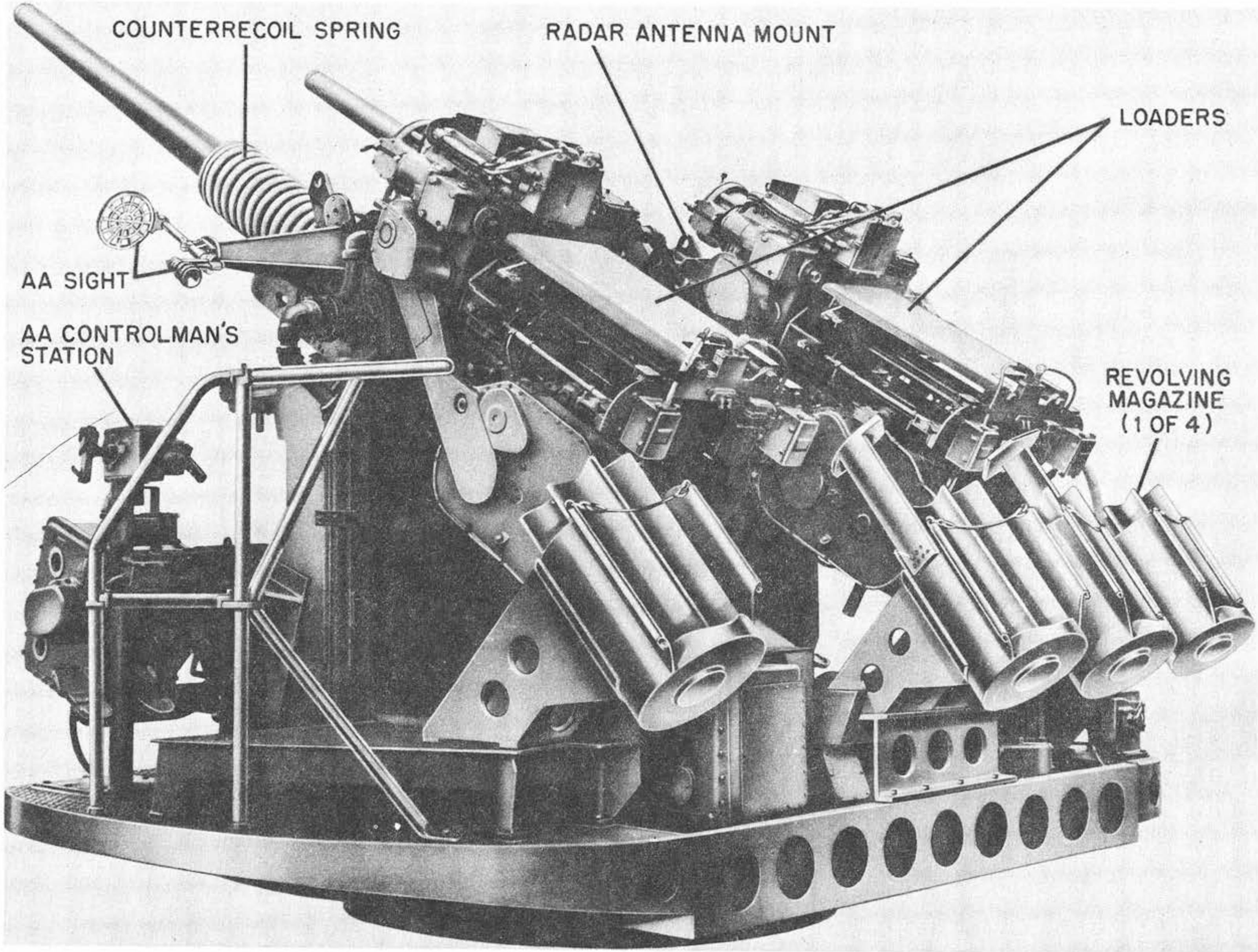

FIGURE 9D1.—3"/50 twin mount with mechanical loader.

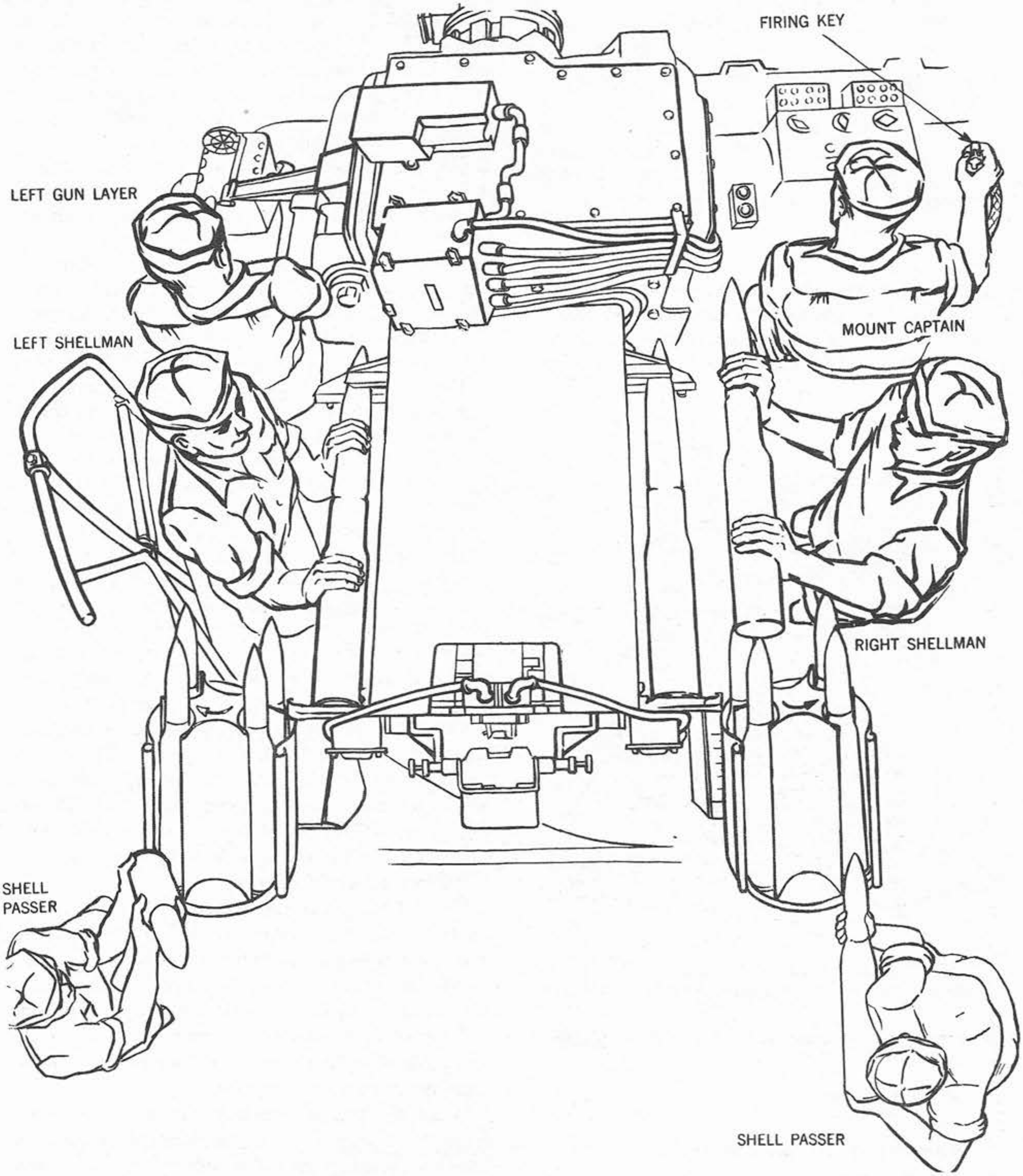

FIGURE 9D2.—3"/50 rapid-fire gun. Ammunition service to loader.

Dimensions, over-all:

Muzzle to rear end	16 feet
Width	38 inches
Height	56.8 inches

In many features of design the 3"/50 rapid-fire gun differs markedly from conventional automatic guns. These differences are chiefly in the automatic loader and the breech mechanism modifications to accommodate the automatic loader. It will be mainly these differences that will be taken up in this chapter.

9D2. Automatic loader

The loader 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, as shown in figure 9D2, and the firing control is operated to fire.

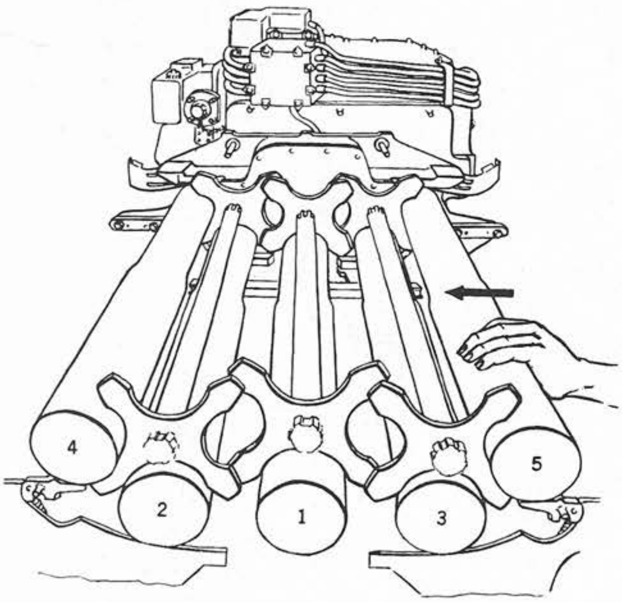

FIGURE 9D3.—3"/50 rapid-fire gun. Sprockets drawing ammunition into the feed mechanism of the automatic loader.

The major loader components that will be discussed are as follows:

1. Loader drive unit.
2. Hopper.
3. Transfer tray and shell carriage.
4. Control system.
5. Left side plate.
6. Right side plate.

The loader drive unit consists of a 3-horsepower motor and various chain and gear drives. Most of the latter are located in the main housing, which is a large, square, box-like structure mounted on top of the gun slide. The drive motor is flange-mounted to the forward face of this housing. The drive motor drives the gearing and chains which in turn cause all the mechanical parts of the loader to function at the proper time and in the proper sequence.

The hopper, into which the ammunition is manually fed by the two shellmen, is located directly abaft the main housing and is secured to the left and right side plates.

The heart of the hopper is the hopper feed mechanism, which consists of right, center, and left shaft-and-sprocket units and right and left round-aligning attachments. The aligning attachments ensure that the ammunition is correctly loaded by the shellmen.

The right and left sprockets revolve intermittently in one direction to move ammunition to the center. The center sprocket revolves in alternate directions to accept rounds from right and left sprockets. After five rounds have been loaded, the first round will be indexed (loaded into the transfer tray for catapulting) by the center sprocket. See figure 9D3.

The transfer tray and shell carriage unit is the loader component that moves each round of ammunition from its index position down into line with the gun bore, and catapults it into the breech chamber. See figure 9D4. The tray is a rectangular box structure with 2 sprockets, 1 in each end of the tray, about which the endless ramming chain is looped.

The tray is supported and positioned by four arms pivoted in the right and left side plates. The two left tray arms, hence the whole tray assembly, are driven by the transfer-tray drive gears mounted in the left side plate. Drive for the rammer chain comes from concentric shafting through the left forward tray arm to the forward chain sprocket.

Secured to the rammer chain on the upper part of the tray is the shell carriage, a small **L**-shaped casting, to support, transport, and release the round on the tray during the ramming cycle. The cycle of operation of the transfer tray assembly begins when an indexed round from the hopper seats in the shell carriage. The four arms then begin to rotate about their pivots, translating the tray downward.

When the tray is almost in line with the breech opening, it begins to swing forward toward the breech. At this point the rammer chain begins moving the shell carriage and round rapidly forward.

When the tray is at its forwardmost point, the carriage is all the way forward, relative to the tray, and is releasing the round, which travels on into the breech

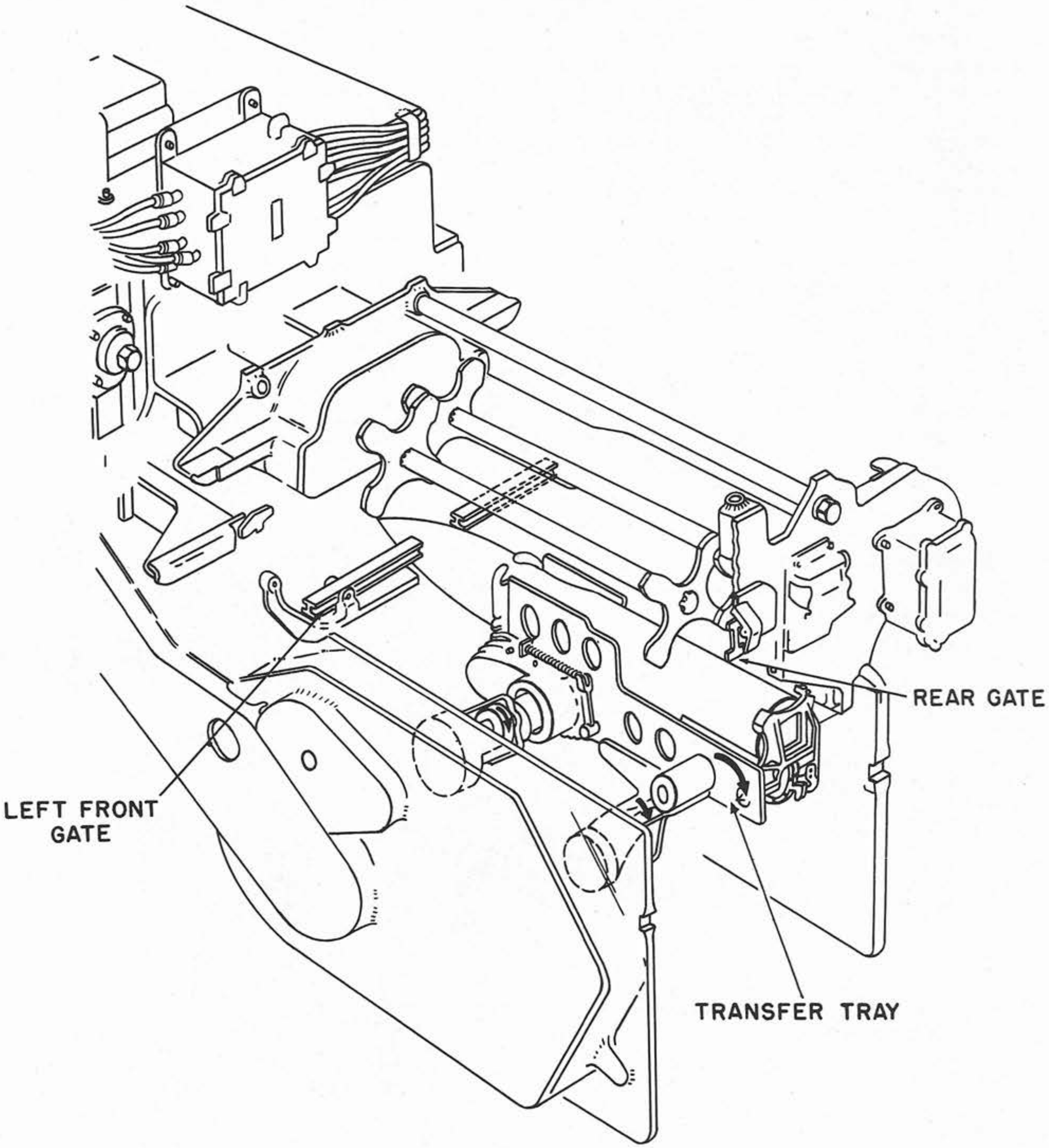

FIGURE 9D4.—3″/50 rapid-fire gun. Tray of automatic loader swinging down into alignment with open breech.

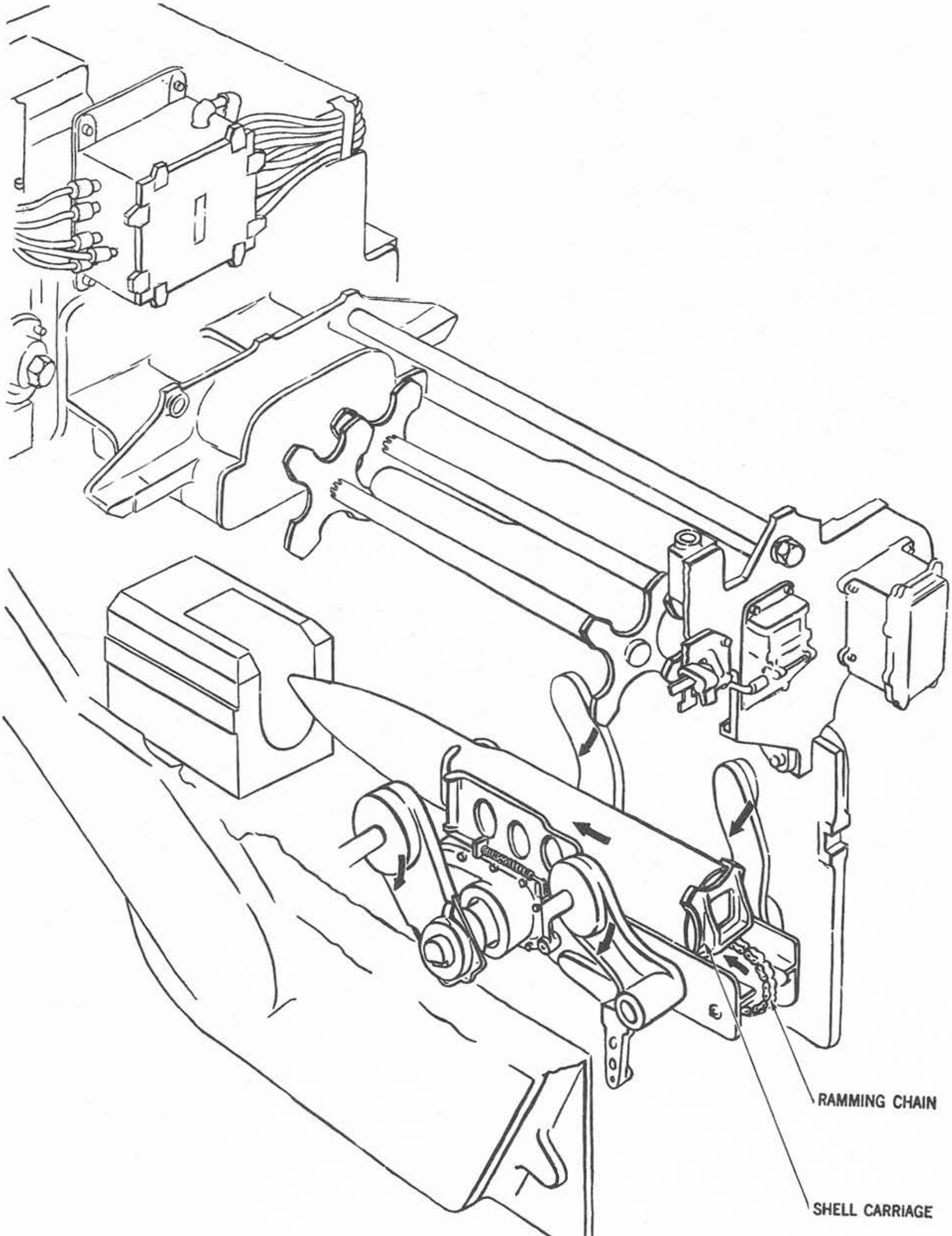

FIGURE 9D5.—3"/50 rapid-fire gun. Shell carriage catapulting cartridge into open breech.

as shown in figure 9D5. The tray then reverses its direction and moves aft and up to pick up another round. During this time the ramming chain moves aft to reposition the shell carriage on the tray.

The right and left side plates of the loader are similar steel forgings—roughly 4 feet long, 2 feet deep, and 6 inches thick—secured to the right and left sides of the gun slide respectively. They support all the loader subassemblies except the drive gear. In addition, each includes many loader operating and control devices and elements of the breech mechanism.

The loader control system synchronizes and interlocks the components of the loader with the breech mechanism and with each other. It consists of electrical circuits, solenoids, selector switches, automatic switches, firing keys, electrical interlocks, and other items. The mount captain's control panel is a combination control and indicator station for the loader control system. (It will be described in more detail in a later paragraph.)

9D3. Breech mechanism

The breechblock is a vertical sliding-wedge type, similar in principle to that of the 5″/38. The breechblock moves as the operating shaft rotates. Much as in the 5″/38 design, in automatic operation the breechblock is lowered and the operating spring is compressed on counterrecoil when the operating-shaft crank is rotated by the operating-shaft cam plate. The breech is closed by the operating spring. A manual breech-opening mechanism is provided. A conventional, 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 is fitted with a firing mechanism, which will be discussed later. Some of the new design features of the breech mechanism are as follows:

1. A breechblock hold-down mechanism holds the breech open until the loader completes delivery of a round.
2. A breech interlock mechanism prevents repetition of the loading cycle until the round has been fired and the breechblock dropped.
3. A shell lock prevents the rebounding of a rammed cartridge.
4. A novel extractor arrangement eliminates resistance to ammunition-ramming action.

9D4. Breech hold-down mechanism

Other guns of similar design usually make use of the extractors to hold the breechblock down until a round is rammed. However, the 3″/50 rapid-fire gun makes use of the breech hold-down mechanism instead. See figure 9D6. The hold-down lever is a vertically positioned lever pivoted near its center. When the gun is in battery and the breechblock is in its held-down position, the hold-down lever bears on the hold-down arm of the breech operating shaft, preventing rotation of the shaft and closing of the breech.

The hold-down latch lever is the positive latch that secures the hold-down lever in place when the latter is holding the block down. The latch lever is disengaged in normal operation by a cam pin on the front right arm of the transfer tray.

The hold-down lever is released from the hold-down arm of the operating shaft in normal automatic loading by movement of the right extractor. When the extractor is carried forward by the rammed ammunition, the extractor push rod is thrust rearward. This actuates the transfer lever, and the thrust is transmitted through another push rod to the hold-down lever, moving it clear of the operating shaft hold-down arm and allowing the block to rise.

9D5. Extractors

The extractors are very similar to those in the 5″/38, except that the inner lugs do not normally bear on the block pallets but are poised above the pallets in a free position. In this free position, the extractors do not impose any appreciable resistance to the ammunition-ramming action, an important factor in rapid automatic loading. While the breech is opened, the extractors are held in their correct position by extractor push rods, which also aid in extracting the empty case. The right extractor push rod is longer than the left and extends through the rear of the breechblock, where it engages the transfer lever for use in the hold-down mechanism as previously described.

In the event of a failure of the breech hold-down mechanism, the breechblock will be held down by the inner lugs bearing on the pallets.

9D6. Shell lock

The breech shell lock (fig. 9D7) functions to prevent a rammed cartridge from rebounding or backing out of the breech to foul the rising breechblock. It is a vertically sliding latch that rides in a slot in the shell-lock carrier on the face of the breech. The latch is moved upward during ramming and allows the round to pass into the bore. It is then moved down by action of the lock spring to trap the seated round. The rising breechblock pushes the shell-lock latch clear. It remains clear after firing until the extractors have moved the lip of the empty case past the shell lock, allowing extraction.

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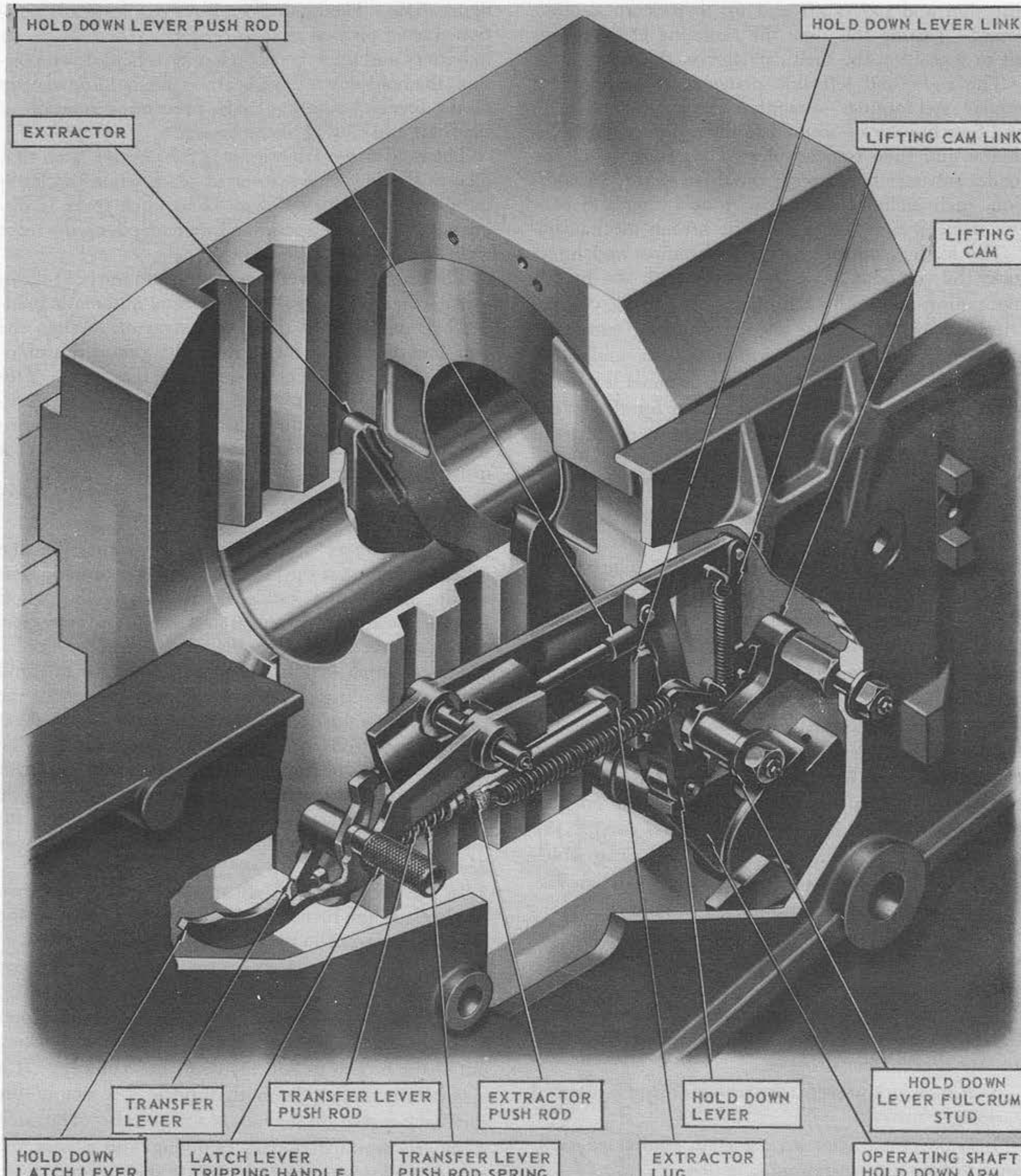

FIGURE 9D6.—3"/50 rapid-fire gun. Breech mechanism. Hold-down mechanism.

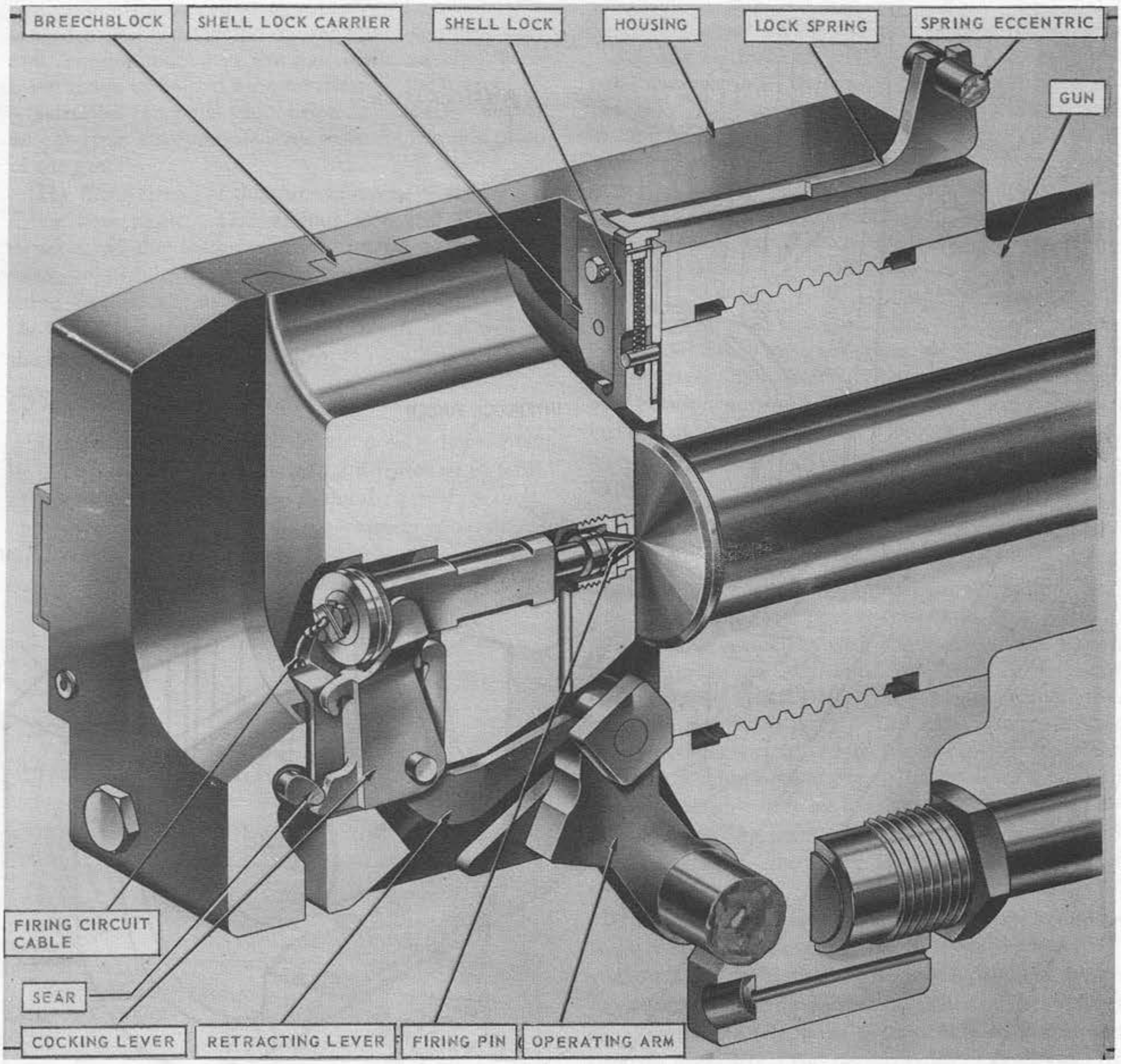

FIGURE 9D7.—3"/50 rapid-fire gun. Breech mechanism.

9D7. Breech interlock

The breech interlock mechanism (fig. 9D8) is a system of mechanical linkages which function 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. The breech interlock latch lever, the first mechanism in the chain of linkages from the breech face to the loader control lever, is pivoted in the shell-lock carrier next to the shell lock and extends down the breech face, partially in front of the breech opening. When either a round is rammed or the block is raised, the latch lever is moved aside, actuating, through linkages, the loader control lever and stopping the loading cycle.

9D8. Firing mechanism

The firing mechanism (fig. 9D7) consists of the following:

1. Breechblock firing-pin insulation.
2. Firing-pin assembly.
3. Firing-pin cocking mechanism and sear.

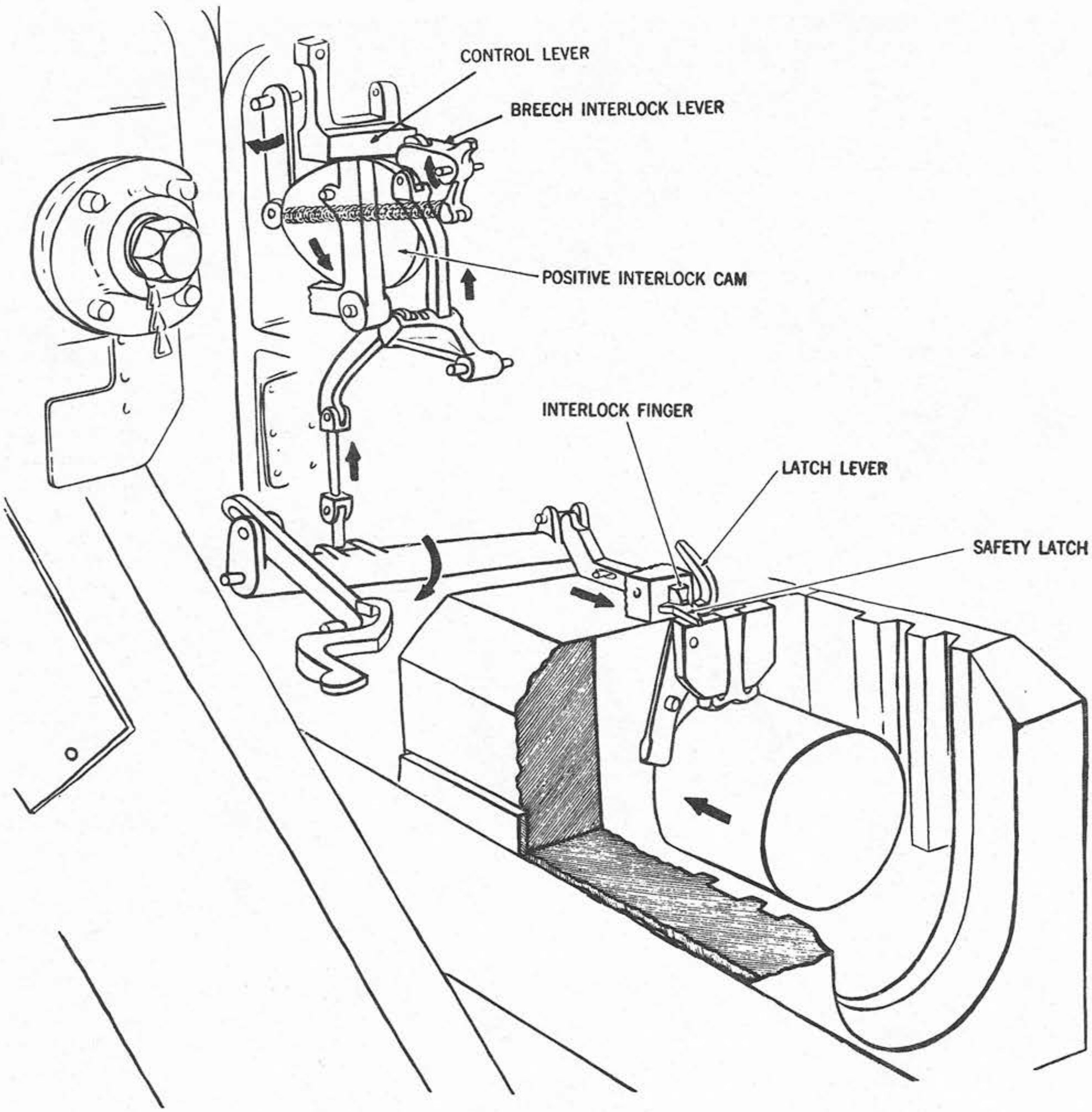

FIGURE 9D8.—3″/50 rapid-fire gun. Functioning of breech interlock.

The firing pin is a steel rod with a conical head that extends through the breechblock. It is similar to the 5″/38 firing pin. It provides an electrical path for electrical firing and hammer action for percussion firing. By action of the cocking mechanism, the firing pin is cocked for percussion firing and positioned for electrical firing with each cycle of the breechblock.

The cocking mechanism consists of the retracting lever and the cocking lever. The retracting lever moves the firing pin aft to keep it from shearing or fouling as the block lowers, and moves it forward into contact with the case electric primer when the block rises. The cocking lever holds the cocking sleeve aft against spring pressure during this up stroke (unless it is released by the sear if percussion-type firing is used).

It should be understood that electrical firing is the normal firing method. Percussion firing, using a spe-

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cial short case with percussion-type primer, is employed for clearing-round action only. This short case is used only if a projectile has separated from the case and remains lodged in the gun while an attempt is being made to unload a round through the breech.

Selection for percussion firing is made by setting an ELECTRIC-PERCUSSION lever near the left side plate of the gun.

The firing circuit of this gun cannot be closed by the firing keys alone. The various electrical interlock switches of the loader control system, such as the TRAY UP switch, must also be closed to energize the firing circuit. Thus any dangerous malfunction of the loading cycle will cause the firing circuit as well as the loader control circuit to open.

9D9. Mount control stations

The mount's amplidyne electric power drives may be controlled in automatic from a director or in local at the mount. There is no manual control as such, only an auxiliary handcrank for securing or servicing the mount. These mounts feature a unique local

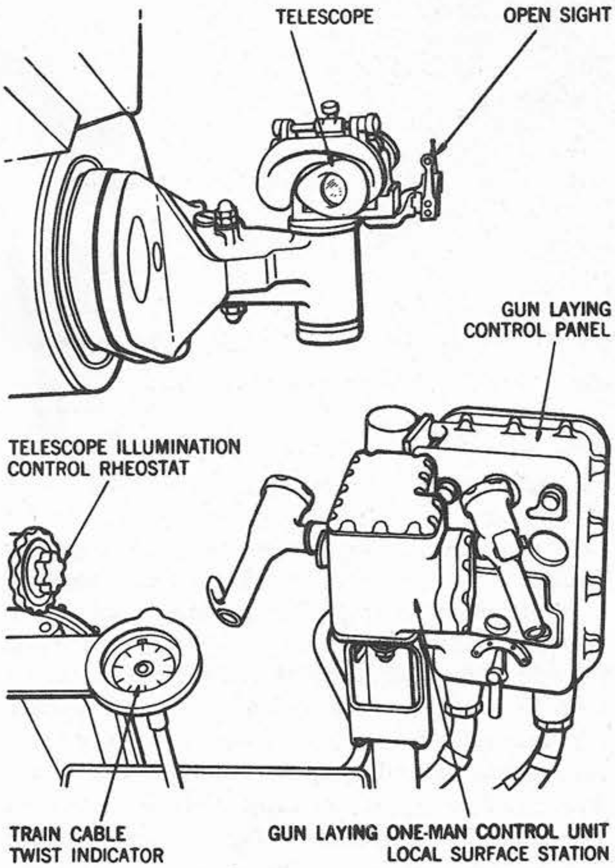

FIGURE 9D9.—3"/50 rapid-fire gun mount. Surface controlman's station.

control arrangement in that there are two types of local control, *local AA* and *local surface*. Each has a separate control station. Local surface is the right gun-laying station (fig. 9D1). Local AA is the left gun-laying station. When the gun-laying drive selection is local AA, the left gun layer controls the mount in both train and elevation, and fires the gun. The left gun layer's controls consist of a ring sight, a one-man gun-laying control unit with gun firing key in right hand grip, a fire cutout indicator, and a gun-laying emergency stop control. There is no sight-setting provision at this station.

The right gun layer is responsible for starting the elevation and train drive, selecting the control station, laying and firing the guns when the drive selection is local surface, and observing correspondence between gun position and gun order signals. The right gun layer's controls consist of a telescope and open sight, a one-man gun-laying control panel, and a train cable-twist indicator (fig. 9D9). The gun-laying control panel, for a twin mount, contains a control-station selector switch, gun-firing cutout lights, power-on lights, correspondence-indicator meters to indicate correspondence between gun and mount position and the order signal, and power START and STOP buttons.

Used in conjunction with the local surface station but requiring an additional operator, is the sight setter's station (fig. 9D10). It is located directly behind the right gun layer. The sight setter operator receives sight-setting orders *via* telephone from the director or other fire control station and sets them into the sight setter's unit by handwheel operation. This action offsets the right gun layer's sight the required amount. The sight setter is used only with local surface gun laying.

The mount captain's station on a twin mount is located between the guns. It is to the right of the gun on a single mount. The mount captain is the supervising gunner and crew captain. His operations are directed *via* telephone by the control officer. He controls and directs the performance of both guns by his use of the mount captain's controls. In emergency he stops the firing of either or both guns. His panel of switches allows him to select the control station, switch to single or automatic fire, and select the gun or guns to fire.

Other elements of his control panel are master push buttons for stopping either one or both of the loaders, power-drive emergency stop buttons, and various illuminating indicators to indicate the occurrence and location of malfunctions. The gun captain's firing key must be closed before the loader's will function. The key has a latch to hold it in closed position when

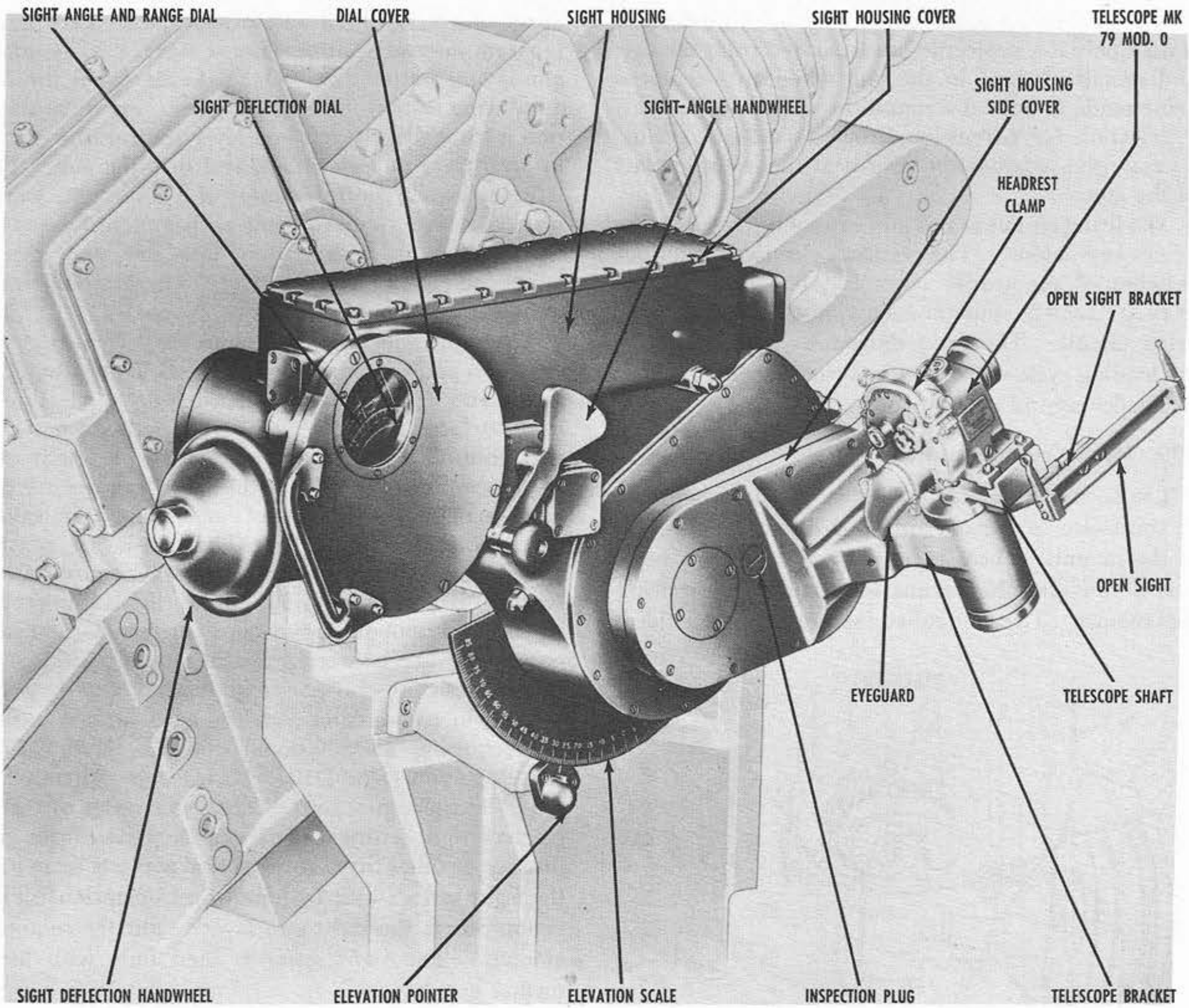

FIGURE 9D10.—3"/50 rapid-fire gun mount. Sight setter's controls and surface controlman's sight.

control of fire is to be at either left or right control station or at the director.

9D10. Ammunition

The 3"/50 gun fires fixed ammunition. A complete round is 34.74 inches long and weighs 24 pounds (the projectile, with fuze, weighs 13 pounds). Since neither the mount installation nor the associated fire control system includes provision for fuze setting, only VT-fuzed projectiles are used in AA fire. Base-fuzed and point-detonating fuzed projectiles for surface fire are also available.

9D11. Personnel

The personnel arrangement of a 3"/50 rapid-fire twin mount is shown in figure 9D11. The normal crew is composed of 11 men, as follows: a mount captain, 2 control-station men, 4 shellmen, and 4 shell passers. (One control-station man controls the mount in local surface, the other in local AA.) An additional crew member, a sight setter, is required in local surface control. The shellmen transfer ammunition from the gun carriage racks to the right and left sides of the hopper of each gun. The shell passers keep the carriage racks, called magazines, supplied with ammunition from a ready-service locker or hand-passing scuttles leading up from the handling rooms. The handling rooms are supplied by dredger hoist from the ship's magazines. The number of passers may vary, depending upon the arrangement of ready-service lockers and passing scuttles.

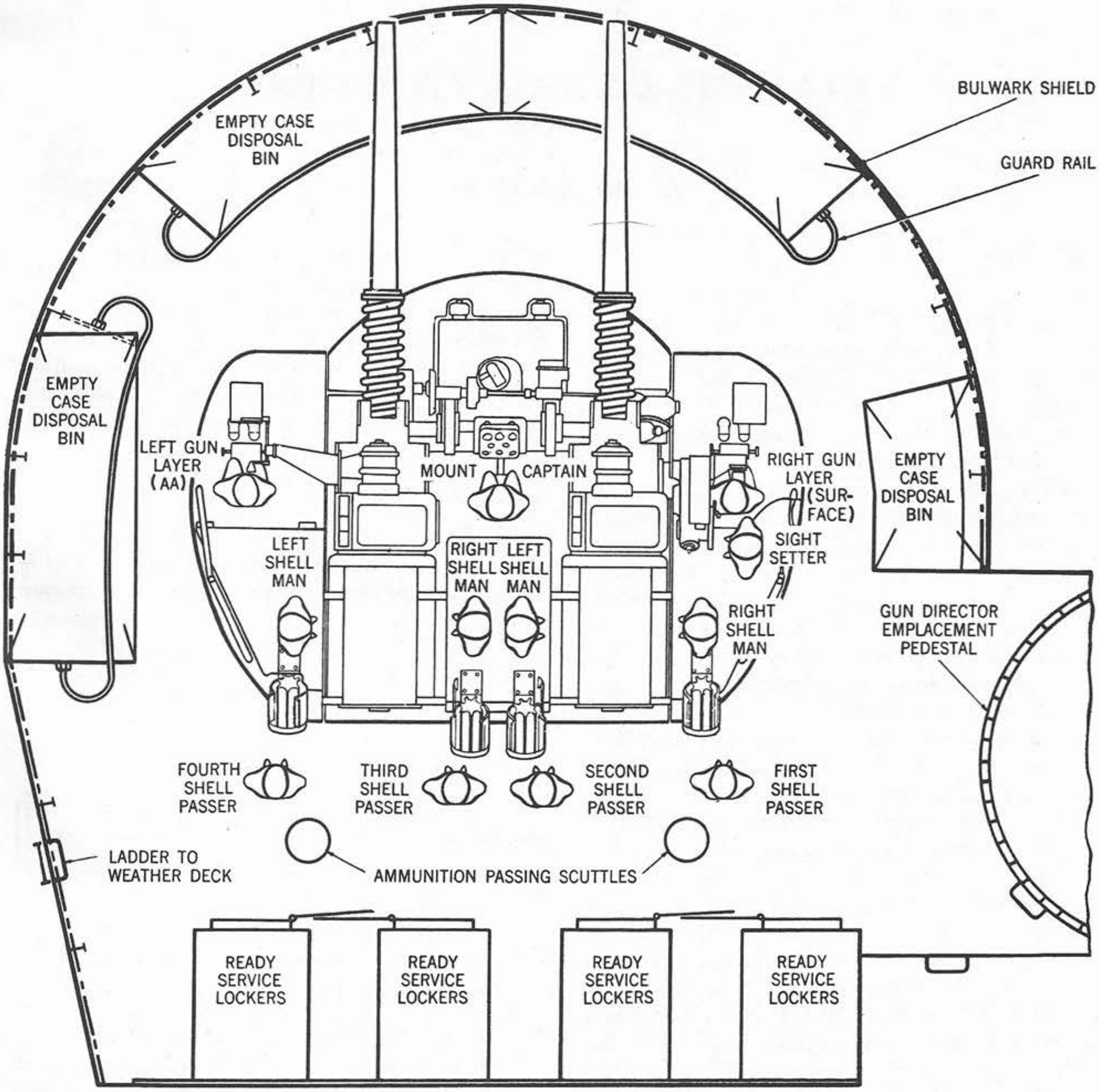

FIGURE 9D11.—3"/50 rapid-fire twin mount. Crew stations.

Chapter 10

AUTOMATIC CONTROL EQUIPMENT

A. Introduction

10A1. General

Automatic control equipment, also referred to as remote-control power-drive equipment, is provided to position the various elements of the battery in correspondence with an electrical order, called the *signal,* received from some other station, generally a computer. The elements commonly using this equipment are turrets, mounts, and directors.

The advantages of automatic control equipment are the speed and accuracy with which guns may be laid and fired. The training and elevating of guns by manual control of power equipment, either by matching indicating dials or by using telescopes, is relatively difficult and inaccurate. Fluctuations in the incoming gun order, the inertia of heavy turrets or mounts, rolling and pitching of the gun platform, and the personal reaction time of the pointers and trainers in observing and responding to a variation in the order—all these tend to cause inaccuracy in the gun laying, with resulting large patterns.

The design of automatic control equipment depends upon the nature and source of the signal, the load to be moved, and the nature of the damping required to eliminate random movements and to ensure accuracy and rapidity of response.

The principle of automatic control is applied in ordnance equipment both where loads are light (as in computers and indicators) and where they are heavy (as in driving gun mounts, turrets, or fire control directors). Light loads are usually driven by small electric motors. For heavy loads, either of two general types of power drive is used: (1) *electric-hydraulic* or (2) *amplidyne.*

Electric-hydraulic drives are powerful, reliable, and accurate. They are used principally where loads are heavy, as in the training and elevating gear of mounts and turrets, or when large starting and stopping forces are involved, as on ammunition hoists and rammer mechanisms. Their principal disadvantage is the constant maintenance effort required.

Amplidyne drives are also reliable and accurate, and require less maintenance. They are superior to electric-hydraulic drives for lighter loads and are used on mounts, directors, and searchlights. To date, the largest size in use is the train unit on the 5″/54 Single Mount Mark 39.

10A2. The basic problem

The basic technical problem incurred in driving a mount or director in response to a remote signal is divided into four general phases, as illustrated in figure 10A1.

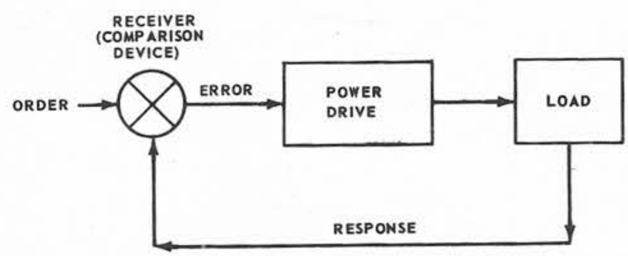

FIGURE 10A1.—Basic automatic control system.

1. An *order signal* is received from a remote station. It is compared with the *response* or position of the load (mount). The result of this comparison is an *error signal.*
2. The *error signal* is amplified to operate the controls of the power drive unit.
3. The power drive unit drives the load in such a manner as to reduce the error signal to zero.
4. In the driving of the load a *response* is sent back to be compared with the order signal.

B. Synchros

10B1. Introduction

The most important unit in a modern transmission system is the *synchro*. Synchros of different types transmit, receive, or combine signals among stations which may be widely separated; for example, they transmit gun order signals from a computer to the automatic control equipment at a gun mount.

The simplest types of synchro units are the *synchro transmitter* (sometimes called *synchro generator*) and the *synchro receiver* (sometimes called *synchro motor*). The transmitter is a device that transmits an electrical signal corresponding to the angle of rotation of its shaft. The receiver is a device that, when it receives such a signal, causes its own shaft (if not appreciably loaded) to rotate to an angle corresponding to the signal. Thus, as figure 10B1 shows, when the transmitter shaft is rotated, the receiver shaft rotates through exactly the same angle.

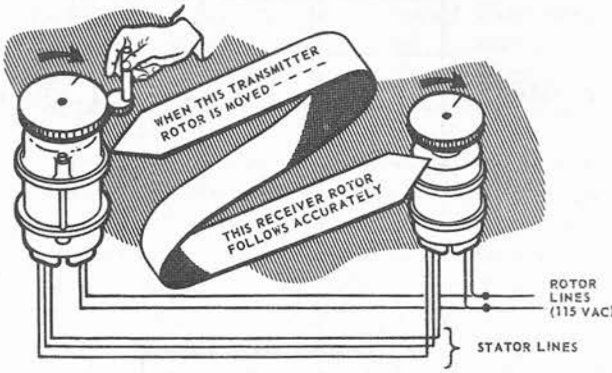

FIGURE 10B1.—Elementary synchro system.

10B2. How a synchro system works

From the outside, a synchro transmitter or receiver looks much like an ordinary small motor or generator (fig. 10B1). So does the inside. See figure 10B2 (B). It has a bobbin-wound ball-bearing mounted rotor surrounded by a wound stator. The stator consists of three iron-core coils connected as in figure 10B2 (A), and terminating in three stator leads (S_1, S_2, S_3). The two rotor leads (R_1 and R_2) shown in figure 10B2 (A) are connected to the rotor. See figure 10B2 (B).

The transmitter and receiver are identical in construction except that the motor has a damper (not illustrated)—a device that keeps it from "running away" when there are violent changes in its electrical input.

To understand how a synchro functions, think of it for the moment as a transformer in which the primary and secondary are wound on separate cores (fig. 10B3). When a current flows in the primary, it forms a magnetic field in its core. As the current changes and reverses (which it does constantly, being an alternating current) so does the magnetic field. The changes in the field induce current in the secondary (whose circuit is closed through a load). The currents in the secondary produce their own magnetic field. At any instant, the induced or secondary field

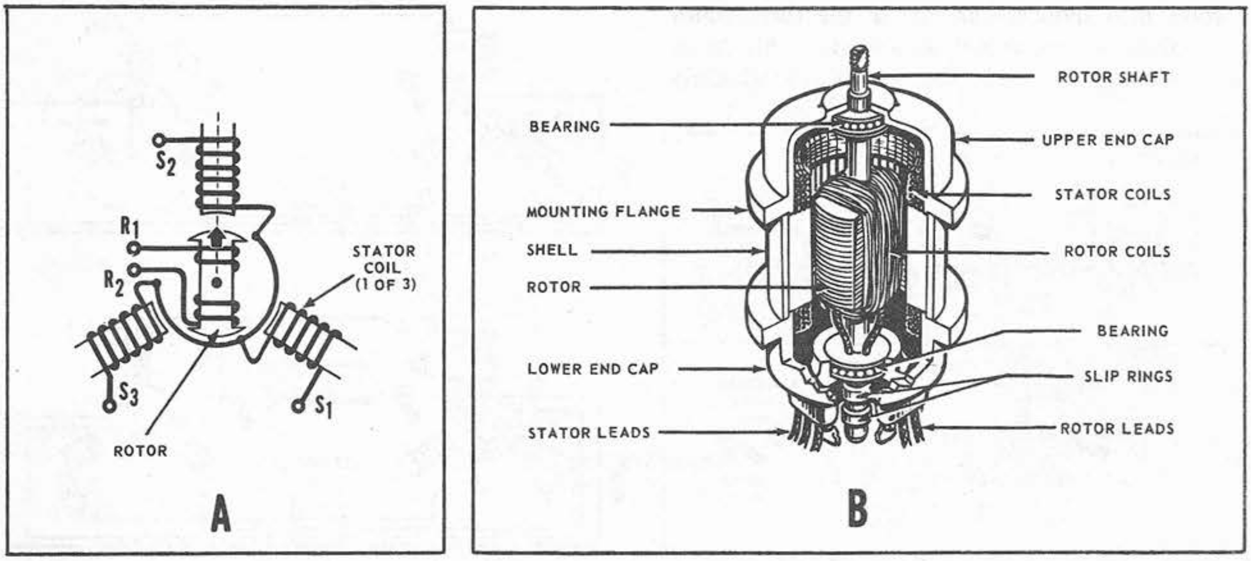

FIGURE 10B2.—Inside a synchro transmitter. A. Schematic representation. B. Construction.

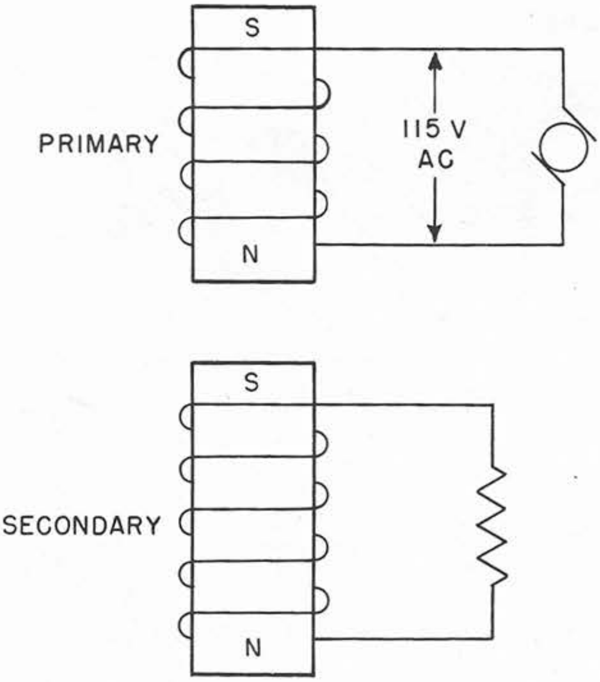

FIGURE 10B3.—Instantaneous magnetic fields in a transformer.

opposes in direction that produced by the primary. Figure 10B3 shows the field at a selected instant. At some other instant the fields might be of opposite polarity, but the primary and secondary fields are always opposed, whatever the instantaneous polarity.

Now consider what happens in a synchro transmitter. Let 115-volt AC flow through the rotor. As shown in figure 10B4 (A), the rotor will produce a changing magnetic field. Its direction at some selected instant is shown by the black arrow. At that instant, the rotor field induces currents in the three stator fields, which are connected to a load. This transformer action produces in the three stator windings

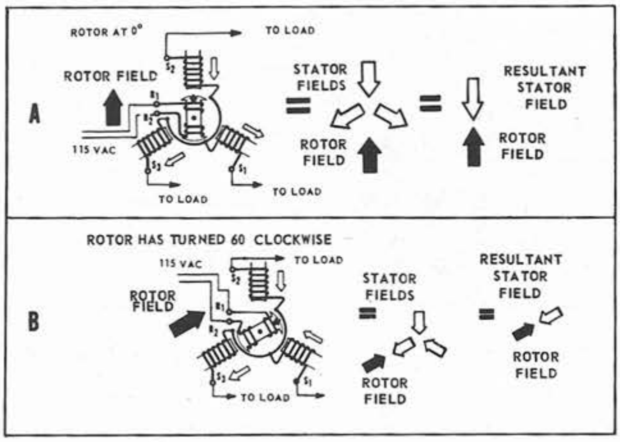

FIGURE 10B4.—Transformer action in a synchro transmitter.

three fields (white arrows) which, when added to produce a resultant (symbolized by a large white arrow), exactly oppose the field in the (primary) rotor winding.

If the rotor is now turned, say, 60 degrees clockwise, as in figure 10B4 (B), the rotor field, shown by the black arrow, will produce in the 3 stator coils 3 fields which will again add up to a resultant directly opposed to the rotor field.

In each of the cases illustrated in figure 10B4, the rotor will induce in the stator coils currents corresponding to that position of the rotor, and to that one only. This is true for all positions of the rotor.

Now consider a synchro transmitter connected to a receiver as in figure 10B5 (A), so that the rotors are fed by the same AC line and the stator coils of the receiver load the corresponding coils of the transmitter. The currents induced in the transmitter stator flow also in the receiver, and produce the resultant stator fields shown by the white arrows. Thus the receiver rotor, which produces a magnetic field similar to that of the transmitter rotor (because it is excited by the same AC line) always, because it is free to rotate, as-

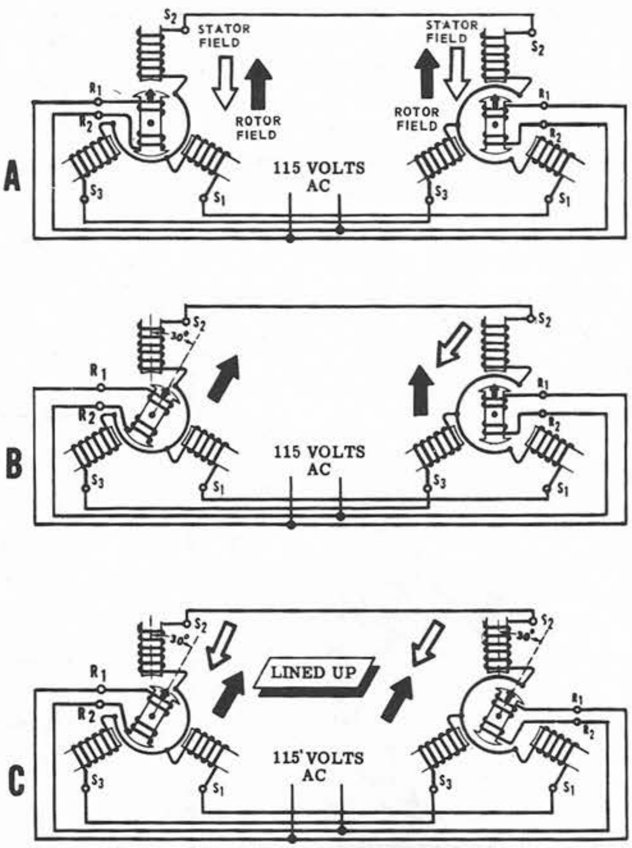

FIGURE 10B5.—Synchro system (transmitter connected to a receiver).

sumes exactly the same angular position (relative to the stator) as does the transmitter rotor.

When the transmitter rotor is turned—say 30°, as in figure 10B5 (B)—the resultant field produced by the stator turns too, as it did in figure 10B4; so does the receiver stator field. And the transmitter rotor, being free to follow, does. See figure 10B5 (C).

NOTE: In this explanation, in the interest of simplicity, the effects of the voltages induced by the receiver rotor in its stator have not been explored. However, since the transmitter does not rotate except in response to whatever drives it, the net action is substantially as described above.

10B3. Other types of synchros

The transmitter and receiver synchros described in the preceding section are only part of the synchro family. The other members are:

1. *Synchro control transformer* (*CT*). This device, like the synchro transmitter, has a wound rotor coil and three stator coils, but the internal construction is different. See figure 10B6 (A). The rotor is round instead of bobbin-shaped (to keep it from tending to line up with a magnetic field as a receiver rotor does) and is wound with finer wire to increase electrical impedance and limit the amount of current it will carry.

The synchro control transformer has 2 inputs, 1 mechanical (its rotor is driven by the mechanism or load whose position it regulates) and the other electrical (the synchro signal from the transmitter which is to control the load). See figure 10B6 (B). The electrical (synchro) 3-wire input goes into the control transformer's stator. The stator's field acts as the primary of the transformer; the rotor is its secondary. The output thus comes from the rotor and varies with its position with respect to the stator. This output is *not* a synchro signal; it is a voltage whose value and polarity with respect to the AC supply depend on the position of the control transformer's rotor with respect to the stator.

This is how the rotor output varies with rotor position. Assume an unchanging field set up by the stator windings of a synchro control transformer, and let the rotor be turned through a full revolution. When the rotor winding is at right angles—dark arrow in figure 10B6 (A)—to the stator field—white arrow in figure 10B6 (A)—the induced voltage in the rotor will be at a minimum. This is called zero or *null* position. (Actually there will be small residual voltages, which can be neglected.)

As the rotor turns, the output voltage increases and reaches a maximum when the rotor winding is parallel to the stator field. As the rotor continues to turn, the output falls. At 180 degrees the output is again zero, then increases and decreases as the rotor turns, much as in the first 180 degrees of revolution. But if in the first half revolution the instantaneous polarity of rotor output was in phase with that of the stator field currents, in the second it was opposed—180 degrees out of phase.

Thus any position of the rotor with respect to the stator field will yield a characteristic output (considering both voltage and phase).

Now consider the synchro control transformer as part of a system set up to control a power unit that positions a load. Suppose that the transmitter in figure 10B6 (B) is cranked from 10 degrees position to zero. This changes the direction of the transmitter's

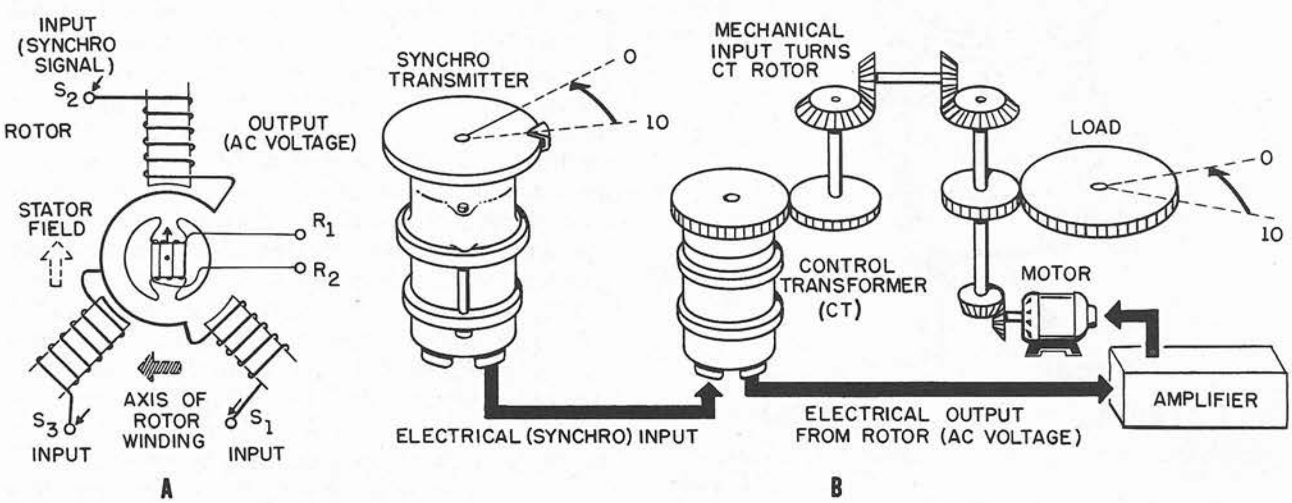

FIGURE 10B6.—Synchro control transformer. A. Circuit diagram (null position). B. How it is used.

stator field. Since the control transformer's stator is connected to the transmitter's stator, the control transformer's stator field rotates similarly. This changes the value of the output of the control transformer's rotor from zero. Since the control transformer's output is too small to drive a motor, it is amplified. The amplifier's output drives a motor which positions the load. But the control transformer's shaft is so geared to the load that, as the motor drives the load, the control transformer's input to the amplifier falls. When the control transformer's output is zero again, the amplifier's output has also fallen to zero, and the motor stops. At this point, the load is in the position required by the transmitter operator.

The main advantage of a transmitter-control transformer system over a transmitter-receiver system is that friction and load weight are unimportant with a synchro control transformer, while they limit the accuracy of a synchro receiver. Any appreciable load increases a receiver's angular error; sensitivity rather than load limits and a control transformer.

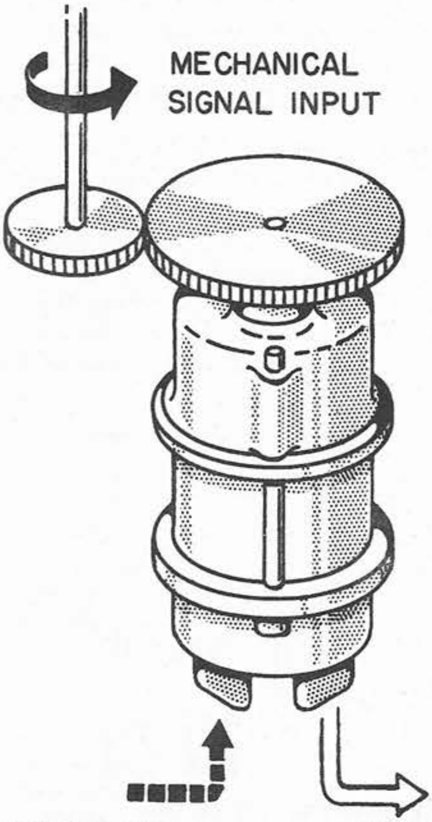

FIGURE 10B7.—Synchro differential transmitter.

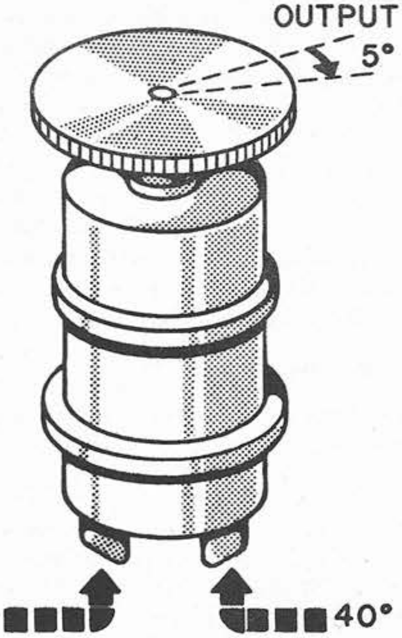

FIGURE 10B8.—Synchro differential receiver.

The application of a synchro control transformer to a gun mount power drive is described in section 10D.

2. *Synchro differential transmitter* (*sometimes called differential generator*). The differential transmitter is a device which yields the sum or difference of two signals.

The differential transmitter's rotor and stator each have three windings. One input to the differential transmitter is a synchro signal to the stator winding. The other input is mechanical—that is, the rotor is driven mechanically to some angle. The output from the rotor of the differential transmitter is an electrical synchro signal that represents (depending on how the system is connected) either the sum or the difference of the mechanical and electrical signal inputs. See figure 10B7. The differential transmitter is not connected to the 115-volt AC line.

3. *Synchro differential receiver* (*sometimes called differential motor*). Like the differential transmitter, the synchro differential motor yields the sum or difference of two inputs. Both inputs (fig. 10B8) are electrical synchro signals. The receiver gives the sum or difference mechanically—generally by rotating a dial. The construction of the differential receiver resembles that of the differential transmitter, except that, like the

synchro receiver taken up above, it is fitted with a damper. It does not have any direct connection to the 115-volt AC line.

10B4. Summary of synchro types

The present functional classification of synchros, as described in OP 1303 (first revision in preparation at this writing), classifies all synchros into seven categories, each described by a group of letters. The classification recognizes not only the categories described in the 2 articles preceding, but also 2 broader categories—synchros designed primarily for systems producing an *electrical* control voltage signal, and synchros designed primarily for systems producing a *mechanical* movement (torque) or dial indication.

As a convenience for the student in learning about the inputs, outputs, and functions of all the types of synchros, the table below and figure 10B9 show in summary form the types of synchros discussed above. For a fully detailed description of all standard Navy types of synchros, and for complete details of the nomenclature and symbol system that also shows the size and mark and mod of standard Navy synchros, see OP 1303 and OP 1755.

10B5. Synchro dial mechanisms

A synchro receiver can be set up very simply (as shown in several figures earlier in this article) with a calibrated dial on its shaft to display information in terms of shaft rotation. It can also be set up so that it can display in addition the response of another mechanism (such as a gun mount) to the information. For example, such a set-up can show the movement of a gun mount in elevation (or train) in response to elevation (or train) gun order.

A common set-up to display such information is the *follow-the-pointer* mechanism, illustrated in figure 10B10. Here the synchro receiver, to which is fed a synchro signal representing gun order, drives a dial. Surrounding this dial is a ring dial geared to the mechanism (in this case, a gun mount) which is supposed to follow the transmitted signal (gun elevator or train order). A third fixed calibrated dial (not illustrated) may surround these two.

Functional nomenclature	*Letter-group symbol*	*Signal input or inputs*	*Output*
Torque transmitter	TX	1 input—rotor positioned mechanically or manually.	*Electrical.* 3-wire synchro signal from starter to TDX, TR, or TDR.
Central transmitter	CX	Same as TX	Same as TX, but fed to CT or CDX.
Torque differential transmitter.	TDX	2 inputs—a. 3-wire synchro signal from TX to TDX stator. b. Rotor positioned mechanically or manually.	*Electrical.* 3-wire synchro output (representing sum or difference of inputs) from rotor to TR, TDX, or TDR.
Central differential transmitter.	CDX	Same as TDX, but synchro input usually from CX.	Same as TDX, but supplied only to CT or CDX.
Torque receiver	TR	1 input—synchro signal from TX or TDX to TR stator.	*Mechanical.* Rotor assumes position corresponding to input synchro signal.
Torque differential receiver	TDR	2 synchro inputs—one to rotor, one to stator; each input from a TDX or TX.	*Mechanical.* Rotor assumes position corresponding to sum or difference of inputs.
Control transformer	CT	2 inputs—a. Synchro signal from CX or CDX to stator. b. Rotor positioned mechanically or manually.	*Electrical.* AC voltage (2-wire signal) from rotor, proportional to sine of difference between rotor position and stator input.

NOTE

The letter-group symbols and functional nomenclature represent current BuOrd practice. Older nomenclature and symbols will often be seen in BuShips and BuOrd publications issued in the past but still in current use, as follows:

Receivers called *motors,* symbol *M.*

Transmitters called *generators,* symbol *G.*

Differential transmitters called *differential generators,* symbol *DG.*

Differential receivers called *differential motors,* symbol *D.*

Older nomenclature and symbols do not distinguish between torque-type and control-type units.

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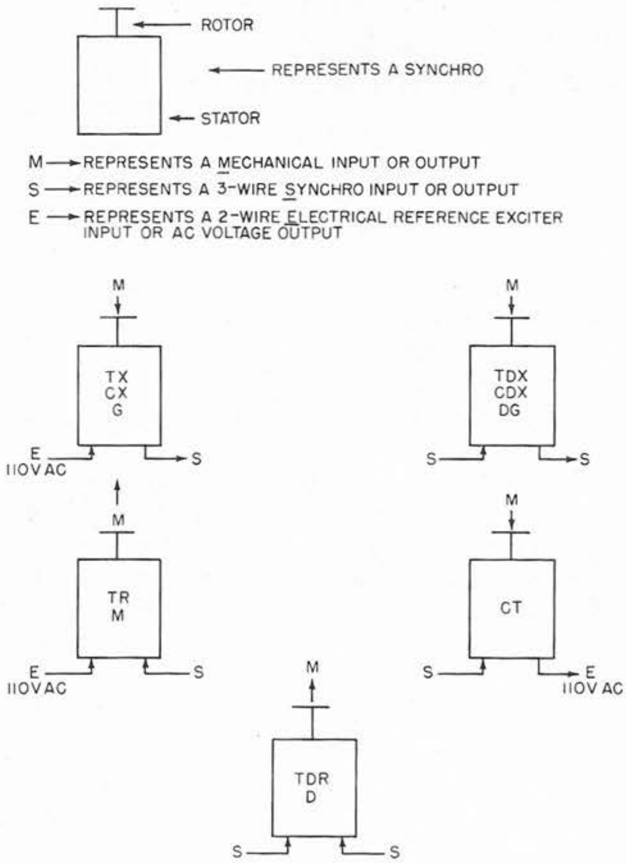

FIGURE 10B9.—Summary of synchro types.

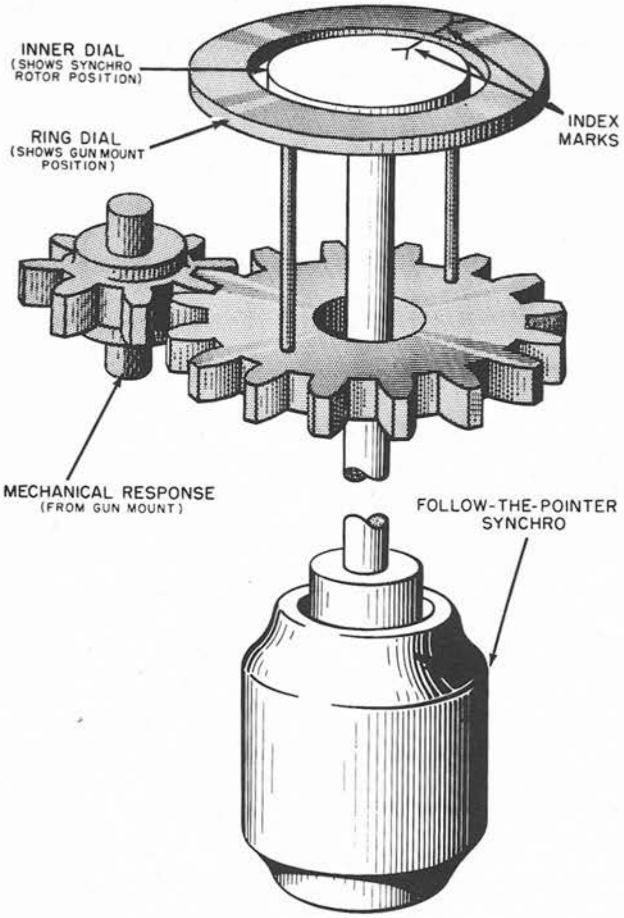

FIGURE 10B10.—Follow-the-pointer mechanism.

When a change in gun order occurs, the synchro rotor turns the dial. When the mount power drive or the gun pointer or trainer responds by moving the gun in accordance with the indicated order, this movement drives the response gearing, which turns the ring dial to follow the inner (synchro-driven) dial. When the two index marks match again, the gun mount is in gun order position.

Synchros are often mounted, as in the above example, so that their stators remain fixed; however, they may also be *bearing-mounted* so that their stators can be mechanically rotated.

A common example of such a mounting is the *zero-reader mechanism*. This mechanism is used to operate a dial which displays response of a gun mount or other load to a synchro signal. The example illustrated in figure 10B11 shows a synchro receiver to which is fed a synchro signal representing gun elevation (or train) order. This turns the rotor, which turns the zero-reader dial off the fixed index mark. As the gun mount is moved automatically (by the power drive) or manually (by the gun pointer or

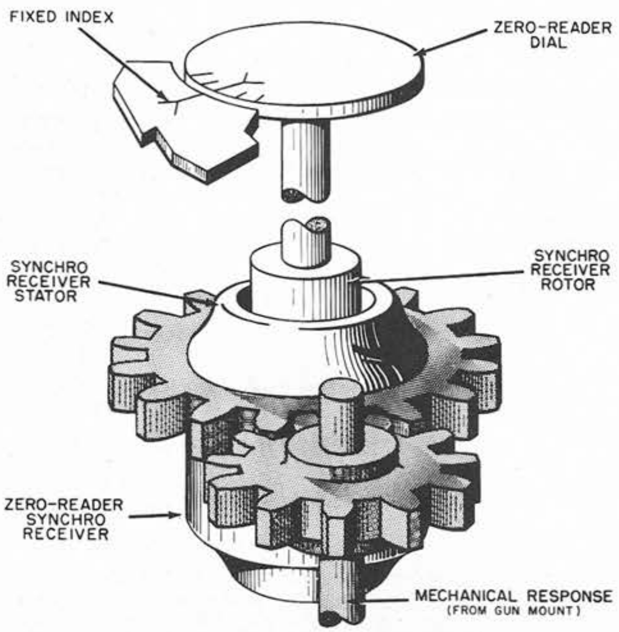

FIGURE 10B11.—Zero-reader mechanism.

trainer), it drives the synchro stator through gearing so that the whole synchro (including the dial) rotates toward the fixed index mark. (The rotor and stator are electrically locked together by their magnetic fields.) The zero-reader dial shows the *difference* between the signal and the response. When the two are equal, their difference is zero, of course. When the indexes are matched, and the dial indicates "zero," the gun mount position coresponds to gun order position. The process of matching the indexes is called *matching zero readers.*

When accurate values of quantities are required, synchros are used in pairs geared to each other so that one transmits coarse readings, the other fine readings. For example, one might be used to transmit 360 degrees per revolution, the other 10 degrees per revolution. This materially increases the sensitivity and accuracy of automatic transmission. In addition, it is evident that the graduations on the fine dial can be more easily read. These are called *double-speed* systems.

It is possible to connect several synchro receivers to

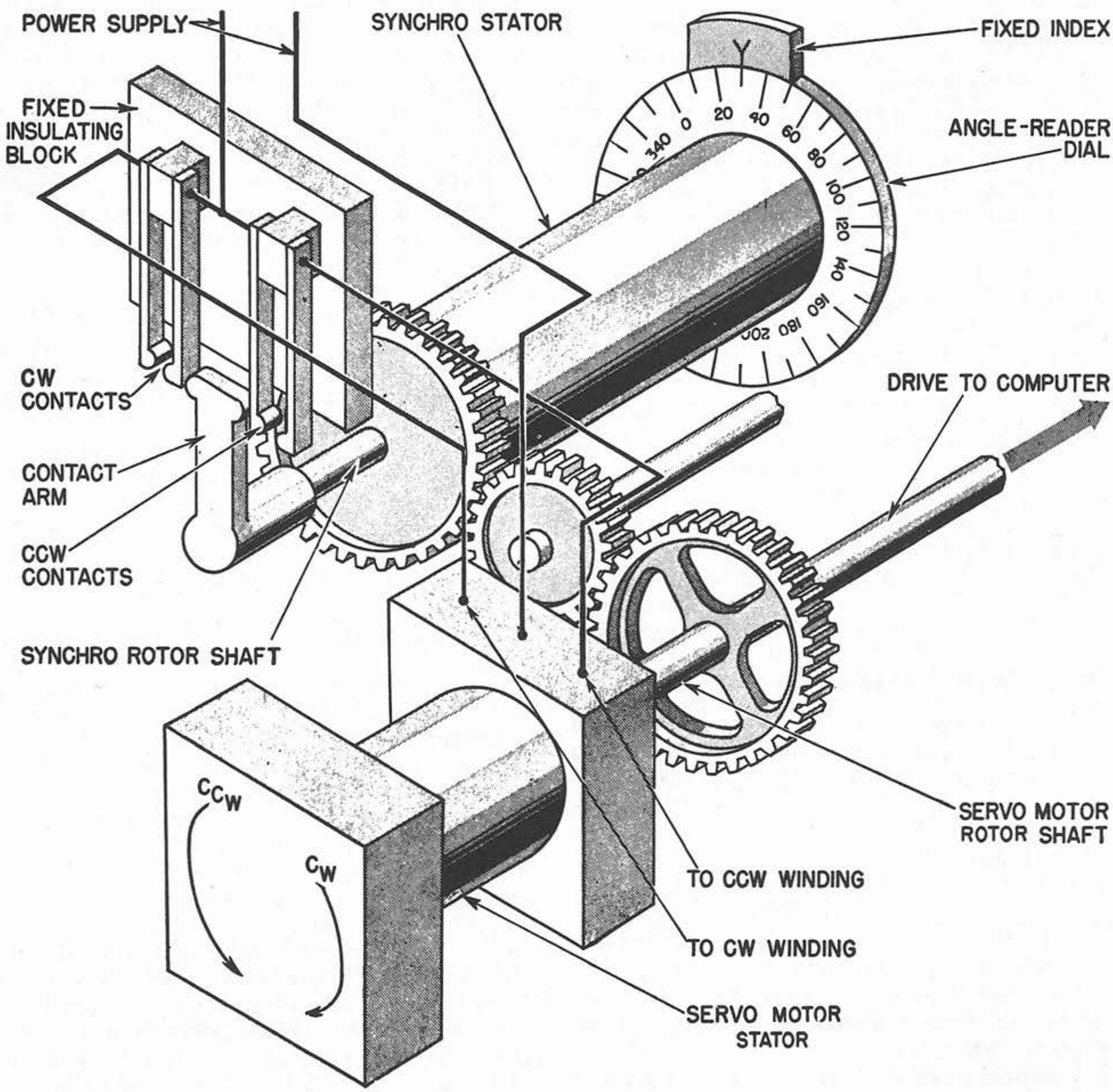

FIGURE 10B12.—An electrical follow-up.

a single transmitter so that the transmitted quantity can be sent to several stations at the same time, and the values received will be synchronized at all stations.

10B6. Synchros and servos

One of the limitations of synchros is their small output torque; hence, their use is limited to positioning dials and opening and closing contacts. But often the response to the indications must be made automatic. Mechanisms which provide automatic response are called *follow-ups* or *servo mechanisms.* An electrical follow-up employs an electric *servo motor* to provide the additional power required.

One such follow-up, using a synchro control transformer, is shown in figure 10B6. As later articles in this chapter will show, this principle can be also used to position massive gun mounts and turrets. However, a synchro receiver can also be used for controlling a small motor in an instrument servo mechanism without requiring an amplifier. Such a set-up, in a fire control computer, is illustrated schematically in figure 10B12.

The servo motor stator has two windings, either of which may be connected in series with a phase-shifting capacitor. When one winding is in series with the capacitor, the servo motor shaft turns clockwise; when the other winding is in series with the capacitor, the rotation is counterclockwise. The servo motor is energized through the follow-up control, which consists of two sets of sensitive contacts mounted on a fixed block. A light contact arm on the synchro rotor shaft operates one or the other set of contacts, depending on which way the synchro rotor turns. The counterclockwise contacts are connected to the servo motor winding which produces counterclockwise rotation (indicated by the arrows on the end of the motor), and the clockwise contacts are connected to the other winding.

Assume that the remote synchro transmitter is sending a zero signal, and that zero bearing is set into the computer. The contact arms is in the neutral position; both sets of contacts are open; and the servo motor is motionless. As the director trains to 30°, the transmitter sends a signal to the synchro receiver which rotates the contact arm clockwise far enough to close the counterclockwise contacts. This energizes the servo motor counterclockwise winding; the motor then turns the drive shaft counterclockwise, and the synchro stator rotates counterclockwise until the synchro rotor puts the contact arm in neutral position. The servo then stops, and the input to the computer is 30°. If the signal then changes to 20°, the contact arms closes the clockwise contacts, and the servo drives the synchro stator 10° to make the remaining input 20°.

Usually dials indicate the settings made by the servos. The dials may be zero readers or angle readers.

Actual follow-up mechanisms, especially in equipment of recent design, have refinements omitted in this presentation. For example, servos in which the speed or power of response is proportional to the amount of error have many advantages, such as reducing oscillation or "hunting" around the signal.

When coarse and fine synchros are used in a system, the servo mechanisms are often so constructed as to respond to a coarse error with high-speed response until it becomes a fine error, when the response is scaled down to the accuracy required for accurate synchronization with the signal.

C. Electric-Hydraulic Systems

10C1. Principles of hydraulic mechanisms

Electric-hydraulic power drives are used with all calibers of naval gun mounts from 40-mm mounts to 16-inch turrets. Their great advantage is that they provide positive control at all speeds, and in both acceleration and deceleration, of the most massive moving units—including rotating turret structures weighing millions of pounds. Complete systems are unavoidably complex, especially in the more highly automatic types of installation; but their principles of functioning can be presented relatively simply, once certain elementary facts about the behavior of liquids are known, and once certain basic hydraulic mechanisms are understood.

This article presents this fundamental background in simplified, somewhat foreshortened, form. Succeeding articles in this section explain a typical electric-hydraulic system—that for the 5"/38 twin mount.

Strictly speaking, hydraulics as a science has to do with the behavior of liquids in motion; hydrostatics has to do with the behavior of liquids at rest. This discussion will not emphasize the distinction.

Whether at rest or in motion, all liquids are nearly incompressible, at least within the pressure ranges that are encountered in ordnance hydraulic systems. The liquid in any system is always under the pressure, called *pressure head,* imposed by its own weight, and this increases in proportion to depth. It varies, of course, with the specific gravity of the liquid. In water, this pressure head is 8 psi at 222 inches below the surface; in a typical oil with a lesser specific gravity, a depth of 252 inches is required to attain this pressure head.

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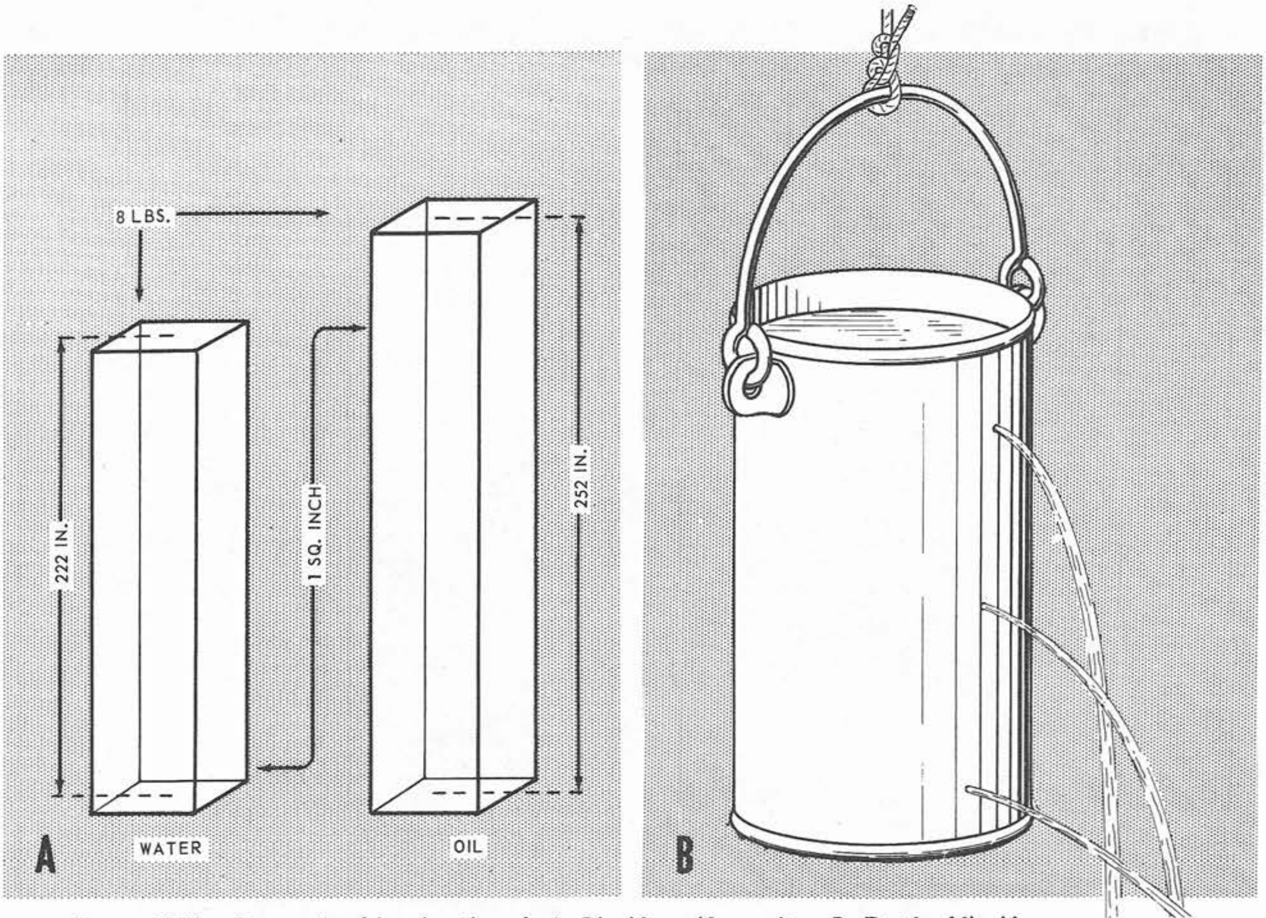

FIGURE 10C1.—Pressure head is a function of: A. Liquid specific gravity. B. Depth of liquid.

Other pressure imposed on an enclosed hydraulic system (for example, pressure imposed by a piston on liquid in a closed cylinder), are distributed equally in all directions throughout the entire volume of the liquid. Thus a pressure imposed at one end of a long liquid-filled tube is communicated undiminished to the other end. (This applies strictly to liquids at rest; other factors modify this behavior when the liquids are in motion.)

Although, with regard to pressure transmission, all liquids are about the same, they differ radically in their *resistance to flow* (otherwise known as viscosity), in their *lubricant effect,* and in their general suitability for use in hydraulic systems. Hydraulic fluids for ordnance hydraulic systems are petroleum-based oils selected for superior lubricant quality (but they are *not* lubricants), low viscosity throughout a wide range of temperatures, low volatility, high stability, and compatibility with the metals of which such systems are constructed.

Hydraulic systems include some or all of the following main types of components:

Pipe or tube lines, to conduct the fluid between components of the systems, and *fittings* to mate these components.

Valves, to direct and control the flow of fluid, and to control fluid pressure. Some valves are hand operated, but most are automatic. Many, like check valves, pressure-regulating valves, and dumping valves, are hydraulically operated; others are operated by electric motors, solenoids, or synchros. Some of the more complex automatic types are described later in this section.

Gages, to measure pressure, velocity, and volume of hydraulic fluid. (Ordnance hydraulic systems use mostly pressure gages.)

Pumps, to drive the hydraulic fluid through the system. There are many types, ranging from simple rotary and reciprocating units to relatively complex axial-piston pumps whose rate and direction of output can be almost instantly varied from zero to full in either direction without varying their speed of rotation. All pumps in ordnance hydraulic systems are driven by electric motors.

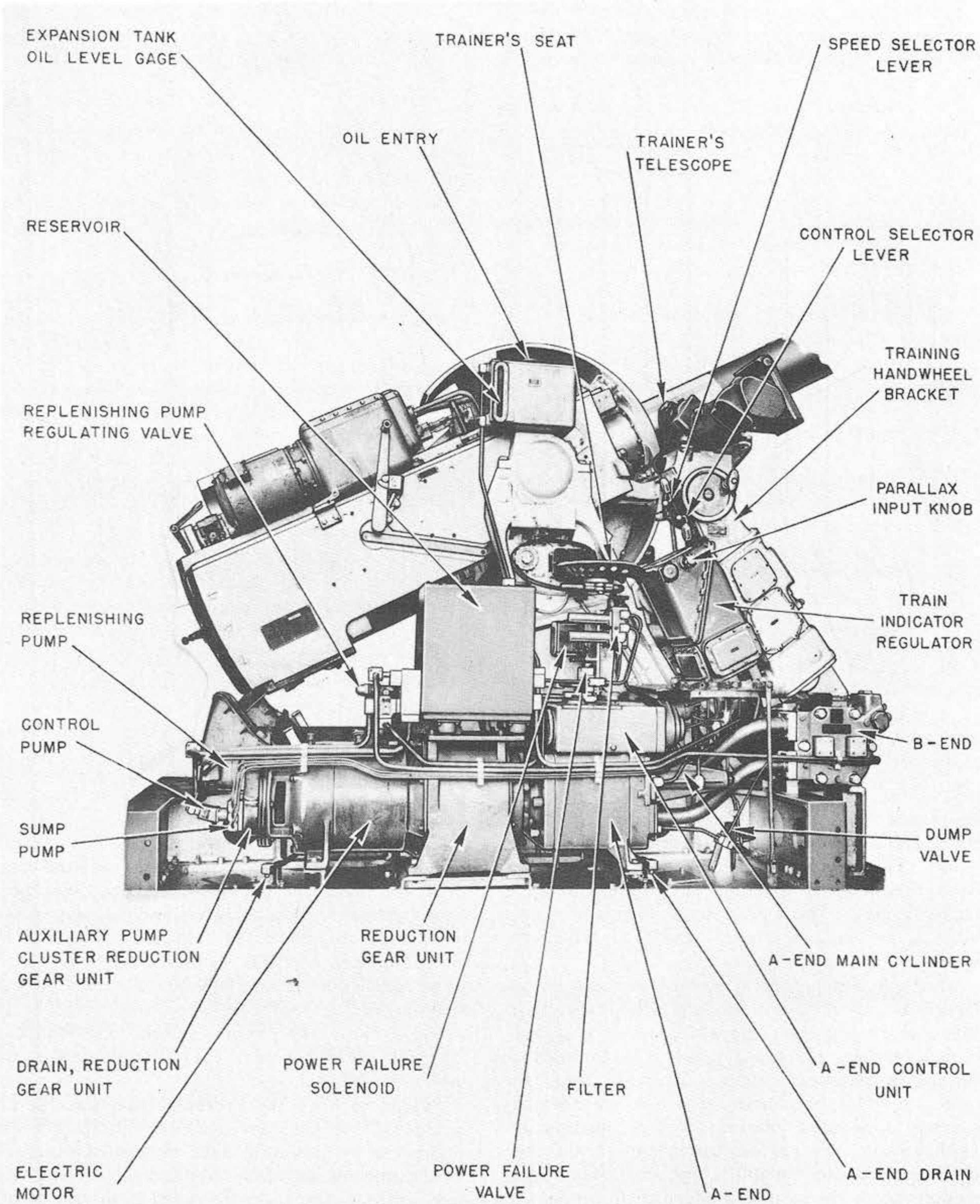

FIGURE 10C2.—5"/38 twin mount, showing electric-hydraulic train drive units.

Hydraulic motors and *work cylinders,* whose function it is to convert the energy delivered through the hydraulic fluid to mechanical motion. Most hydraulic motors are actually somewhat modified pumps of one type or another, working in reverse.

Pressure chambers, to protect the hydraulic system against sudden shocks and surges, and *accumulators,* which store a certain amount of fluid under air pressure to equalize fluid flow under sudden heavy demand in excess of the capacity of the pumps, or to complete an operating cycle in case of power failure.

Reservoirs and *tanks,* to store fluid and provide for its expansion with heat.

Gaskets to seal joints, and *packing* to seal openings around moving parts against leakage of fluid.

10C2. Introduction to 5″/38 twin mount train power drive

The system described in this article is a simplified version of the train drive for the 5″/38 twin mount. See figure 10C2. Refinements omitted are needed for smooth operation but do not contribute to an understanding of the principles of the system.

The main equipment consists of a variable-speed drive, an indicator-receiver-regulator, and associated auxiliary equipment.

10C3. Methods of control

This system has four methods of control: AUTO, LOCAL, HAND, and MANUAL. Selection of the type in use is made by the control-selector lever at the trainer's station. Also located at the station is a speed-selector lever having two positions, HIGH and LOW. It has no function in automatic control, but determines the ratio between handwheel movement and follow-up operation in the other control methods.

In AUTO gun laying, the remote signal is received by a synchro receiver, is amplified hydraulically, and causes the training system to follow the signal at a maximum rate of 25 degrees per second. Figure 10C3 is a block diagram representation of this system in automatic control.

In LOCAL power control for indicator gun laying, movement of the handwheels takes the place of the remote signal entering the indicator-regulator. See figure 10C4.

In HAND control, movement of the handwheels goes directly to the A-end control unit, bypassing the indicator-regulator. See figure 10C5.

In MANUAL control, the handwheels are geared directly to the training rack, bypassing the entire power-drive unit.

10C4. Variable-speed drive (hydraulic speed gear)

The speed gear consists of a variable-displacement hydraulic pump, the output of which drives a hydraulic motor. The pump is called the A-end, and the hydraulic motor is called the B-end. The hydraulic system through the two units and the two large

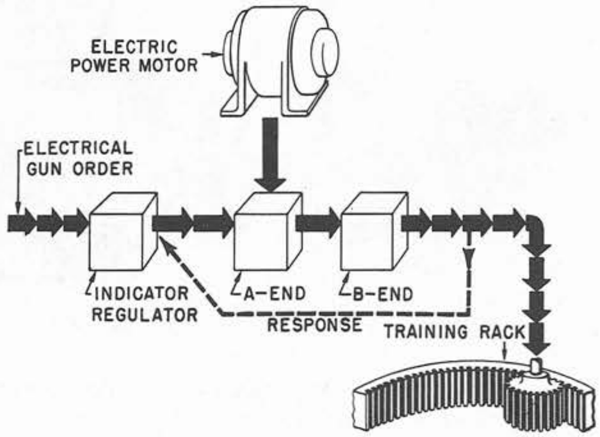

FIGURE 10C3.—Power drive operation in automatic control.

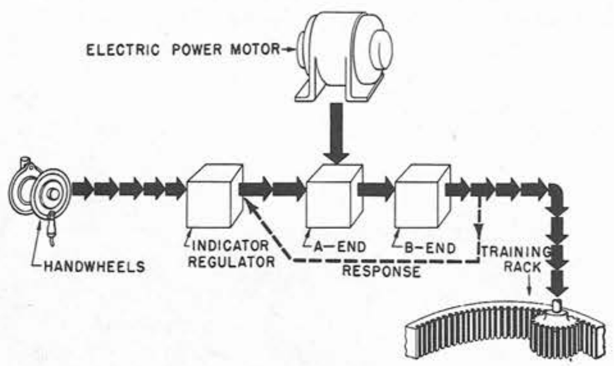

FIGURE 10C4.—Power drive operation in local control.

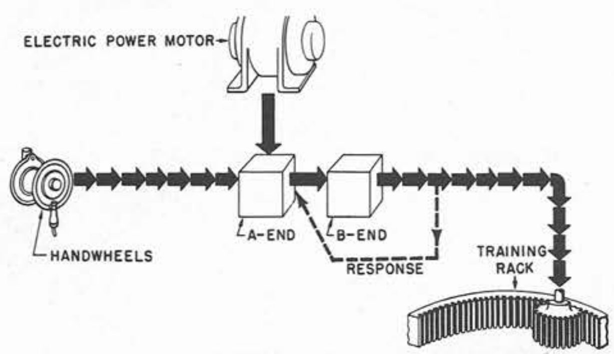

FIGURE 10C5.—Power drive operation in hand control.

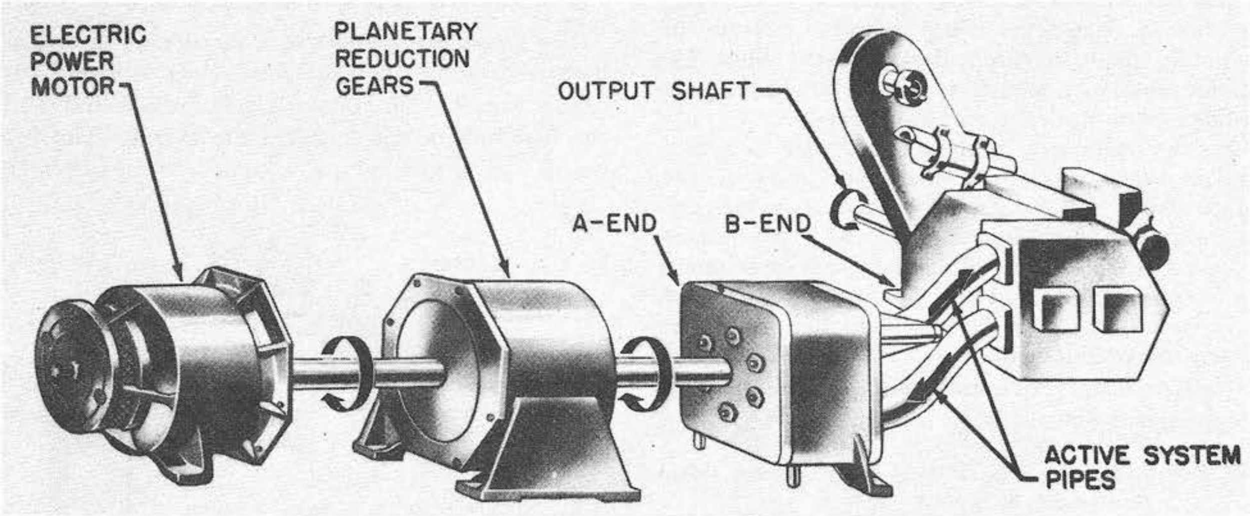

FIGURE 10C6.—The hydraulic speed gear.

interconnecting pipes is referred to as the *active system*.

The A-end is driven at constant speed by an electric power motor through a set of planetary reduction gears. The B-end, as already mentioned, is driven by the hydraulic output of the A-end, and the mount itself is driven by the mechanical output of the B-end. See figure 10C6. By controlling the variable output of the A-end, the direction and speed of rotation of the B-end can be controlled; therefore, the direction and speed of the motion of the mount can be controlled.

The hydraulic output of the A-end is controlled by varying the angle between the socket ring and cylinder barrel of the rotating group of the A-end. See figures 10C7, 10C8, and 10C9. This angle is called the *angle of tilt* and is controlled by the A-end control unit

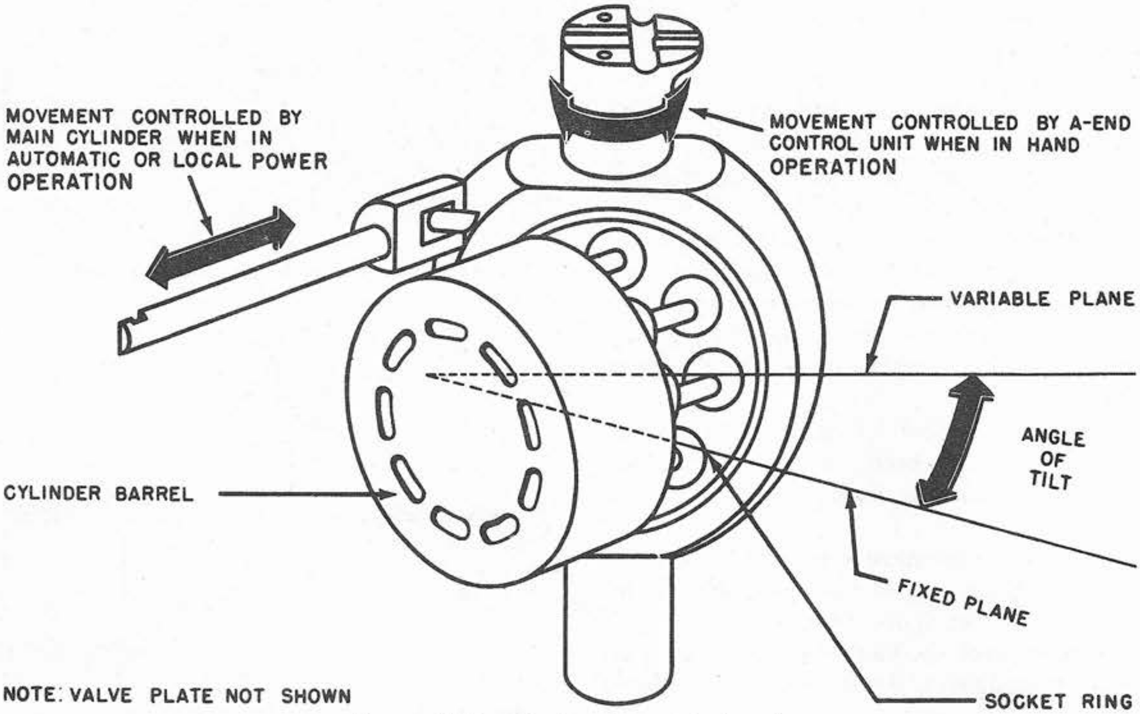

FIGURE 10C7.—Varying tilt angle in A-end.

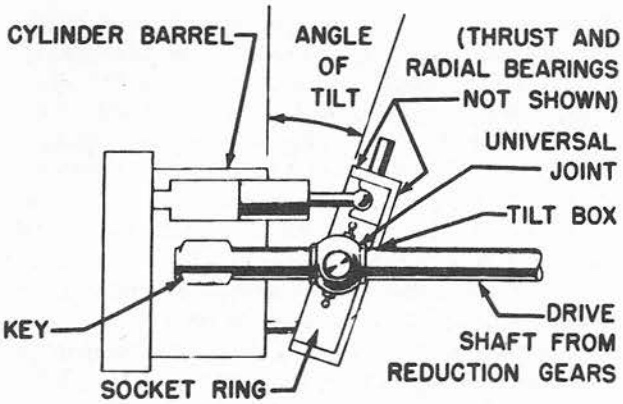

FIGURE 10C8.—Tilt-box arrangement.

when the equipment is in HAND control. In AUTO and LOCAL power control, the angle of tilt is controlled by the position of the main piston. The position of the main piston is in turn controlled by the hydraulic follow-up system.

The cylinder barrel rotates in a fixed plane, while the socket ring rotates in a plane whose angle to the fixed plane of rotation of the cylinder barrel may be varied. The angle between these two planes is the angle of tilt. See figures 10C7 and 10C8.

The socket ring is mounted inside a large, steel, cup-like casting. This yoke is called the *tilt box* and does not rotate with the socket ring. Therefore, suitable thrust and radial roller bearings are provided to support the socket ring inside the tilt box. The tilt box is trunnion-mounted in large ball bearings so that the tilt box and the socket ring may be tilted anywhere within a limit of ±20 degrees from the zero tilt position. A universal joint is provided so that the socket ring may be rotated by the drive shaft as the angle of tilt varies between its limits of ±20 degrees. The same drive shaft that rotates the socket ring rotates the cylinder barrel. The cylinder barrel is keyed to the drive shaft. See figure 10C8.

To follow piston A through a complete revolution, refer to figure 10C10. Note that the numbers are arranged as are the numbers on the dial of a clock. Then consider piston A to be at a position equivalent to 3 o'clock and the rotation clockwise as indicated by the arrows.

As rotation progresses, piston A will begin to move outward in relation to the cylinder in which it operates. The relative motion of the piston is outward until the

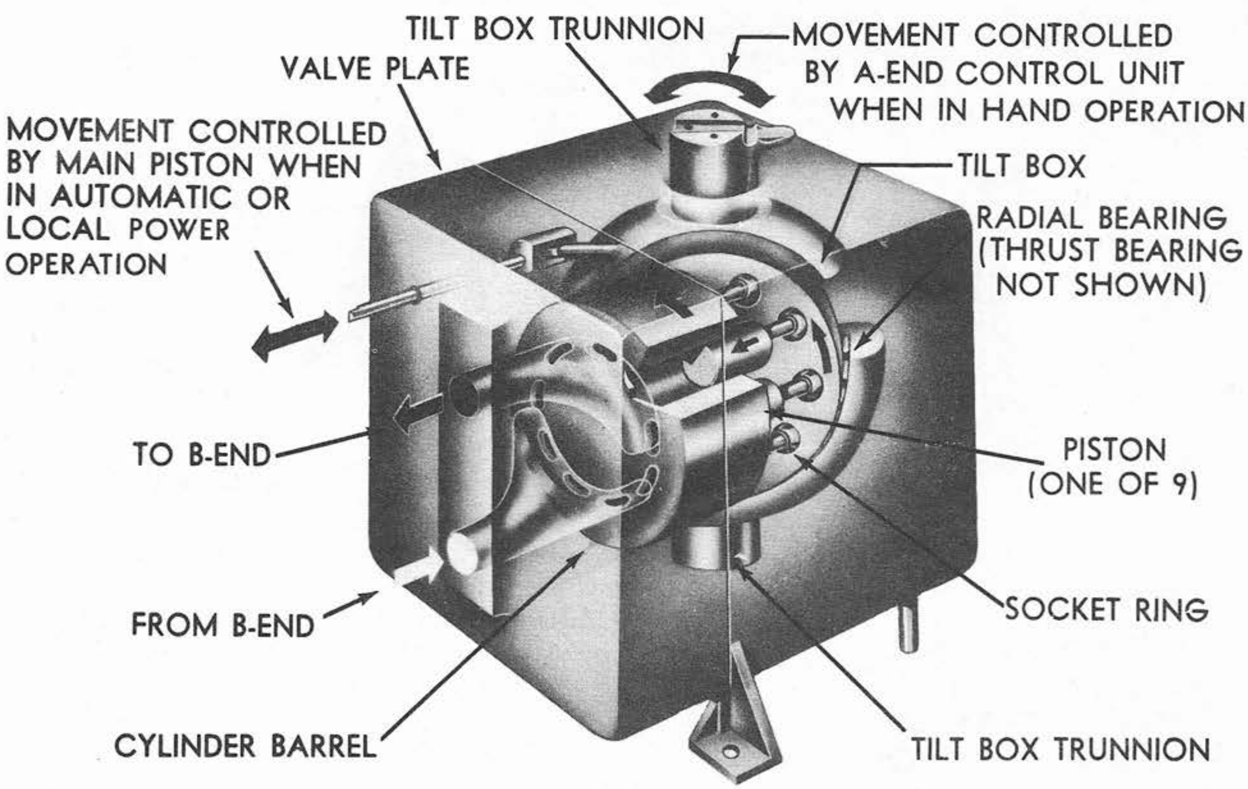

FIGURE 10C9.—Phantom view of A-end.

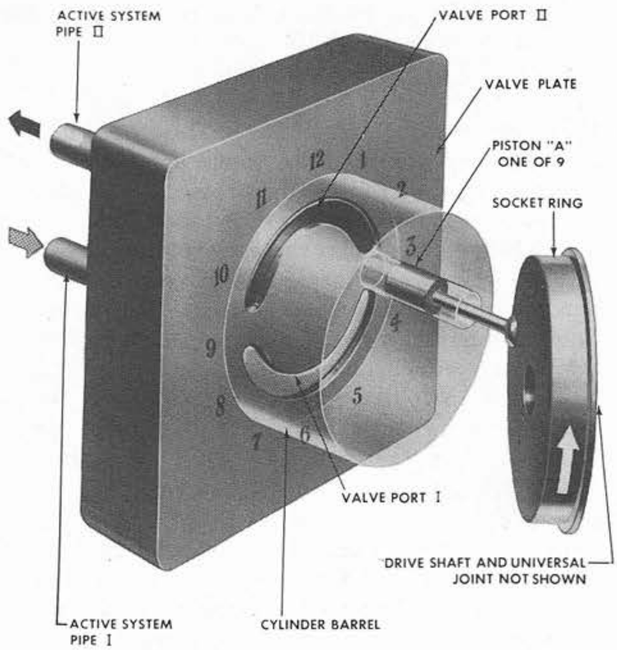

FIGURE 10C10.—A-end operation.

piston is at the 9 o'clock piston. The piston motion up to this point has been such as to draw oil into the cylinder in which the piston operates. The oil has entered the cylinder through valve port I and active-system pipe I. Continuing the rotation from 9 o'clock to 3 o'clock it must be noted that the relative motion of the piston in its cylinder is now reversed and is inward, forcing oil out of the cylinder through valve port II and active-system pipe II.

At 9 o'clock and at 3 o'clock, where the relative motion of the piston in its cylinder reverses and where the relative motion is zero, lands are provided in the valve plate to separate port I from port II. These two points are points of commutation where the piston motion reverses from that of drawing in oil to that of pumping out oil under pressure. The two lands separate the high-pressure discharge port from the low-pressure intake port. The width of these lands must be at least as great as the diameter of the opening at the end of the cylinder. This is necessary in order to prevent a hydraulic short circuit between the low-pressure port and the high-pressure port as any one of the nine pistons of the rotating group passes over one of the lands.

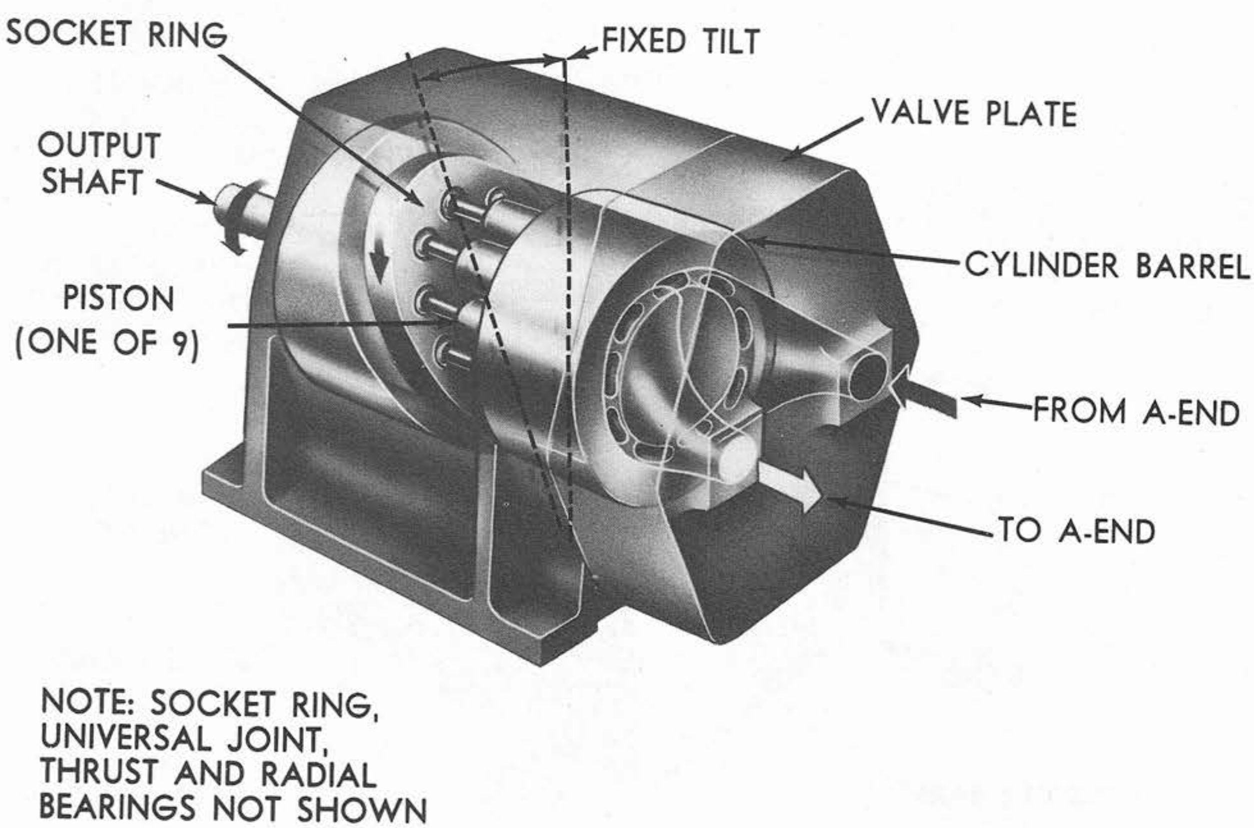

FIGURE 10C11.—Phantom view of B-end.

The cylinder barrels bears against the valve plate at all times, and the construction of the two parts is such that leakage is reduced to a minimum.

The tilt-box trunnions are adjacent to the points designated as 6 o'clock and 12 o'clock. See figure 10C9. The tilt box rotates within limits about an axis through these two points.

It should be evident at this point that, with the tilt shown, the pumping action is such as to force oil out through port II and to draw oil in through port I. That is, the oil drawn in through port I at low pressure is pumped out through port II at high pressure. It should also be noted that if the angle of tilt is reversed the direction of flow is reversed, and that the volumetric rate of pumping depends upon the value of the angle of tilt.

The active-system piping leading from the two valve-plate ports of the A-end provides for flow of oil through to the B-end.

The B-end is similar in construction to the A-end, except that the tilt of the socket ring is fixed. The angle of tilt of the B-end is built into the unit and cannot be changed. See figure 10C11.

The flow of oil under pressure to the B-end will exert forces normal (at right angles) to the faces of the pistons open to the valve port receiving the oil under pressure. See figure 10C12. These forces on the piston faces will result in:

1. A thrust component along the axis of rotation of the socket ring. This component does no useful work and is neutralized by a suitable thrust roller bearing.
2. A turning component which will rotate the socket ring. This force component is at right angles to that described in 1. The cylinder barrel will rotate, driven by the rotation of the socket ring, through the drive shaft and universal joint. This, of course, will cause the B-end to rotate, and thereby provide the power required to drive the guns.

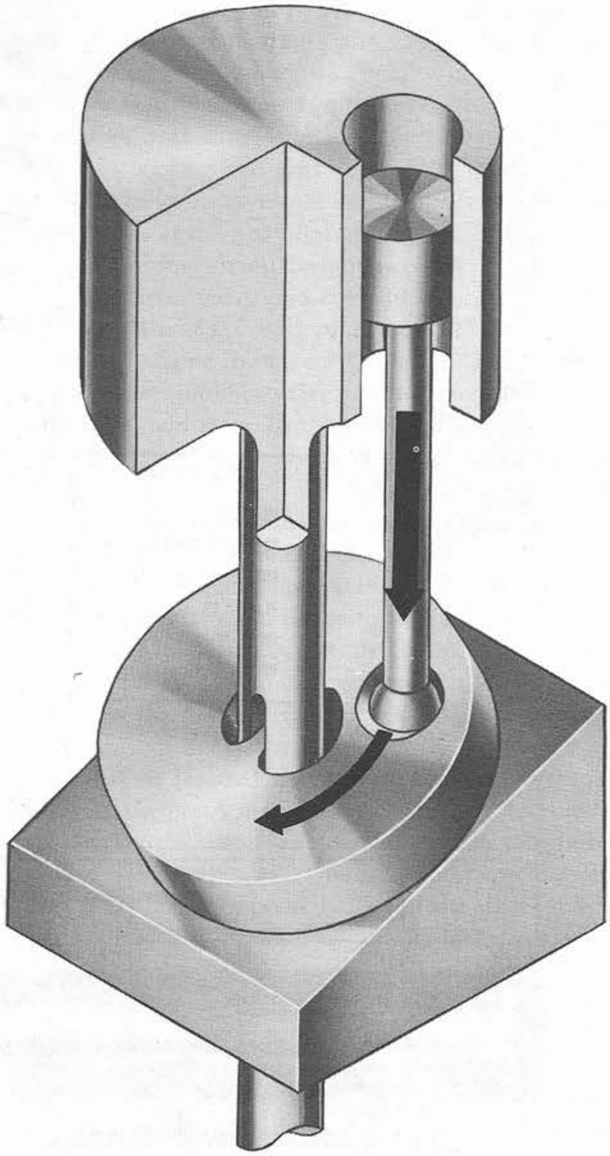

FIGURE 10C12.—B-end operation.

10C5. The A-end control unit

Control of the speed-gear output for driving the guns when the equipment is in HAND control is accomplished by action of the A-end control unit. In HAND control (see figure 10C5), the signal to the A-end control unit is transmitted mechanically through shafting and gearing from the pointer's or trainer's handwheels. Mechanical response is also transmitted to this unit through shafts and gears.

Within the unit is a special type of mechanical differential. Any difference between the signal and response will cause axial movement of a shaft which introduces a change in the value of the angle of tilt of the A-end tilt box.

The action of the A-end control unit is to change the angle of tilt until mechanical response and therefore gun movement is synchronized with the handwheel motion.

10C6. The indicator-receiver-regulator

The indicator-receiver-regulator (commonly called the indicator-regulator) contains all the equipment necessary for (1) receiving the order signal and the response, (2) comparing them to obtain the error

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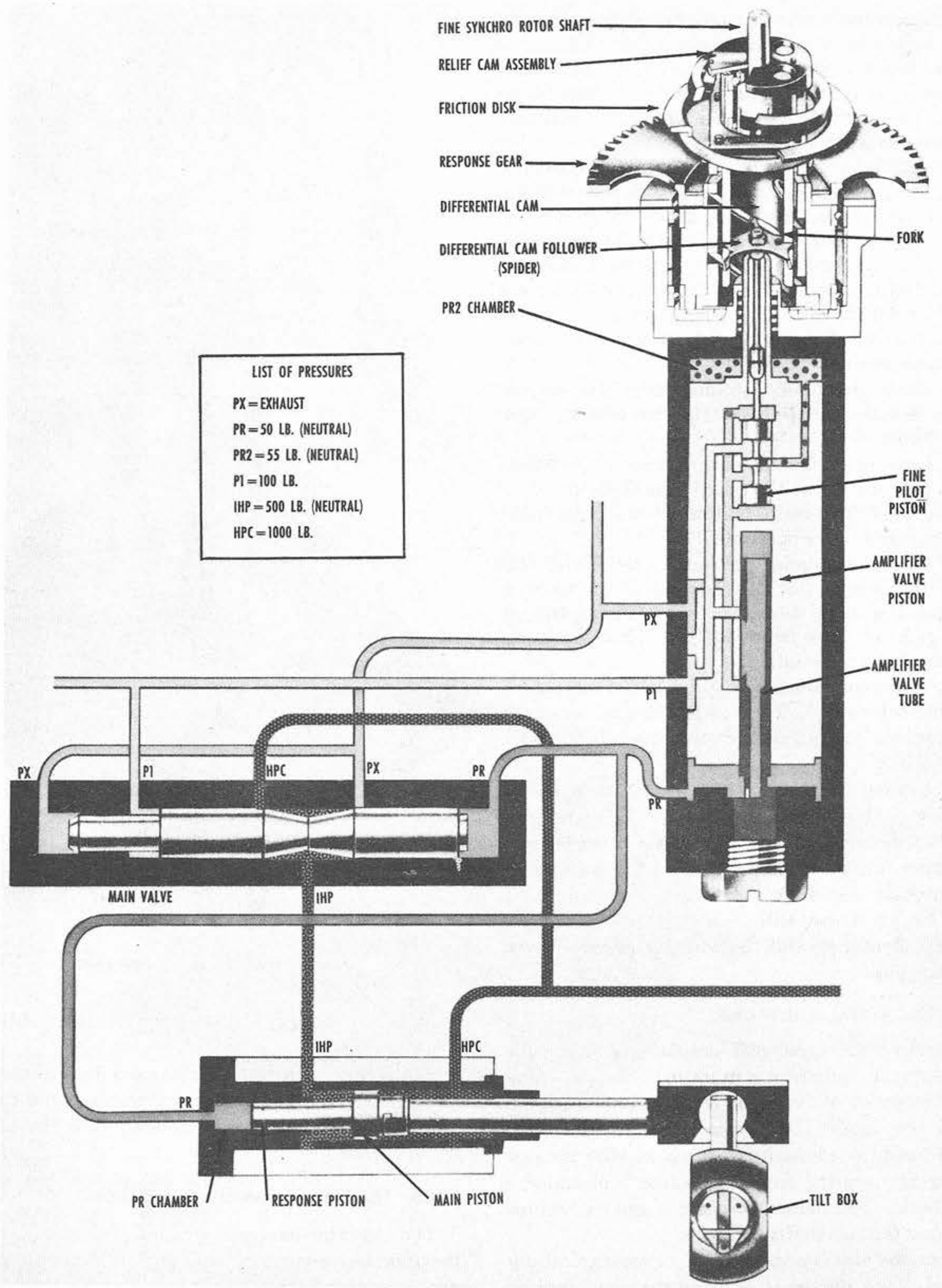

FIGURE 10C13.—Action of hydraulic valves.

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signal, (3) amplifying the error signal, and (4) transmitting it to the A-end properly. It is equipped with dials which indicate the order signal and the response. The indicator-regulator is in use only when AUTO or LOCAL power gun laying is employed. (See figures 10C3 and 10C4.)

Figure 10C13 shows only the major parts of the (train) indicator-regulator. It demonstrates the control of the principal valves by movement of the *fine* synchro receiver. Rotation of the synchro rotor causes the *fine pilot piston* to move up or down. The *amplifier valve* piston follows the movement of the fine pilot piston. This positions the *main valve,* and the main valve controls the *main piston,* which is attached to the A-end tilt box. As the B-end drives the mount, response gearing rotates the *response gear,* which repositions the fine pilot piston to bring the system to rest.

In automatic control, the synchro receiver rotor receives a gun-train order from the synchro transmitter in the computer. As the rotor moves, it turns the *rotating fork* through the *relief-cam assembly.* The ends of the fork fit in slots in the *differential-cam follower* (*spider*). Since the spider is constrained to move in helical grooves in the differential cam as it is rotated, it moves up or down. Attached to the lower end of the spider is the fine pilot piston which moves with it.

Now, as the mount moves in train as a result of the above signal, gearing from the B-end output shaft turns the *response gear* of the differential cam. The helical grooves of the differential cam are moved while the rotating fork is preventing the spider from rotating. Thus, the spider and the fine pilot piston are raised or lowered in accordance with the signal.

On figure 10C13, we will trace one cycle of operation of the hydraulic valves shown. Assume that a signal has caused the fine piston to move *up*:

1. Oil in chamber PR2 (at the top of the amplifier valve) escapes through the port (opened by the fine pilot piston movement) to the PX (exhaust) line. As the pressures on the top and bottom of the amplifier valve piston are no longer in balance, PR pressure on its bottom will cause the amplifier valve piston to move up, closing the port from PR2 to PX. The amplifier valve piston moves exactly the same direction and amount as the fine pilot piston, and it follows the fine pilot piston almost instantaneously.
2. The main valve had been in balance, with the pressures P1 and PX working against PR. Now with the loss of volume from the PR side resulting from the rising of the amplifier valve piston, the piston of the main valve will move to the right. The IHP line to the center of the main valve is then open to the exhaust PX.
3. The main piston had been in balance, with PR and IHP working against pressure HPC. With IHP opened to the exhaust, the resulting unbalance permits HPC to force the main piston to the left.
4. The main piston is directly connected to the tilt box, so that its movement produces an angle of tilt.
5. Now the B-end drives the mount until response gearing brings the system to rest.

It must be realized that the preceding paragraphs deal with the problem in the simplest terms. Actually, two synchro receivers are used to initiate the movement of the pilot piston. One is a coarse synchro; the other a fine at the ratio of 1:36. If the signal differs from the existing position of the mount by an angle equal to 3.8 degrees, the coarse synchro will take control to move the fine pilot piston to its maximum position and keep it there until this difference becomes less than 3.8 degrees. Then the fine synchro, through the cam, will again perform its function as described above. Also there are other valves in the system such as the acceleration, offset control, and synchronizing valves.

D. Amplidyne Follow-up System

10D1. General

An amplidyne follow-up system in its simplest form consists of the four units shown in figure 10D1:

1. The synchro control transformer.
2. The amplifier.
3. The amplidyne motor-generator.
4. The follow-up DC motor.

The synchro control transformer receives the order signal which indicates electrically what the position of the load should be. The rotor of the synchro control transformer is turned by the response shaft, which is geared to the load and so indicates what the position of the load actually is. The synchro compares the actual load position with the ordered position; and, if the two do not agree, it generates an alternating-current signal which is transmitted to the amplifier. The angular difference between the two positions is called the *error,* and the signal to the amplifier is the *error signal.* The error signal indicates by its electrical characteristics the size and direction of the error. If no error exists, the system is said to be *in correspondence* and the error signal is zero.

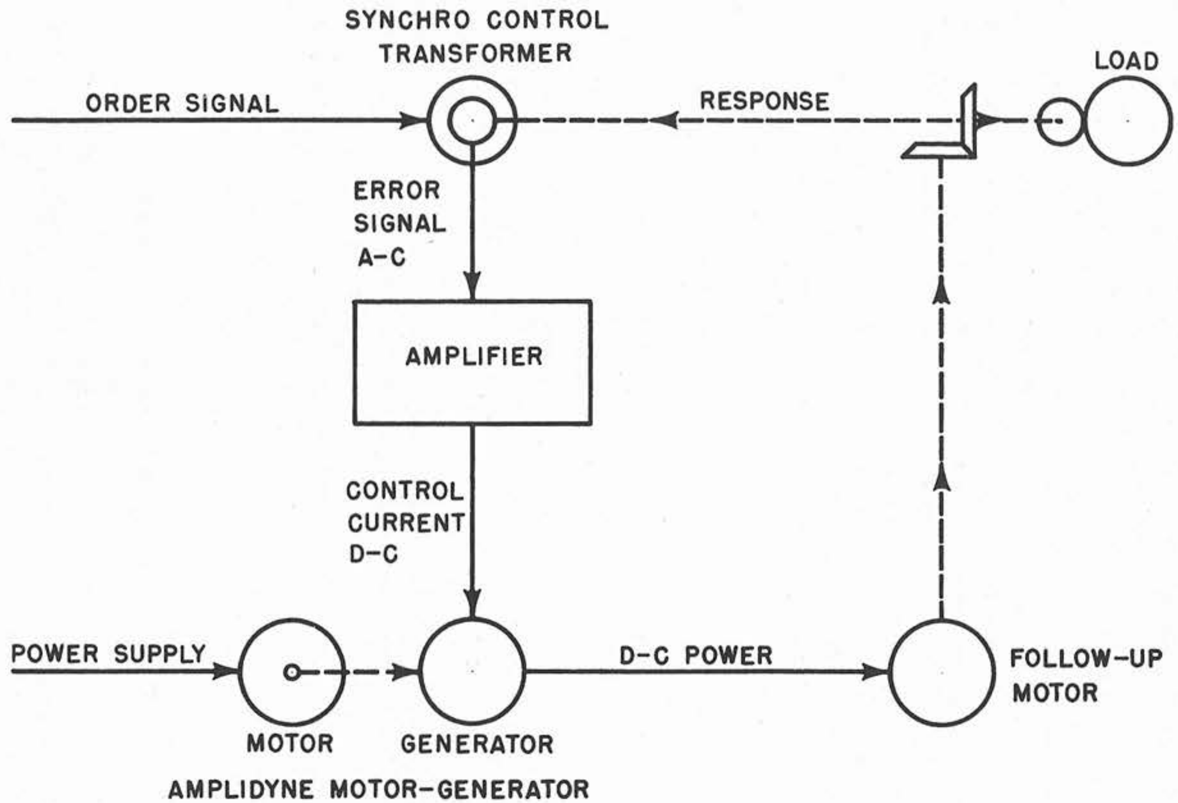

FIGURE 10D1.—The amplidyne follow-up system.

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The amplifier receives the alternating-current error signal, amplifies it, and converts it into direct current suitable to energize the field windings of the amplidyne generator.

The amplidyne generator supplies direct current to operate the follow-up motor. The direction of rotation of the motor depends on the polarity of the output of the amplidyne generator, which in turn depends on the direction of the error as indicated by the error signal. As a result, the motor moves the load in the proper direction to reduce the error.

The amplidyne generator is a power amplifier on a large scale. Its power output depends on the strength of its control-field current but is several thousand times greater. The additional power is supplied by the motor which drives the amplidyne generator. The strength of the control-field current from the amplifier depends on the size of the error as indicated by the error signal. The power applied to the follow-up motor, therefore, is greater for a large error than for a small one.

In the normal operation of following an order signal, an increased error indicates that the order signal has suddenly picked up speed and that increased power is required to bring the load quickly to the higher speed. In response to an increased error, the amplidyne generator promptly supplies the necessary added power. If the order signal suddenly slows down, the load may overrun the signal and reverse the direction of the error. As a result, the polarity of the amplidyne output is reversed; the motor tries to run in the reverse direction, and so applies a retarding force to the load.

When the order signal moves at a uniform speed, the motor must supply only enough power to overcome the friction in the system. The power output of the amplidyne is then much less than when the speed is increasing or decreasing, and the error will be correspondingly smaller.

Because of the immense power amplification available in the amplidyne generator and amplifier, an extremely small error signal supplies enough power to control the mount. In following the usual gun-train or gun-elevation order, the errors should not be more than a few minutes of arc under the most adverse conditions.

10D2. Synchro control transformer

The functioning of a synchro control transformer was described earlier in this chapter. As in the system described in article 10B3, the synchro control transformer's output in an amplidyne system produces an AC output signal which depends on the position of the rotor with respect to the stator's magnetic field. The stator receives a gun-order synchro signal from a synchro transmitter, and the synchro control transformer's rotor is driven by the gun mount. As the gun mount is driven toward gun-order position by the amplidyne power drive, the control transformer's rotor approaches the null position. At null, the gun mount is in gun-order position.

Because of the sensitivity of the system, the synchro control transformer's output very closely controls the operation of the power drive, increasing acceleration of the mount's movement as the rotor signal increases, and minimizing overshooting.

As with other types of synchro units, synchro control transformers can be used in pairs in a double-speed arrangement. Identical synchros are used, but they are geared at 36:1. Both synchros are connected to the input of an electronic amplifier, but a relay, switching circuit, or electrical network automatically selects the output of either the coarse or the fine synchro. The coarse synchro control transformer's signal is switched to the amplifier input when the gun mount is more than about 3° out of synchronism. As the gun mount approaches synchronism with the gun-order signal, the fine synchro signal automatically switches into the circuit to furnish the controlling input to the amplifier and continue gun mount movement until it is fully matched with gun order.

10D3. Amplifier

The function of the amplifier is to supply two control-field currents for the amplidyne generator. In following an order signal in automatic control, these currents must be varied in accordance with changes in the error signal. When the error signal is zero, the two control currents should be equal. When the error signal calls for movement of the mount in one direction, one control current must increase and the other must decrease. When the mount is to move in the opposite direction, the unbalance in the control currents must be reversed.

The amplifier has two stages. The first stage is primarily a rectifier stage in which two direct currents are produced whose magnitudes are controlled by the error signal. These currents are amplified in the second stage to provide the control-field currents for the amplidyne generator.

10D4. Amplidyne generator

The construction and operation of the amplidyne generator can best be understood by following through the steps necessary to convert an ordinary direct-current generator into an amplidyne generator.

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When a coil of wire is rotated in a magnetic field, voltage are induced in the coil, and, if the ends of the coil are connected together, these voltages cause electric currents to flow in the coil. This is the basic principle of a generator.

The principal parts of a generator are the *stator,* or stationary part, and the *armature,* or rotating part. In a common form of generator, a coil of wire is wound on a part of the stator and is supplied with a small *exciting current* which magnetizes the iron in the stator and armature to provide the necessary magnetic fields. The armature carries other coils which are rotated in the magnetic field as the armature is turned. As a result, voltages are induced in the armature coils.

The ends of the armature coils in a DC generator are connected to copper bars on a *commutator* which rotates with the armature. The voltages induced in the coils are taken off by stationary carbon brushes engaging the commutator as it turns. If the brushes are connected together through an external circuit, current will flow in the circuit and through the armature coils.

The connections to the commutators are such that the maximum voltage appears across two points on opposite sides of the commutator. The positions of these points depend on the direction of the magnetic field and do not change as the commutator rotates. The brushes are located at or near these points to take advantage of the maximum voltage.

In figure 10D2, the upper view represents an ordinary direct-current generator such as the one just described. The inner circle is the commutator, with brushes at top and bottom. The next circle represents the armature, and the outer structure is the stator with a coil carrying the exciting current wound on its pole piece. Other conditions being equal, the power output of the generator will be *proportional* to the power input to the excitation winding, within the limits of normal operation. 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 excitation current produces a magnetic field whose direction is indicated by the arrow FC. It is this magnetic field which induces the 100 volts which appears across the brushes. At the same time, the 100-amp load current flowing in the armature coils creates another magnetic field FS at right angles to FC. It has about the same strength as the field FC. This second magnetic field, called *armature reaction,* does no useful work in the ordinary generator and is, in fact, a source of trouble.

If now the brushes are short-circuited, as shown in the second view, an immense armature current will

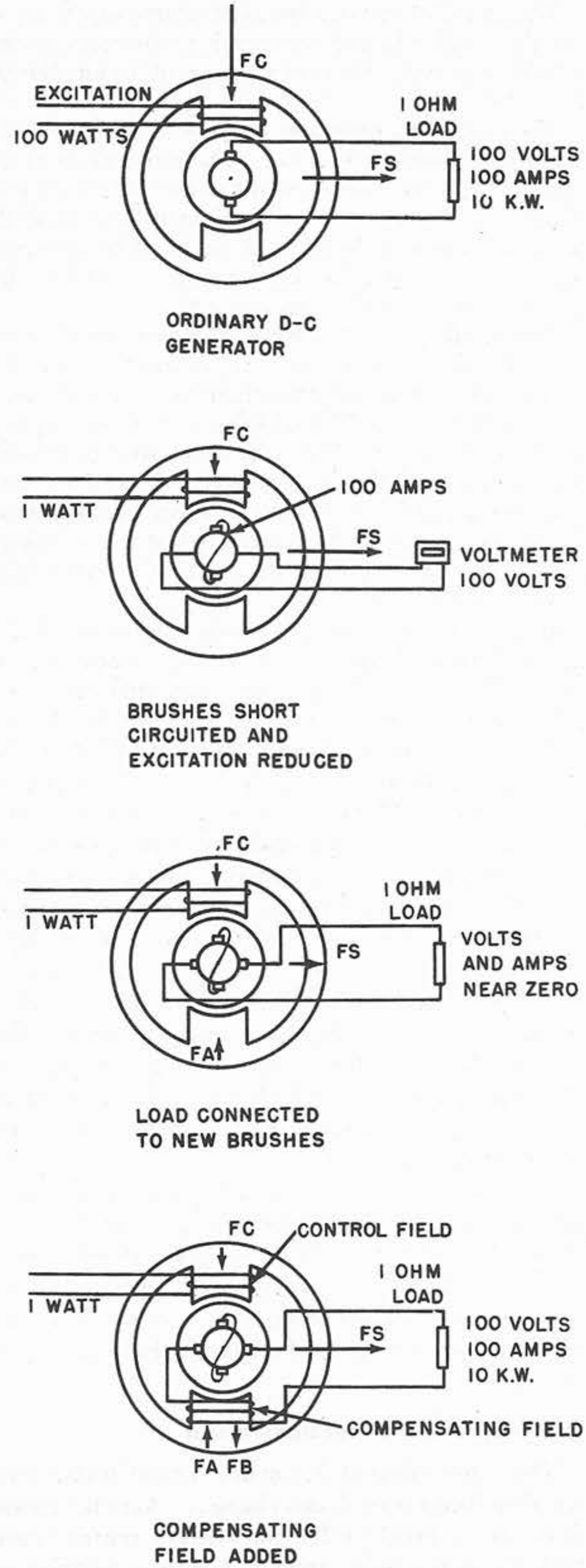

FIGURE 10D2.—Development of amplidyne generator.

flow unless the excitation is reduced. If the excitation is cut down to about 1 watt, FC is reduced accordingly, and the normal full-load current of 100 amperes flows through the short-circuit path. This current produces the same armature reaction FS as before.

The armature reaction FS induces a voltage in the armature in the same manner as flux FC but this voltage appears on the commutator at 90 degrees from the voltage induced by FC. A voltmeter connected to points on the commutator, as shown in the second view, will indicate approximately full-load voltage.

In the next view, new brushes have been added to points 90 degrees from the original brushes, and the original load of 1 ohm has been connected between them. The high voltage formerly existing between these points has almost disappeared. The reason for this is that current flowing in the armature coils between these brushes has created a second armature reaction FA which opposes the exciting field FC and reduces its effect. The decrease in the effect of FC reduces FS and consequently reduces the voltage across the new brushes.

The lower view shows the last modification necessary to produce an amplidyne generator. The armature current from the new brushes has been taken through a compensating field winding and creates a magnetic field FB opposed to FA. This field may be adjusted to balance out FA and thus restore the full effect of the exciting field FC. FS is restored to normal, and full-load current may be drawn from the new brushes. Since both FA and FB depend on armature current, they will always be approximately balanced and the output voltage is nearly independent of the armature current. Full-load output has been obtained with only 1-watt excitation instead of 100. The amplification is 10,000 to 1 instead of 100 to 1.

Other refinements are necessary to produce the fast, stable operation necessary in a follow-up system, but the machine shown in the lower view of figure 10D2 is the basic form of all amplidyne generators. In the equipment now in use, excitation is supplied to two control windings which are oppositely wound. The direction of the magnetic field FC and the polarity of the output of the generator depend upon which winding receives the stronger current. Thus, the direction of rotation of the follow-up motor, which receives its power supply from the amplidyne generator, can be controlled at will by supplying the stronger current to one or the other of the control fields. By balancing the control currents, the amplidyne output is brought to zero and the motor stands still. The difference between the two control currents determines the amount of power supplied to the motor.

10D5. 5″/54 amplidyne train drive

An example of amplidyne power drives in the Navy is the Train Power Drive Mark 14 on the 5″/54 single mount.

The main units in this system at the mount are (1) gun train indicator-regulator, (2) 40-hp train motor, (3) brake unit, (4) train-selector switch, (5) master switch, and (6) shifting clutch; those located in the amplidyne control room below deck are (7) train amplidyne motor-generator and (8) amplifier unit. See figure 10D3.

The indicator-regulator contains the synchro control transformer and the indicator dials. The brake unit is a safety mechanism which locks the drive and holds the mount stationary if power supply fails during power operation. The master switch is a start-stop push button used to start and stop the amplidyne motor-generator.

The shifting lever has two main positions, MANUAL and POWER. A middle position of STOP acts as a safety feature in shifting the mount between power and manual.

The selector switch has four positions: AUTO, LOCAL HIGH, LOCAL MEDIUM, and LOCAL LOW. It is used to select any of these four means of power operation of the mount.

E. Other Types

10E1. Thyratron system

Thyratron systems are found on stable elements and stable verticals which require a simple and accurate low-power automatic control system. In this system the electrical (AC) signal is amplified by electronic tubes. The amplified signal is then changed to DC by 1 of 2 half-wave rectifier tubes. A signal in 1 direction utilizes 1 rectifier tube, while a signal in the other direction utilizes the other rectifier tube. The DC output of the rectifier tubes is led to a DC motor, the direction of rotation of which depends upon which of the rectifier tubes furnishes the voltage. This DC motor furnishes the working power for the system.

10E2. York Safe and Lock Company drive

This drive, used extensively as the train and elevation units on 40-mm mounts, is an electric-hydraulic drive using both electronic and hydraulic amplifica-

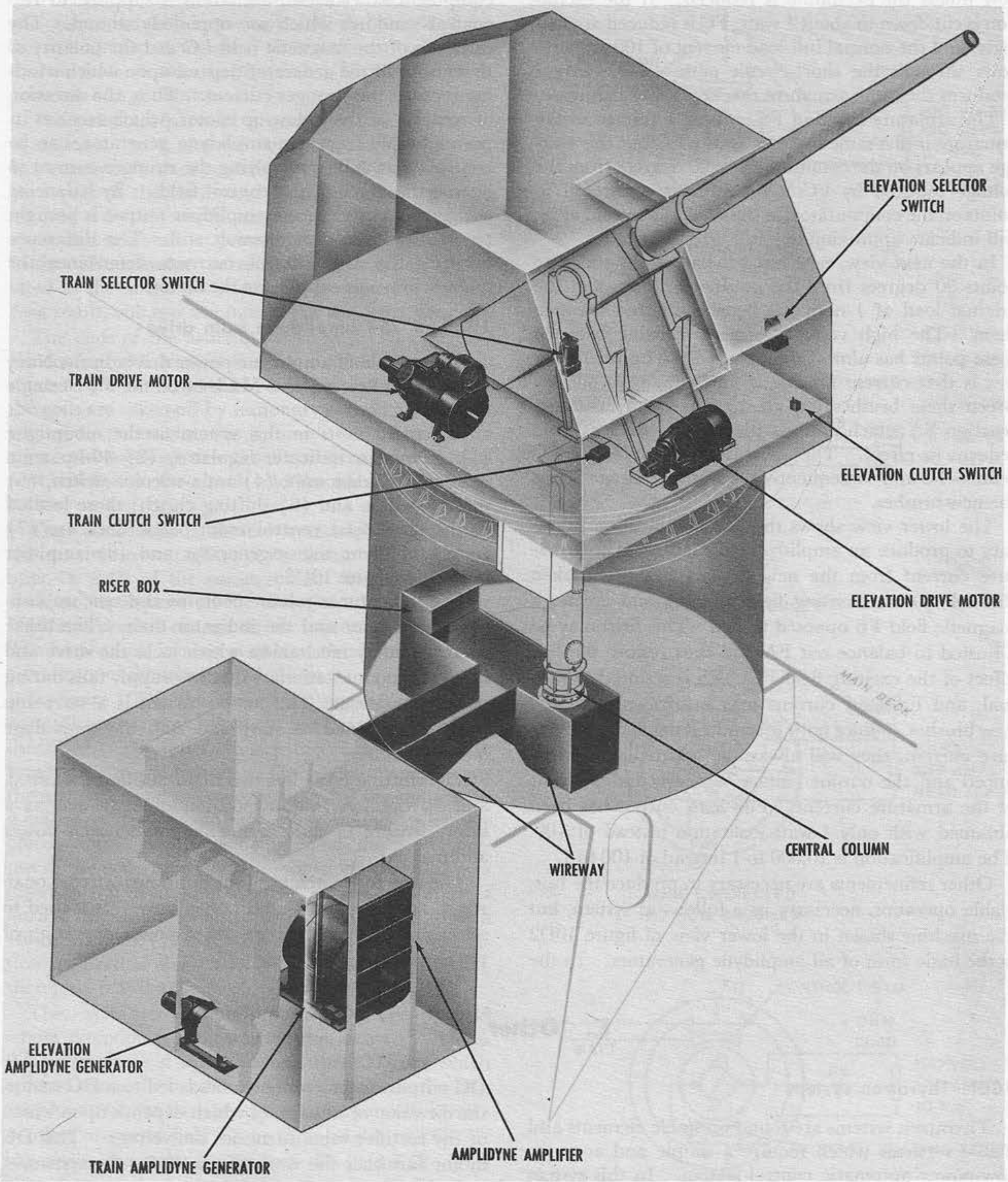

FIGURE 10D3.—5"/54 amplidyne equipment in mount.

tion. Figure 10E1 is a simplified schematic drawing of the drive.

The main parts of this system consist of an electric power motor, a hydraulic A-end pump and B-end motor, and a receiver-regulator control system. The electric motor drives the A-end pump. Fluid from the A-end drives the B-end in the proper direction and amount. The B-end is directly geared to the mount

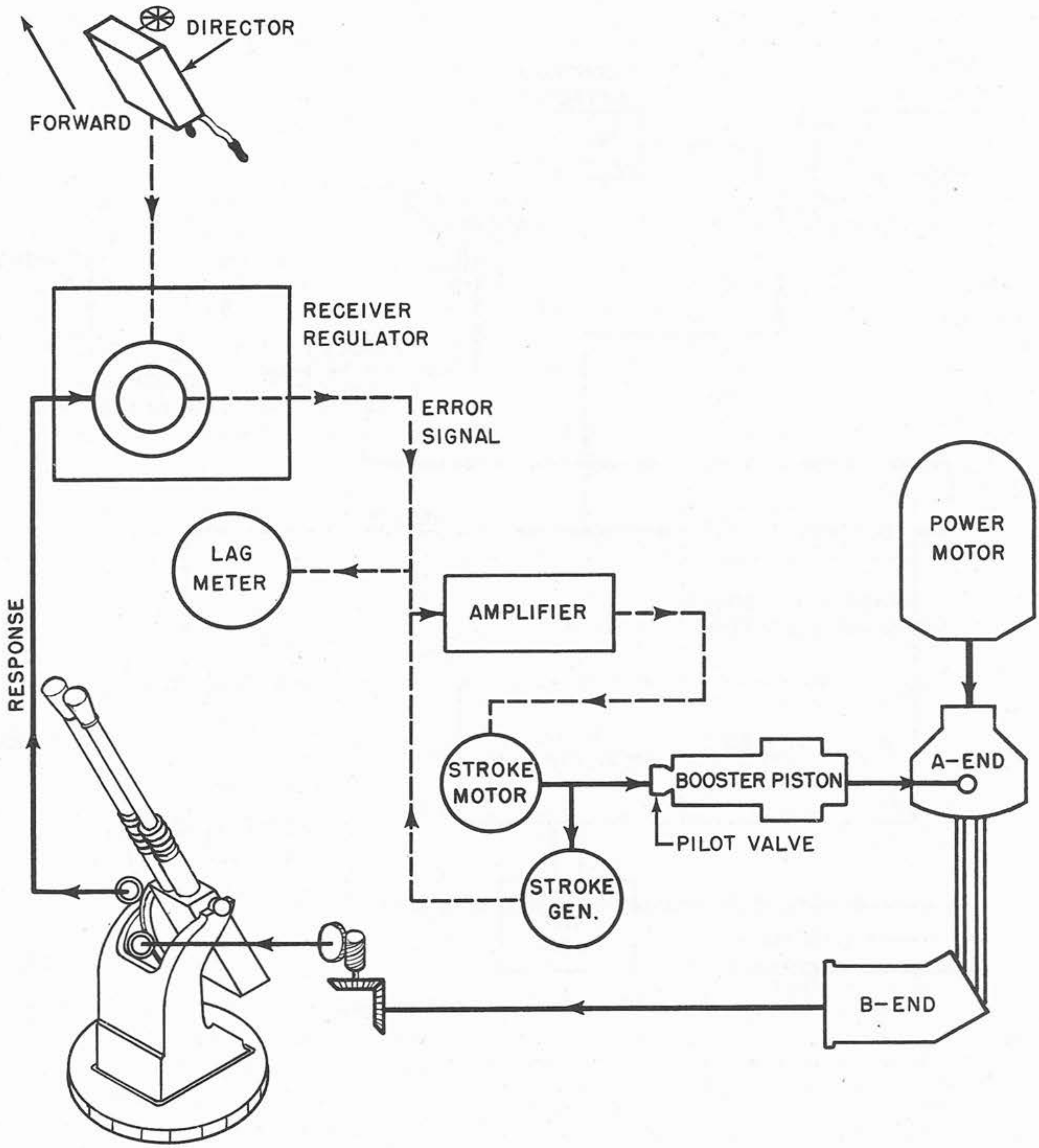

FIGURE 10E1.—York Safe and Lock drive.

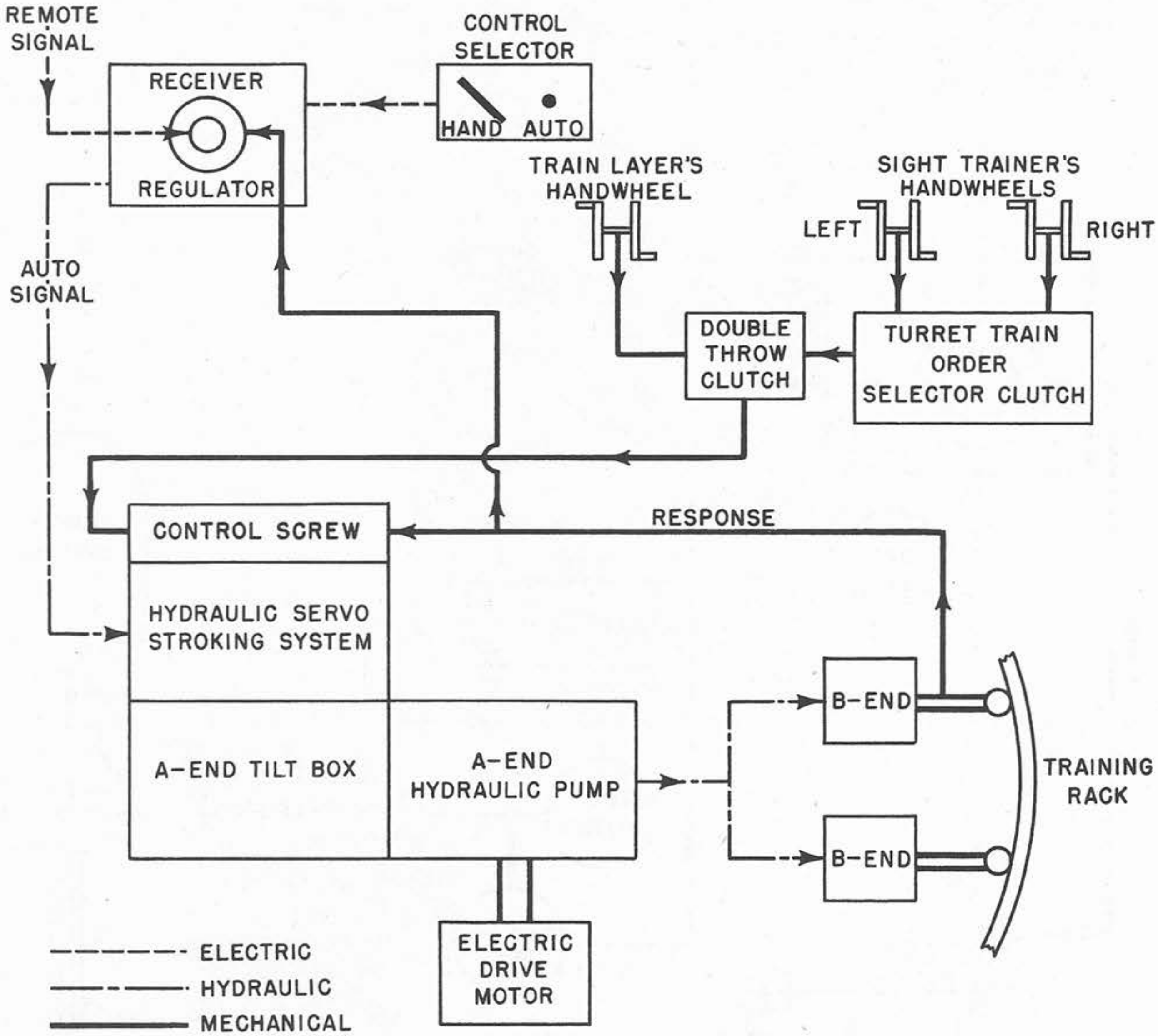

FIGURE 10E2.—16"/50 caliber train power drive.

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to drive it in train (elevation). The receiver-regulator controls the position of the tilt box of the A-end in the following manner:

The receiver-regulator has a control transformer which sends an electrical error signal to an electronic amplifier. The amplified signal drives a stroke motor which controls a hydraulic pilot valve. This pilot valve positions the booster piston directly connected to the A-end tilt box, thereby providing the necessary control of the mount. As the stroke motor rotates, it drives the stroke generator, which sends a pre-response signal back to the amplifier, thus smoothing out the operation of the system.

This mount is equipped with a three-position selector lever whose settings are: MANUAL, LOCAL, and AUTO. In MANUAL control the pointer's and trainer's handwheels drive the mount and the power motors are not energized; however, the *lag meter* may be used to match a signal from the director. The lag meter is a voltmeter indication of the error signal. In LOCAL power control, the pointer controls the mount in train and elevation through use of the handle control (joy stick). In AUTO, the mount is positioned by the power drives using remote signals from a director.

10E3. 16"/50 turret train drive

The automatic control equipment used to train the 16"/50 caliber turret is an electric-hydraulic drive designed by the General Electric Company. See figure 10E2.

The main units of this system are the electric drive motor, the variable-speed gear consisting of 1 A-end and 2 B-ends, a servo stroking system, and a receiver-regulator.

Turret train movement is controlled by positioning the A-end tilt box. Such tilt-box movement is performed by a servo stroking cylinder and piston under hydraulic pressure from a control pressure pump. Opening of servo pressure to the stroking cylinder is controlled by two methods: HAND and AUTO.

In HAND control, movement of the trainer's handwheels rotates a nut on the control screw, causing the screw to move axially within the nut. This movement of the screw through linkages and valves controls the flow of fluid into the servo cylinder, moving the servo piston. The servo piston, being directly connected to the A-end tilt box, tilts it the amount ordered. As the turret trains, response turns the control screw, moving it axially and thereby repositioning the tilt box back to its neutral position. Handwheel motion, as can be seen from figure 10E2, may come from the train layer's station or from either the left or the right sight trainer's stations, depending on the positions of the clutches.

In AUTO control, the remote signal is received at the receiver-regulator by a synchro. The rotor of the synchro positions a small hydraulic valve. This signal is amplified hydraulically and controls the flow of fluid into the servo cylinder. This positions the servo piston and, hence, the A-end tilt box. Response, as the turret trains, rotates the stator of the synchro and returns the synchro rotor and the A-end tilt box to neutral.

10E4. Fuze-setting drives

An all-electric type of drive is used on automatic fuze setters. This drive may be considered nothing more than a two-stage servo-motor drive. Movement of the synchro receiver rotor, in response to the remote signal, closes contacts to a 115-volt AC pilot motor. Rotation of this pilot motor shaft closes silver contacts which sends 115-volt alternating current to the power motor, and causes it to drive the load in the proper direction. Rotation of this pilot-motor shaft also rotates the synchro receiver stator, returning it to neutral and opening the first set of contacts. Response from the load drives back to the power-control head of the pilot motor, opening the second set of silver contacts and stopping the power motor when the load is positioned in response to the original signal.

F. Shipboard Tests of Automatic Control Equipment

10F1. General

Frequently, errors made by automatic control equipment in following a remote signal are obvious and may be readily determined without special apparatus. A mount matching a fixed signal may be in error by a constant amount such as 10 or 120 degrees. This type of error may be only a mistake in wiring, which is easily corrected. In certain types of drives, such as 40-mm, matching 180 degrees out may occur because the error voltage for 180 degrees error is zero, since the coarse synchro is 2-speed (*i. e.,* 1 revolution of the synchro causes 180° revolution of the mount). Excessive oscillation of the mount or sluggishness in following a signal indicates that the drive needs adjustment. In order to determine whether a drive is following a signal accurately, instruments such as the dummy director with its accompanying error recorder are used. See the next article.

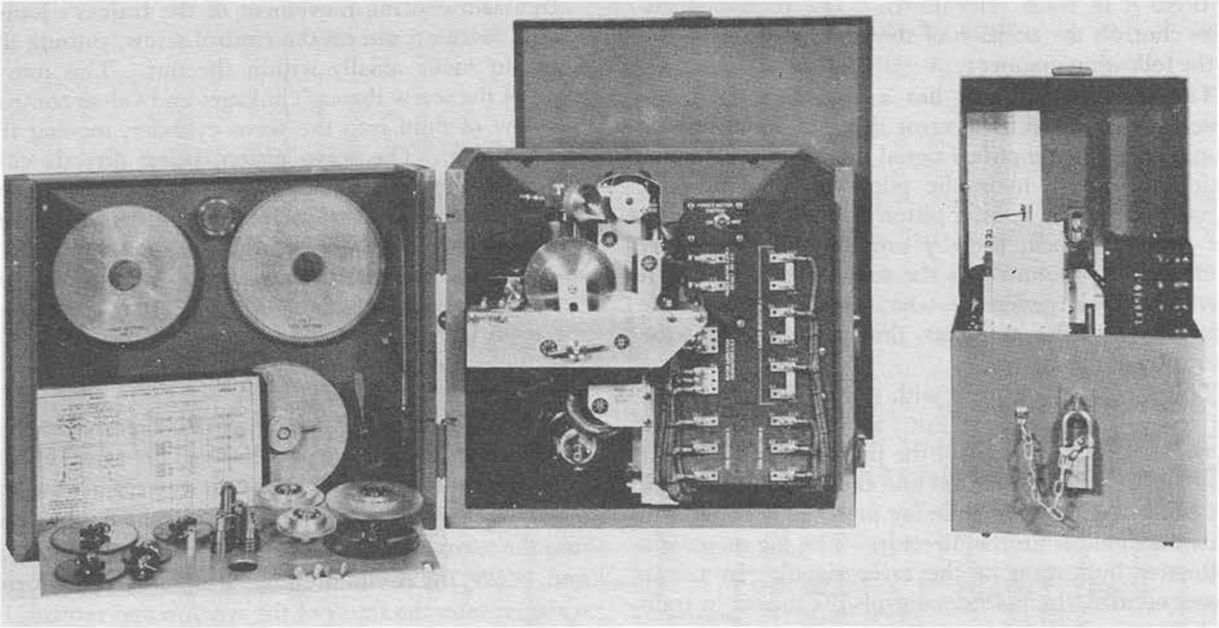


FIGURE 10F1.—Dummy director and error recorder.

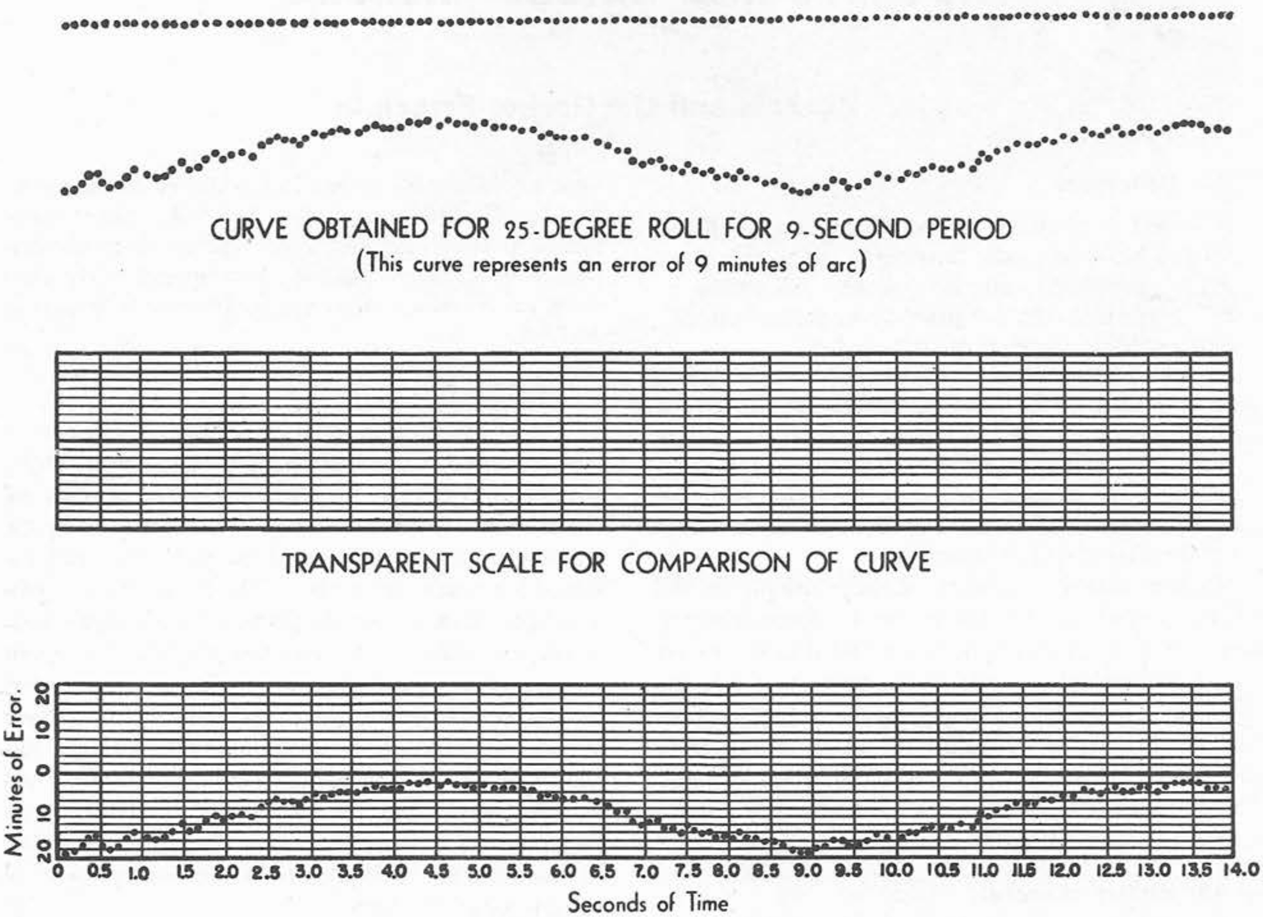
10F2. Dummy-director tests

Using a dummy director and error recorder, the dynamic accuracy (error in following a remote signal) of automatic control equipment may be determined.

The dummy director is an instrument which transmits an electrical order signal to the control equipment of the unit under test. The motion introduced may be either constant or simple harmonic.

The error recorder (spark recorder) measures and makes a permanent record of the error on a strip of paper. Figure 10F2 shows sample recordings. If no error exists, the recording shows a straight horizontal line. The amount of variation of the plot from the zero error line, therefore, is a measure of the error in minutes.

Such tests are made whenever equipment does not seem to be functioning properly, as well as periodically each quarter and during shipyard overhaul.



The time from peak to peak is read on the horizontal scale. The error in minutes of arc is read on the vertical scale, and is then divided by 2. Here the reading of 18:2 represents an error of 9 minutes, which is within the maximum allowance error of 10 minutes for a roll of 25 degrees. A similar curve, if obtained for a roll of 20 degrees or less however, would indicate excessive error.

FIGURE 10F2.—Sample error-recorder strip.

Chapter 11

ROCKETS AND GUIDED MISSILES

A. Rockets and the Rocket Principle

11A1. Definitions

A rocket is a missile propelled by the escape of gases produced from the burning of solid, liquid, or gaseous propellants completely contained within itself. A true rocket by definition does not, for example, use atmospheric oxygen to burn its fuel.

Figure 11A1 shows the external appearance of one type of rocket. The *head* of this rocket contains a high-explosive charge and a *nose fuze* to initiate detonation. The *motor* contains the combustion chamber, and houses the propellant charge. Hot gases from the combustion chamber issue from a *nozzle* at the after end of the assembly.

Rockets exhibit two characteristics unique in the field of propulsion: (1) the propulsive force delivered is independent of atmospheric air, and thus the rocket may be propelled through empty space, and (2) the propulsive force is unaffected by the velocity. One of the challenging problems in rocket design is to develop an acceptable degree of stabilization in flight. The rocket shown in figure 11A1 represents a *spin-stabilized* rocket.

11A2. History of rockets

Rockets were used in the Far East as early as the 13th century. In the first decades of the 19th century several western armies employed rocket projectiles with greater or lesser success, a notable incident in the history of our own country being the use of rockets by the British during the attack on Washington in the War of 1812.

But the military use of rockets languished after the middle of the 19th century, attention being diverted from them by improvement in guns and gunnery. Projectiles fired from guns proved to be superior to rockets in both range and accuracy. So for many years the employment of rockets was largely associated with pyrotechnic displays. During World War II, however, the development of military rockets underwent a considerable revival in the United States, Great Britain, Germany, and the U.S.S.R. Short-range rockets were developed for use against shore installations, ships, tanks, airplanes, and personnel. The Germans produced a long-range rocket missile known as the V–2.

11A3. Principles of rockets

A rocket motor is a metal tube that serves as a combustion chamber. The burning propellant generates hot gas, and the gas pressure within the combustion chamber rises quickly to some value determined by the amount and characteristics of the propellant and the size of the nozzle or nozzles. The gas exerts approximately the same outward pressure on each square inch of surface within the combustion chamber; however, the gas rushes out of the nozzle without exerting any force upon the area of the opening, but with exertion of full force upon the corresponding area at the forward end of the combustion chamber. Thus a net force or thrust acts in the forward direction. The magnitude of this force is roughly the area of the orifice in square inches multiplied by the internal pressure in pounds per square inch.

Fundamental to rocket propulsion, then, is the conversion of heat energy into kinetic energy by an adiabatic expansion. This poses two basic problems: (1) to generate gas under high pressure and at a constant rate—a problem of chemical reaction; and (2) to direct the high-pressure gases into a high-velocity stream—a problem of nozzle design. Pressure in a rocket motor depends largely upon the burning rate and escape rate. In the case of solid-fuel rockets, for example, the composition of powder, shape of grain, and rate of burning, which have important relationships to performance as discussed in chapters 2 and 3, are also important factors in rocket design.

a. *Rocket motors.* The thrust of a rocket motor is an equal and opposite reaction to the expansion of

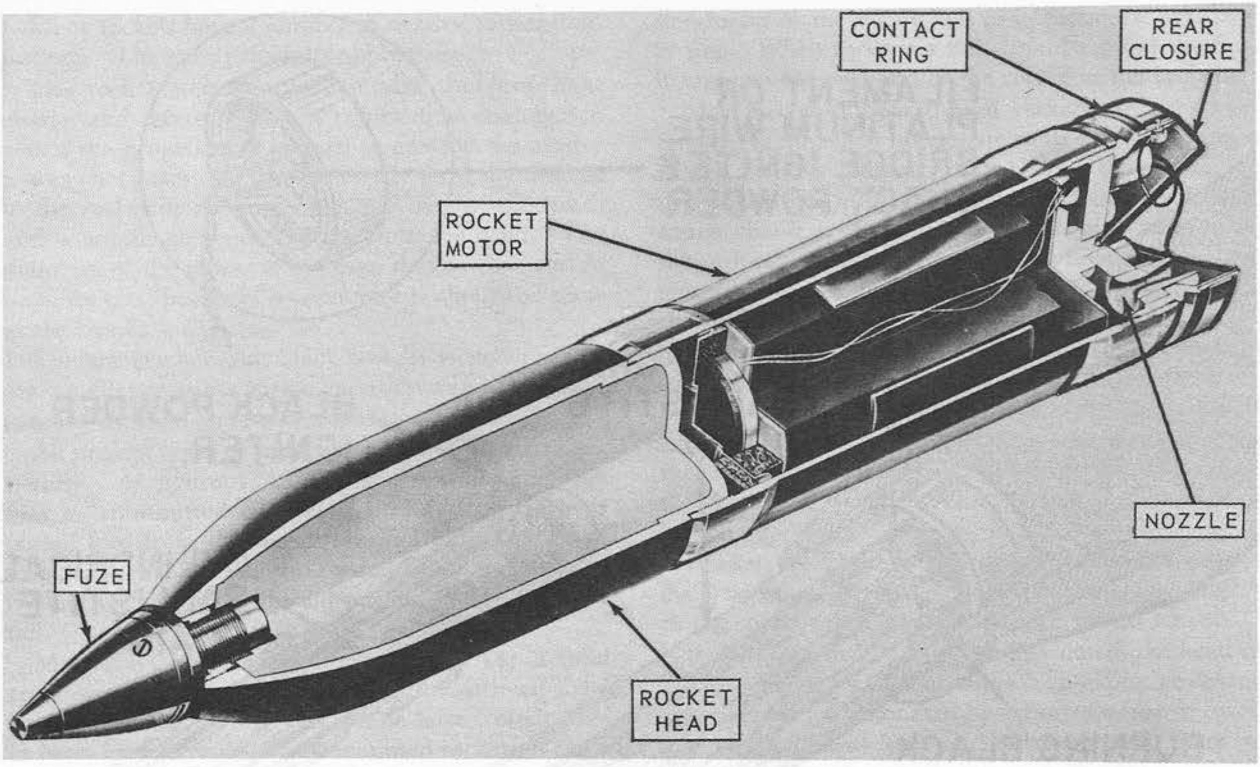


FIGURE 11A1.—5-inch spin-stabilized rocket.

gases discharged at the nozzle; and since the expansion of these gases is maximum in a vacuum, rockets function most efficiently in such a medium. Rocket motors contain all the essentials for functioning, and do not require atmospheric oxygen for combustion.

Consider the nozzle in a little more detail.

The function of the nozzle is to permit the hot gas produced by the burning ballistite propellant to flow out of the rocket motor, pushing the rocket along as it goes.

The shape of the nozzle determines the characteristics of gas flow, and hence has much to do with how efficiently the gas flow propels the rocket. Gas flow must be smooth (nonturbulent). For a smooth, controlled trajectory, it must produce thrust along the long axis of the rocket. And the nozzle must be designed to develop every possible bit of thrust from the flow.

By tapering the rear of the chamber so that it narrows smoothly toward the nozzle aperture, a smooth, nonturbulent flow of escaping gas is created. This tapered section forms the forward half of the nozzle. The tapered extension, forming the after end of the nozzle, which leads outward from the nozzle aperture, forces the escaping gas, as it expands to furnish additional (about 33 percent) forward thrust. (Fig. 11A2.)

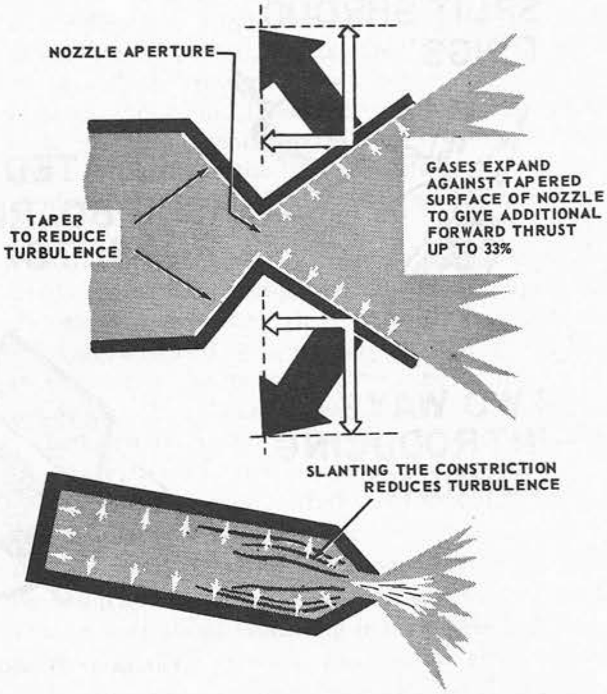


FIGURE 11A2.—Rocket motor nozzle design.

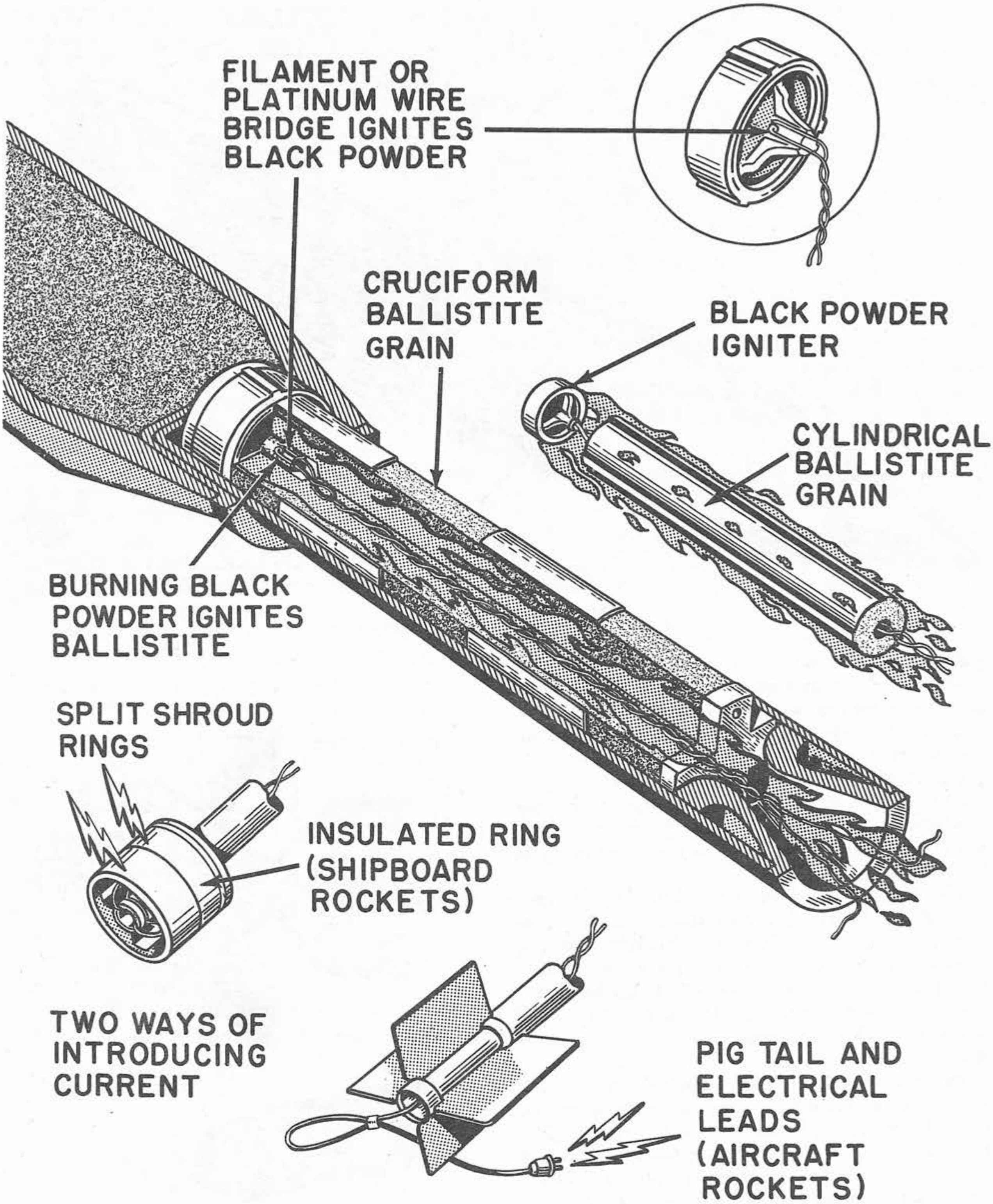


FIGURE 11A3.—Rocket motor ignition.

Many rockets have a number of nozzles, rather than just one. The same principles apply there.

The rocket MOTOR TUBE contains the propellant charge and igniter. It is a combustion chamber in which the propellant is burned to provide the motive power (hot gases) for the rocket. It generally threads to the rocket or an adapter in the base of the head, and is usually shipped separate from the head. The diameter of the motor is less than that of the head in some rockets; in others its diameter is about the same as the head's.

The IGNITER contains black powder loosely packed, and an electric SQUIB with a low-resistance bridge wire running through a match composition.

All present types of rocket motors are initiated electrically. As figure 11A3 shows, the firing impulses may be transmitted either (in aircraft rockets) by a pigtail lead from the rocket plugged into a source of firing current, or (in surface-launched rockets) by contact surface on the shroud surrounding the rocket's tail.

Most Navy rockets use either (fig. 11A4) a solid cruciform grain or a cylindrical grain with an axial hole and radial perforations. The latter, often used in Navy ground or shipboard mounted rockets, is characterized by three ridges spaced 120° apart and running longitudinally along the grain. The cruciform grain, usually found in Navy aircraft rockets, in section is a symmetrical cross. If all of the exterior surface of this grain were permitted to burn, there would be a gradual decrease of area, and the burning rate would be regressive—that is, the rate of gas production would decrease as the grain continued to burn. Since a uniform burning rate is desired, a number of slower burning plastic strips or INHIBITORS are bonded to certain parts of the area exposed on the outer curved ends of the arms. These slow the initial burning rate, and gas production rate is approximately uniform as long as the grain burns.

Hollow cylindrical grains have inherently uniform burning rates and usually require no inhibitors.

Grain sizes vary according to the motor in which they are to be used. Most use only a single grain, but some may use up to four.

The *grid* is a metal piece near the nozzle which supports the propellent grain so that sufficient clearance is allowed between the grain and the nozzle to permit a free flow of gas through the nozzle. Without the grid, the grain will move aft, blocking the nozzle and causing excessive pressures to build up in the motor.

Tail *fins* provide stability in flight, prevent tumbling, and ensure head-on impact. During burning, the action of the air against the fins tends to resist side forces of the nozzle and to improve the accuracy of fire. When there is a tail shroud around the fins, it supports the rear end of the rocket in the launcher.

Most newer shipboard-fired rockets are SPIN-STABILIZED; that is, their nozzles are canted to exert torque as well as forward thrust. The result is that the rocket spins like a gun projectile in flight. Such rockets, of course, have no fins. Since spin begins as soon as the propellant starts to burn, the stabilizing effect begins as soon as sufficient thrust is developed to launch the rocket.

Aircraft rockets are fin-stabilized designs. (To save space, folding fins that open on launching are often used.) Fin stabilization is poor when a rocket is launched at zero or low air speed (as is the case on surface craft); in aircraft, however, the plane's air speed ensures good stabilization at the instant of launching.

Rockets have been designed with canted fins, to produce spin. This kind of design is, however, subject to the drawbacks common to other finned rockets.

b. *Rocket heads.* As previously noted, the head of a conventional rocket contains a high-explosive charge capable of being detonated by action of a fuze or fuzes. Use of centrifugal force and setback to arm fuzes, as in gun projectiles, is not universally applicable to rocket fuzes. In part, this is because rockets accelerate at a lower rate than do gun projectiles; moreover, with fin-stabilized rockets no centrifugal forces are available. For these reasons various other devices are employed to arm rocket fuzes. The fuzes of some antisubmarine rockets, for example, are armed either by hydrostatic pressure or by rotation of a propeller after travel of 15 to 20 feet in the water. When armed, such rockets detonate upon impact with any solid object. Several methods have been utilized to arm the fuzes of barrage or bombardment rockets so that they will detonate upon impact or after a predetermined delay. In one type of nose fuze, arming depends upon rotation imparted to a small propeller as the rocket moves through the air. A base-detonating type is armed by a mechanism that is actuated by pressure in the rocket motor during burning.

On the other hand, fuzes used on spin-stabilized rockets may be similar to the fuzes of gun projectiles, since centrifugal force is present.

c. *Rocket launchers.* Modern rockets are launched from various types of launchers, which in essence are mechanisms designed to point the rocket in the right direction and to actuate or ignite the motor. One significant fact about launching is that there is little or no recoil. The forward momentum given to the rocket is balanced by the rearward escape of propellant gases. Therefore, a very large total weight of "pay

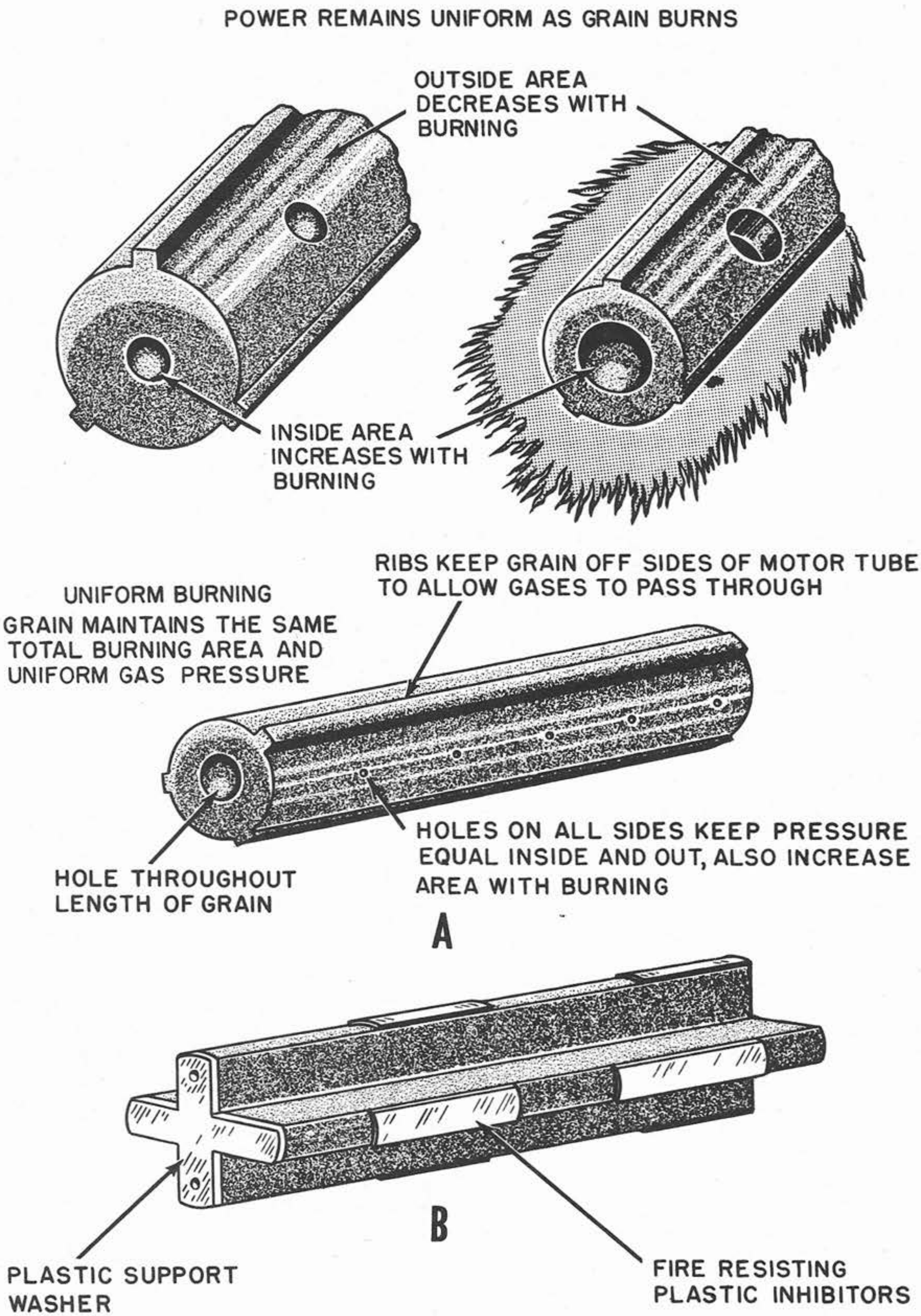


FIGURE 11A4.—Rocket motor grains. A. Cylindrical. B. Cruciform.

load" may be fired from boats, airplanes, or other conveyances which could not possibly withstand the recoil shock incident to firing equivalent projectiles from traditional types of larger guns. This is why the development of aircraft rockets, to cite one example, has been so significant. Inability of aircraft structure to stand up under the recoil shock of conventional-type guns had long been a limiting factor in aircraft armament. Until the rebirth of military rockets occurred, the largest projectile fired by most aircraft guns weighed only 2 or 3 pounds. The modern rocket-firing plane, however, is capable of launching rockets which weigh over 1,000 pounds.

It also is noteworthy that many rocket launchers are relatively light in weight, simple, inexpensive, and more readily replaceable than comparable guns. On the other hand, much more propellant is required to bring a rocket up to a given velocity than is the case with a gun projectile. Moreover, rocket fire (with conventional short-range rockets) launched from the ground or from the deck of a ship compares unfavorably in accuracy with gunfire.

Shipboard rocket launching devices always have a tube or rail which supports the rocket until firing, and guides it during the critical initial portion of its trajectory. This is necessary because, especially with fin-stabilized rockets, the stability of the rocket is relatively poor until it attains a fairly high air speed.

On fixed-wing aircraft, as has already been explained, fin stabilization of rockets is effective at the instant of launching because of the plane's air speed. Rocket launchers in aircraft are therefore merely supports which hold the rocket until launching, and then release it as the propellant is ignited. These are called "zero length" launchers.

Shipboard launchers may be of "repeater" design to fire rockets successively at short intervals from a magazine or loading device. Electrical contact to the rocket's squib in such launchers is made through a set of contactors which rub against insulated metal contacts on the rocket. In aircraft launchers, only one rocket is fired per launcher per flight. The electrical connection from plane firing system to rocket is made through pigtail leads and plugs, which part upon firing.

11A4. Rocket trajectory and stabilization

Mention has been made of the fact that conventional rockets are less accurate than gun projectiles. One reason for this is that gun projectiles are guided by the gun bore during the entire period in which the propellant is burning and maximum velocity is being attained. A rocket, on the other hand, is guided by its launcher, if at all, during only a very small portion of the time that its propellant burns; in all cases, maximum velocity of the rocket is attained after it has left the launcher, and in some cases after the rocket has passed through hundreds of feet of free flight. In addition, the center of gravity of a gun projectile remains fixed in position in relation to the projectile while the latter is in flight, whereas the center of gravity of the rocket necessarily shifts in relation to the rocket as the fuel in the motor is consumed.

After a rocket has attained maximum velocity, it may traverse a trajectory similar to the path traversed by a gun projectile. On the other hand, it is possible to place lifting surfaces (wings) on the rocket head, which will cause the missile to follow a *glide path* rather than a purely ballistic path, once acceleration is completed.

The older type of rockets which came into widespread use during World War II were fin stabilized. Such rockets have the advantage of being relatively simple to manufacture, but are likely to prove somewhat cumbersome in handling, launching, and stowing. It may be pointed out, however, that fin stabilization is the type associated with a glide path of flight, and that stabilizing fins, with proper adaptation, may be used as rudders and elevators in controlling the path of flight. These facts take on special significance when we consider the potentialities of guided missile.

Spin stabilization has also been used extensively in the case of rockets. A spin-stabilized rocket, like a gun projectile, tends to maintain a relatively stable course because of the gyroscopic effect resulting from its rotating motion, which in part counteracts forces that otherwise would produce deviation in line of flight. As a case in point, one type of 5.0-inch spin-stabilized rocket developed during World War II had a nearly flat trajectory at short ranges, and rotated at about the same or even higher speed than 5"/38 caliber projectile.

In a gun projectile, rotary motion or "spin" is imparted by rifling of the gun barrel. Spin-stabilized rockets, however, achieve a spinning motion because they have several nozzles, slightly canted in position. Since fins are absent, such rockets can be relatively compact, which makes for greater convenience in handling, launching, and stowing. The degree of stabilization may also be considerably greater than that of fin-stabilized rockets. The old fin-stabilized 4.5-inch barrage rockets, for example, had a dispersion of from 20 to 40 mils, whereas the comparable figure for spin-stabilized rockets is about 20 mils. When fired forward from airplanes, fin-stabilized rockets achieve a much better performance.

Fired from aircraft, dispersion of fin-stabilized rockets may be no more than 6 to 8 mils. Comparable dispersion of gun projectiles would be a single mil or less.

It therefore is evident that the accuracy of conventional-type rocket fire is not on a par with the accuracy of gunfire. Rockets, however, have proved to be extremely valuable weapons for special purposes. Examples include the employment of rockets in antisubmarine attacks, and the saturation of enemy-held beach positions by rocket fire launched both from airplanes and from the decks of landing ships. Figure 11A5 shows barrage rockets being launched from an LSI which is moving in toward a beach.

11A5. Rocket fuels

From the standpoint of fuels there are two general types of rockets: those incorporating liquid-fuel units as typified by the German V–2, and those incorporating solid-fuel units as represented by various barrage rockets.

In liquid-fuel rockets, the fuel and the oxidizer are carried in separate containers from which they are ejected into a relatively small combustion chamber where the propelling reaction takes place. A comparatively elaborate mechanism was used in the V–2 rocket to control this use of fuel and oxidizer; however, simple designs have been developed subsequently which permit the use of liquid propellants in high-performance antiaircraft rockets, less than 4-inch diameter, capable of developing high thrust for a short period of time. Also the fuel tanks of liquid-fuel rockets for guided missile propulsion can be so located that change in center of gravity is reduced to a minimum as fuel consumption proceeds.

Among the advantages of solid-fuel rockets is simplicity of design and operation. A single chamber serves as a container for the propellant and as a combustion chamber. Rate of gas production is controlled by the chemical composition of the propellant (especially by the ratio of the oxidizing agent to the fuel), by the operating pressure and temperature, and by the shape of the propellent charge and combustion chamber. In some cases *inhibitors,* consisting of slow-burning material attached to certain surfaces of the powder grain to delay combustion, are used. A disadvantage of solid-fuel rockets is the relatively great weight of the motor housing.

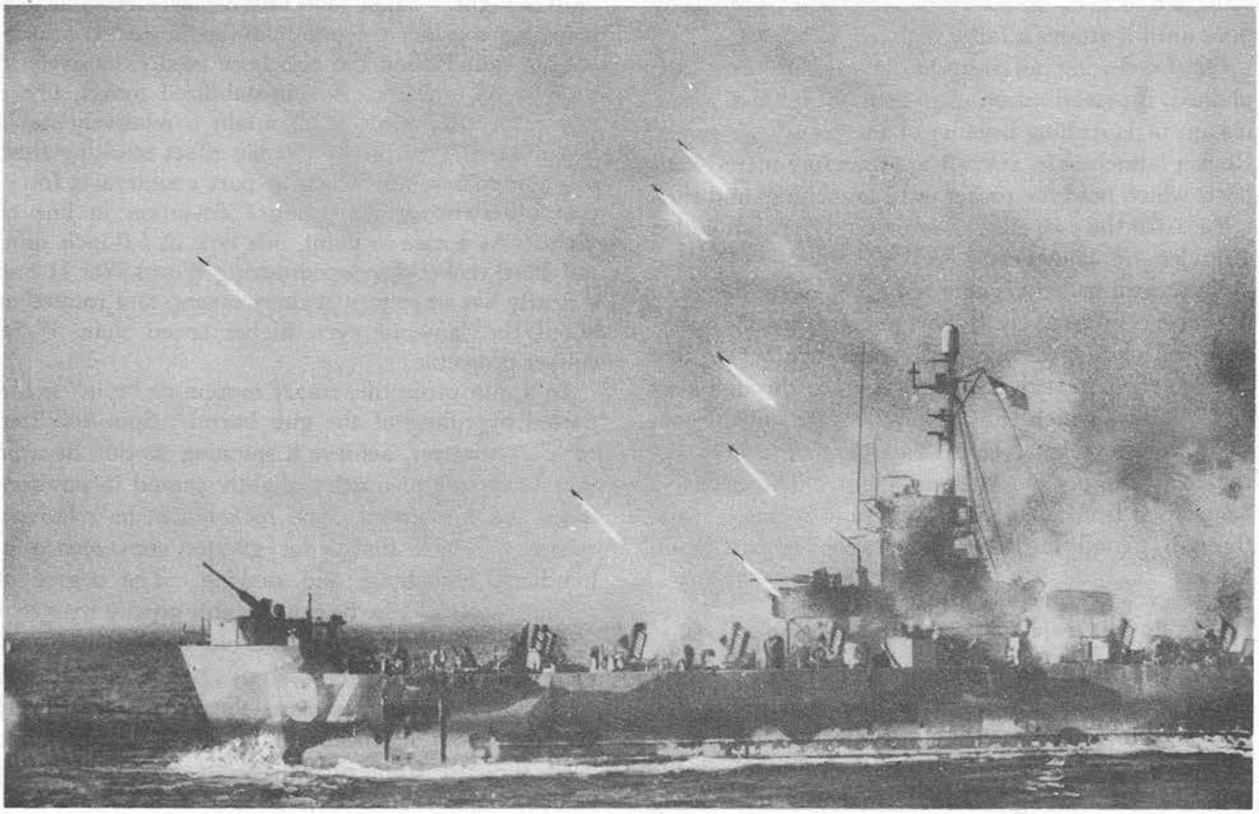


FIGURE 11A5.—Rocket being launched from an LSI.

11A6. Naval uses of solid-fuel rockets

Rockets (but not guided missiles) fired by naval ships and aircraft are designated by head diameter in inches. (This is analogous to the caliber of gun projectiles.) The motor may be the same size as, or smaller than, the head, but never larger.

Several types of rocket of 3-inch and smaller caliber are used for practice firing, for targets at which other weapons can fire, or for signaling. Subcaliber rockets which fit into the launchers of larger types and are used as inexpensive substitutes for training purposes are also in this range of sizes.

Aircraft rockets intended for use against enemy targets or for other combat use are made in 3.5-inch, 5.0-inch, and 11.75-inch sizes. (Other sizes may be under development.) Rockets fired from surface craft are the obsolescent 4.5-inch fin-stabilized barrage rocket, several types of 5.0-inch spin-stabilized rockets, a 7.2-inch rocket designed for antisubmarine use, and the antisubmarine 12.75-inch rocket.

11A7. General safety precautions in handling and firing rockets

1. *Review of ordnance instructions.* Frequent review of ordnance pamphlets and the latest ordnance instructions pertaining to each piece of equipment should be made mandatory by all authorities in command of units afloat and ashore, wherever rockets are stowed, assembled, or fired.

2. *Nozzle blast.* It should be remembered that nozzle blast from a rocket motor is intensely hot. Small pieces of burning powder frequently are blown out of the nozzles and may be hard to extinguish. Steel sheathing is therefore used to protect decks and superstructure areas around launchers. Some launchers have blast deflectors for protection of the immediate area, while others are mounted slightly outboard, so that blast is directed into the water. It is obviously unsafe for any one to be directly in front of or behind a loaded launcher, or one that is being loaded. Personnel loading a launcher should always stand to one side of the path that would be taken by rocket or blast in the event of accidental or intentional firing. All personnel in the vicinity of a launcher should wear long trousers, and long shirt sleeves buttoned about the wrists.

3. *Firing precautions.* The firing circuit must be open at all times until the launcher is ready to fire. All extra rockets must be kept at a safe distance from loaded deck-mounted launchers. No personnel may approach a loaded launcher until the safety plug or firing key has been removed from the firing circuit. The fuze safety wire must be reinserted as soon as the safety plug or firing key has been removed, but not before. No test of the firing circuit may be conducted until all rockets have been removed from the launcher and placed at a safe distance. Naked lights, matches, or other flame-producing apparatus must *never* be allowed in the vicinity of rocket ammunition.

4. *Fuzes.* At no time are any personnel permitted to attempt disassembly of an armed fuze. Such a fuze must be disposed of.

5. *Propellent grains.* Under no circumstances may a propellent grain be removed from a motor. No surveillance tests are made of rocket propellants.

Other safety precautions are detailed in appropriate ordnance publications, in appendix A of this volume, and in the next section, on shipboard-fired rockets.

B. Rockets Fired From Surface Craft

11B1. General

As the previous article stated, the most important operational Navy rockets fired from surface craft are the spin-stabilized 5.0-inch (of which there is an entire family, with matching heads and motors), and two fin-stabilized A/S rockets, one 7.2-inch and one 12.75-inch. The 4.5-inch barrage rocket is now considered quite obsolete, and therefore is not taken up in this text.

The 7.2-inch and 12.75-inch rockets are designed to serve primarily as launching devices for A/S charges (although the 7.2-inch type can be used against surface targets when equipped with the proper type of fuze). They are therefore discussed elsewhere in this course, along with other A/S weapons. The remainder of this section is devoted to the 5.0-inch spin-stabilized surface-fired rocket.

11B2. 5.0-inch spin-stabilized rockets

These rockets may be divided into three types, with respective maximum ranges of 2,500, 5,000, and 10,000 yards. All three have the same over-all length, so that they may be fired interchangeably from the same launchers. The shorter-range rockets, requiring smaller motors, are therefore provided with larger heads. For example, the 2,500-yard rocket has a small motor, and a large head that contains about 12 pounds of explosive. The 5,000-yard rocket is about half motor and half head; it carries a 9.6-pound bursting charge. The head of the 10,000-yard rocket contains only about 2.8 pounds of explosive.

The bursting charges, heads, fuzes, and motor designations of 5.0-inch spin-stabilized rockets Marks 12, 10, 7, and 8 are compared in the table on page 250.

5.0-INCH SPIN-STABILIZED ROCKETS

Mark 12 (2,500 yards)	*Mark 10 (5,000 yards)*	*Mark 7 (10,000 yards)*	*Mark 8 (10,000 yards)*
Head: Mark 12 (General-Purpose). Fuze: Nose Mark 30 PD. Filler: 12 pounds TNT. Motor: Mark 5.	Head: Mark 10 (High-Capacity). Fuze: Mark 30 PD, Mark 173 VT. Filler: 9.6 pounds TNT. Motor: Mark 4.	Head: Mark 7 (General-Purpose). Fuze: Mark 100 PD, Delay. Filler: 2.8 pounds TNT. Motor: Mark 3.	Head: Mark 8 (Common). Fuze: Mark 31 base. Filler: 1.7 pounds Explosive "D". Motor: Mark 3.

Rockets of this type are designed for shipboard use, to which end several launchers or launcher assemblies have been developed. Spin-stabilized rockets have proved very effective for beach neutralization and shore bombardment when fired by LSMR or other Inshore Fire Support type vessels. Their relative neutralization effect, as compared to 5"/38 AA Common projectiles, is as follows: 1 Mark 12 (at 2,500 yards) equals 2 AA Common projectiles; 1 Mark 10 (at 5,000 yards) equals 1.7 AA Common projectiles; 1 Mark 8 (at 10,000 yards) equals 1 AA Common projectile.

Since an LSMR–IFS vessel has a firing rate of 250-350 rounds per minute, these rockets give these relatively small ships a fire power almost equal to that of a light cruiser in weight of projectiles per minute. The general-purpose and common rounds are particularly well adapted to PT-boat attacks at ranges up to 10,000 yards.

11B3. 5.0-inch rocket motor

The 5.0-inch Rocket Motor Mark 3 is used to propel common and general-purpose 5.0-inch spin-stabilized rockets. It is shown in figure 11B1. The *motor tube* is about 22 inches long. It houses the propellant and serves as a combustion chamber. The motor tube has internal threads and an external bourrelet ring at each end. A *shipping cap* is screwed into the front end of the motor tube during shipment. The front closure is a sheet-metal disc pressed in position near the front end of the motor tube. This front closure seals the forward end of the motor tube and holds the *igniter* and propellant in place. There is a light, metal *blow-out disc* in the center of the front closure; on its inner surface a thin felt pad is cemented. Just inboard of this pad is the igniter, which is a flat, tinned case containing 35 grams of black powder and an electric squib. Two wires pass from the squib to the rear of the motor tube, where one wire is connected with the *contact ring* and the other wire is grounded to the motor tube at the *nozzle-ring plate*. A 1-inch thick felt washer is placed forward of the propellent grain to protect against accidental shock.

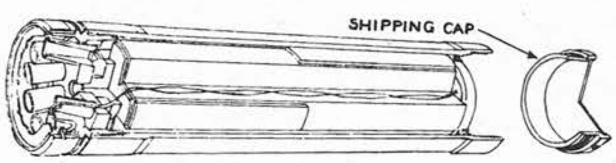


FIGURE 11B1.—5.0-inch Rocket Motor Mark 3 Mod 1.

The propellent used in this motor is an inhibited, cruciform extruded grain of Ballistite weighing about 10 pounds. A plastic inhibitor is cemented to both ends of the grain, and plastic inhibitor strips are cemented on the webs. These inhibitors control the burning area of the grain and thus regulate the pressure developed within the combustion chamber during the burning period. The *nozzle-plate assembly* consists of eight nozzles and a grid mounted on a nozzle plate. The nozzles have a 12-degree cant, which produces clockwise rotation when the rocket is fired. At the after end of the motor is an assembly consisting of a nozzle-plate ring and an insulated contact ring. The nozzle-plate ring has external threads which engage internal threads of the motor tube. The contact ring is riveted to the nozzle-plate ring, but electrically insulated from the latter. The nozzle-plate ring and the contact ring act as terminals of the igniter electrical circuit. A *short-circuiting band* creates a short circuit between the nozzle-plate ring and the contact ring; it is removed when the rocket is prepared for firing. The after end of the motor tube is sealed by a thin metal disc cemented in place within the rear of the nozzle-plate ring. Front and rear closures of the motor tube should remain in place at all times; if a closure has been broken, the motor should be turned over to an ammunition depot or disposed of by lowering into deep water.

11B4. 5.0-inch spin-stabilized Rocket Head Mark 7 and fuzes

Rocket Head Mark 7 and Mods is used for general-purpose rounds in the case of the 5.0-inch spin-stabilized rockets. This head, with nose fuze in place, is shown in figure 11B2. When shipped, the head is protected by a nose shipping plug and a base shipping cap. The head is closed at the after end, where it is threaded externally for assembly to the Motor Mark 3. The forward end of the rocket head is internally threaded to receive the adapter, on which the Auxiliary Detonating Fuze Mark 44 Mod 2 is mounted. When the adapter is screwed into the forward end of the body, the auxiliary fuze is properly positioned within the body. The Nose Fuze Mark 100 Mod 2 is then screwed into the adapter. The rocket head contains a 2.8-pound charge of TNT.

The Nose Fuze Mark 100 is a selective-action type which is armed by rotation during flight. A *selector* in the side of the fuze body may be turned to DELAY or S. Q. (superquick). The amount of delay incorporated is 0.025 second.

11B5. 5.0-inch spin-stabilized Rocket Head Mark 8 and fuze

The Rocket Head Mark 8 and Mods is also used for assembly with the Mark 3 motor. The Mark 8 head, designated for common rounds, is a hollow steel shell with a solid nose, containing a 1.7-pound charge of Explosive D. It is shown in figure 11B3. Its after end bears external threads for assembly to the motor; it also is threaded internally to receive an adapter. The Base Fuze Mark 31 is screwed into this adapter. The head is shipped with the base fuze in place, and protected by a base shipping cap. The latter is removed when the head is assembled to the motor. Personnel must not attempt to remove the base fuze from the head at any time. This fuze is armed by rotation during flight, and functions upon impact.

11B6. Stowing and assembly of 5.0-inch spin-stabilized rockets

The motors of 5.0-inch spin-stabilized rockets should be stowed in the shipping boxes or tanks in which issued, in smokeless-powder magazines where temperatures are maintained below 90° F. Prolonged stowage at or about 100° F. is considered to be hazardous. Where magazine stowage in shipping boxes is not practicable, the Bureau of Ordnance prescribes special stowage conditions. Motors should not be stowed in the same compartment with or near electronic apparatus or antenna leads.

At the discretion of the Commanding Officer, *ready-service rounds* may be stowed with the rounds pointing

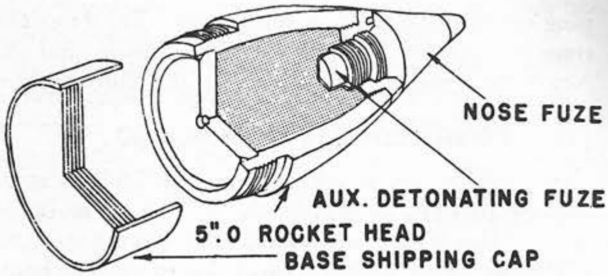


FIGURE 11B2.—Rocket Head Mark 7, with fuze.

outboard if practicable. Fuzing of general-purpose and high-capacity rounds should be delayed as much as is commensurate with the tactical situation. The rockets should be kept in the shade, and should not be fired if motors have been exposed for more than an hour to temperatures outside the safe temperature limits specified on the motor tubes.

In assembling the rocket, the gasket and shipping cap are first removed from the motor tube. Forward and after closures of the motor tube must remain in position. The base shipping cap is now removed from the head. A Mark 8 head must be examined to assure that the base fuze is in place; if not, the rocket head must be disposed of. If such a rocket head were assembled to a motor, the main charge would detonate when the motor was fired. Strap wrenches and bench clamps are now used to engage the threads of the motor and head until the seating surfaces meet firmly. In the case of the Mark 7 rocket head, a further step is to remove the nose plug and make sure that the auxiliary detonating fuze is present and screwed in the nose fuze.

In disassembling 5.0-inch spin-stabilized rockets which have Mark 7 heads, the nose fuze is first removed and replaced by the nose plug. It is necessary to be sure at this stage that the short-circuiting band remains on the motor, or has been replaced thereon. Strap wrenches and bench clamps are then employed to disengage the motor and rocket head. The base shipping cap is replaced on the head, and the gasket and ship-

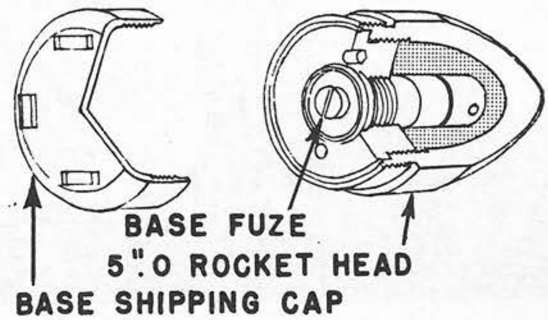


FIGURE 11B3.—Rocket Head Mark 8, with fuze.

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ping cap are replaced on the motor. The bourrelet rings are greased lightly to prevent rusting, and the rocket head and motor replaced in the shipping box.

11B7. 5.0-inch Rocket Launcher Mark 50

One of the launchers used to fire 5.0-inch spin-stabilized rockets is the Mark 50, shown in figure 11B4. This is an 8-tube launcher designed for use on PT boats. Two launchers are mounted on each boat; they may be swung inboard for loading and outboard for firing. The barrels are arranged in 2 rows of 4 each, 1 row above and the other below a horizontal supporting shaft. Elevation is adjustable, and train is effected by turning the PT boat. When a firing button is depressed (on the bridge), one rocket is fired from each launcher. Current to fire a motor is fed to a rocket by means of the contact ring. The electrical impulse passes from the contact ring to the squib, causing the latter to set off the black powder in the igniter.

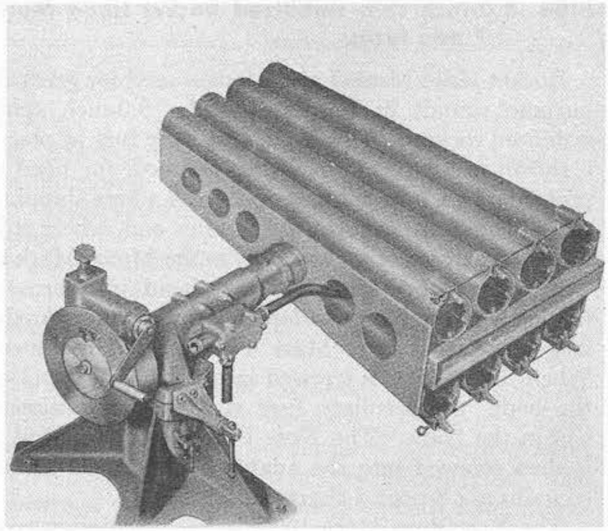

FIGURE 11B4.—Rocket Launcher Mark 50.

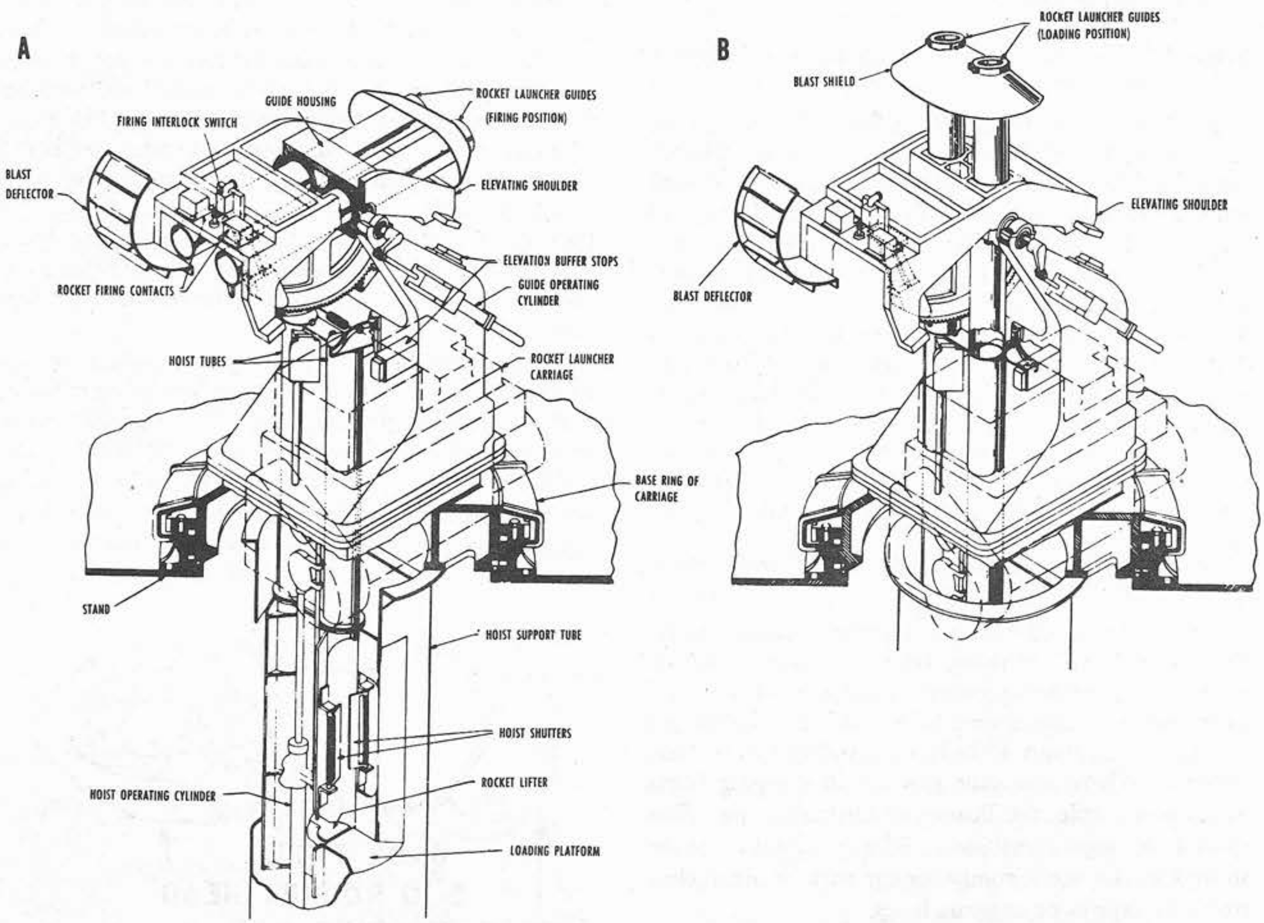

FIGURE 11B5.—The Mark 102 rocker launcher assembly.
A. Firing position. B. Loading position.

11B8. 5.0-inch Rocket Launcher Mark 102

Another launcher for 5.0-inch spin-stabilized rockets, the Mark 102, is designed for use on LSMR's. This launcher is a mechanism for the automatic firing of rockets at a sustained rate of 30 rounds per minute. The assembly includes the deck-mounted rocket-launcher components, and a rocket-launcher ammunition hoist below decks, both of which are mounted on a carriage, power-driven in train. Elevation is accomplished by movement of the rocket-launcher guides. Remote control is possible in both elevation and train. The assembly is shown in figure 11B5.

The five principal components of the Mark 102 Mod 0 rocket-launcher are:

a. The *rocket-launcher guides,* a pair of tubular guides mounted in a guide housing which is hydraulically moved from a vertical position for reloading. Mounted forward on the guides is a *blast shield.*

b. The second component is the *cradle,* which supports the launcher guides. The cradle includes the elevating shoulder, a support for holding the launcher guides at the proper elevation for firing.

c. The third component is the *carriage assembly,* which supports the cradle and the train and elevating power drives above decks. The carriage assembly also supports the hoist below decks.

d. The fourth component is the *stand,* which is fixed to the deck and supports a roller path that provides for train of the rocket-launcher assembly.

e. The final component is the *hoist,* which consists of 2 tubes and hydraulic lifting devices provided for simultaneous lifting of 2 rockets from a below-decks handling room into the rocket launcher guides. The hoist rotates in train with the rest of the rocket-launcher assembly.

The carriage of this assembly represents an unusual adaptation of equipment designed for a very different purpose, in that it is really a modified 40-mm Carriage Mark 1 Mod 2. This carriage, described in chapter 9, has been modified by removal of the guns, firing mechanism, cooling system, loader's platform, and other

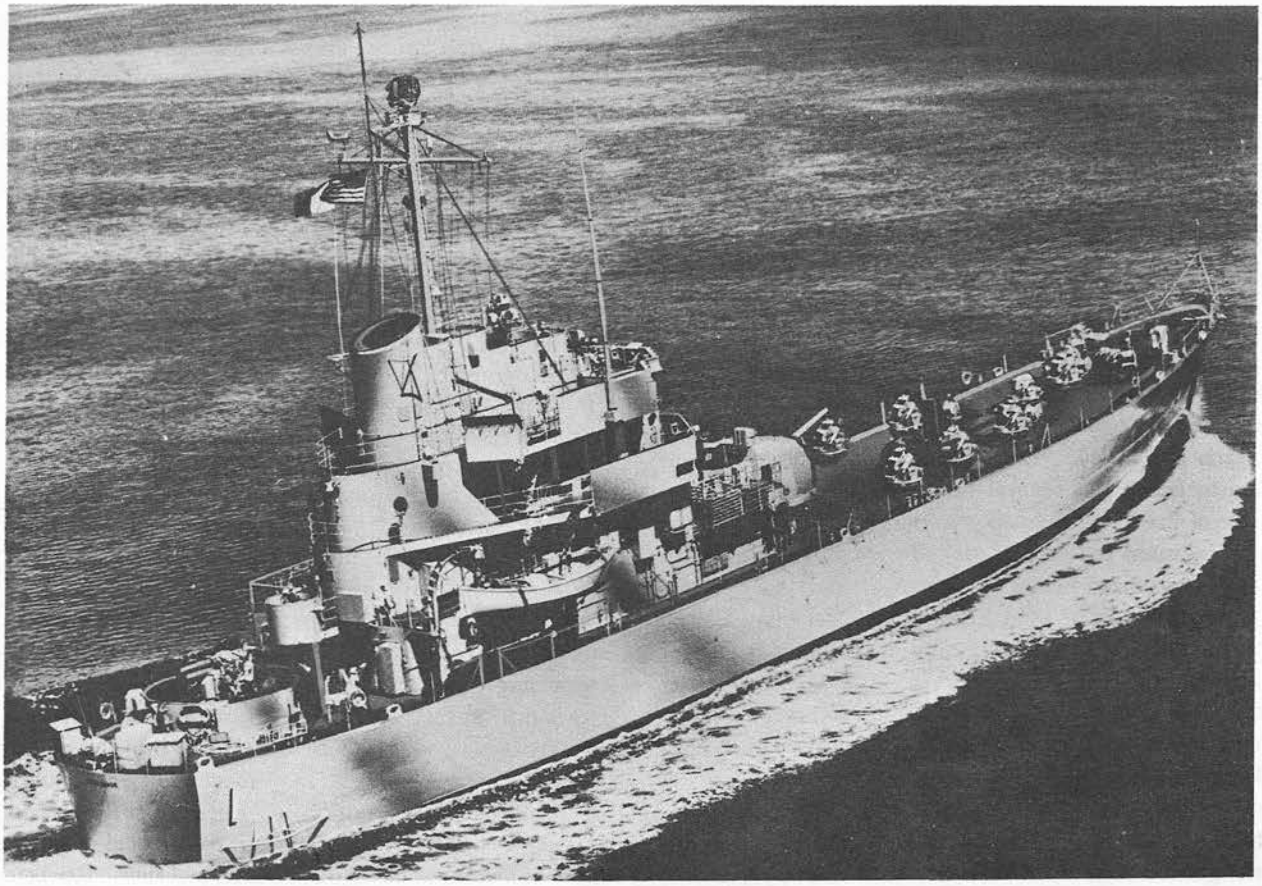

FIGURE 11B6.—Mark 105 rocket launcher installation on IFS–1.

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normal components. Various additions have been made, of which the principal items are the rocket-launcher cradle and ammunition hoist. Train and Elevation Power Drives Mark 4 Mod 3 are the same as those used with the 40-mm carriage, except that a train and elevation emergency start push button and a train emergency stop switch have been added. The stand is the 40-mm Stand Mark 1.

Rocket-Launcher Assembly Mark 102 Mod 0 is subject to remote control by a director fire control system. A *firing stop mechanism* prevents firing into ship's own structures. In automatic firing the loading of two rockets into the hoist tubes in the handling room below decks initiates the cycle of hoisting the rockets, transferring the rockets to the launcher guides, moving the guides to the firing position, firing the rockets, and returning the guides and hoist lifter to the loading position. Each step in this automatic cycle is controlled in proper phase by mechanically actuated switches. The *intervalometer,* a device in the firing circuit, introduces a 0.66-second delay between the firing of two rockets, to avoid blast interference. A safety interlock prevents the rocket-launcher guides from returning to reloading position until the rockets fired from both guides are clear.

11B9. 5.0-inch Rocket Launcher Mark 105

The official nomenclature for this weapon is Rocket Launcher Assembly Mark 105 Mod 2, and it fires the 5.0-inch spin-stabilized rocket ammunition described in this section. It is a barrage weapon designed for installation aboard amphibious warfare support vessels such as inshore fire support ships (IFS). Figure 11B6 shows the U. S. S. *Carronade,* which is equipped with eight Mark 105 launchers.

Figure 11B7 is a view of the installed launcher assembly showing below-deck as well as above-deck components. The Mark 105 launcher resembles the Mark 102 in using twin rocket guide tubes and twin hoists, but it has several novel features and a higher rate of fire (48 rounds per minute).

The main features of the Mark 105 rocket mount are summarized below:

Structure. The launcher stand is a deck ring bolted to the rocket launcher foundation. The top face of the stand is the main support of the entire rocket launcher assembly. The carriage is a flanged base ring that trains on roller bearings and supports the oscillating assembly, the dud jettisoning unit, and all the other units that rotate in train. The oscillating assembly's main components are the elevating shoulder and the guide tubes. The elevating shoulder is positioned according to elevation order by the elevating power drive. The guide tubes are moved in elevation by a hydraulic cylinder which positions them at either elevation order position (firing position) or at 90° elevation (loading position). This arrangement resembles that in the Mark 102 mount. The rocket guides are fitted with blast deflectors fore and aft.

The rocket launcher ammunition hoist is suspended from the underside of the carriage base ring and rotates in train with it. The hoist extends downward inside a stationary barbette through the second deck to the third deck of the ship, which is the magazine level.

Power drives. The electric-hydraulic train and elevation power drives used in the Mark 105 Mod 2 rocket launcher are similar to the Mark 10 drives used in Mark 3 Mod 4 40-mm (single) mounts. They are equipped with radial-piston A-ends and B-ends. The friction brakes and linkages in the original Mark 10's have been omitted, there is no local (power) control, and the output speed ratio is modified. Normal launcher operation is director-controlled. Manual operation for maintenance and starting up the equipment is possible by declutching the power drive units and operating the handwheels by hand.

The train power drive is on the right side of the carriage; the elevation drive is on the left.

Ammunition hoist. This is a manually loaded four-stage arrangement which lifts the ammunition rounds in pairs, one stage at a time, when the rocket guide tubes are in loading (vertical) position. The hoist is not of the endless-chain type. A fixed-tilt axial-piston pump feeds hydraulic fluid under pressure, through control valves, to a hydraulic cylinder. The piston rod of the cylinder is connected through wire rope tackle and pulleys to the four-stage lifter, which, upon each piston stroke (26.25 in.) moves upward or downward one stage (52.5 in.).

The complete cycle of operation for a single-stage lift consists of a hydraulic piston downstroke (lifter upstroke), followed immediately by a piston upstroke (lifter downstroke). During the first lifter upstroke, pawls on the lowest part of the lifter engage the bases of the 2 rockets just loaded into the hoist, and raise them 1 stage. While the lifters downstroke, pawls in the hoist tube support the rounds in the tube. At the next lifter upstroke, the second-level lifter pawls engage the rounds, and carry them up the tube another stage, where they are held by stationary tube pawls during the next lifter downstroke. The process repeats as necessary to hoist the rockets into the rocket guide tubes. Electrical and mechanical interlocks start up the hoisting action when the hoist lower end is loaded, and prevent hoisting into the rocket guide tubes unless the tubes are in loading position. Rockets are loaded manually at the hoist lower end through

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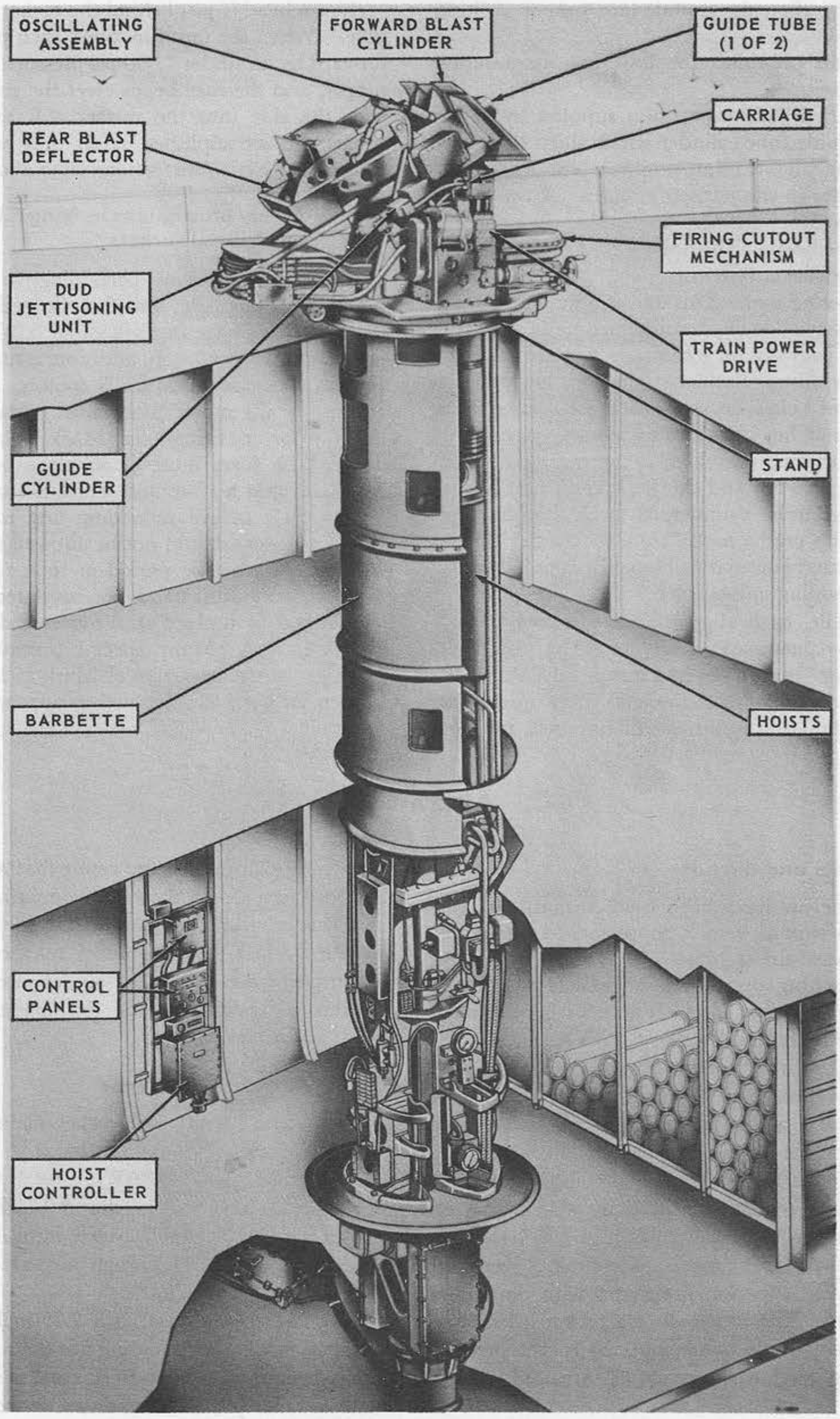

FIGURE 11B7.—Mark 105 rocket launcher assembly. Partial cutaway of launcher installation.

shutters which align the rounds into proper position for loading.

There is no provision for lowering ammunition through the hoist.

The hoist hydraulic pump also supplies hydraulic fluid to the guide tube cylinder which shifts the guide between firing and loading position, and to the hydraulic cylinder in the jettisoning unit. A water line with quick-connect fittings provides for emergency flooding of the hoist. The hoist is also equipped with a central lubrication system.

Dud jettisoning unit. This unit is a semiautomatic, electrically controlled, hydraulic-pneumatic operated device which provides for jettisoning misfired or otherwise defective ammunition that has been loaded from a remote point below decks. When jettisoning is required, the launcher is trained to relative bearing 90° or 270° (depending on which is the outboard direction), elevated to 5°, and the jettisoning unit is activated. A hydraulic cylinder in the jettisoning unit raises the unit's cradle to 40°; the rocket guide tubes are then elevated automatically to 40° to line them up with the jettisoning unit cradle.

In the cradle, each aligned with one rocket guide tube, are two pneumatic cylinders. The piston rod of each cylinder terminates in a ram head. When the guide tubes are aligned with the jettisoning unit cradle, and the pneumatic pistons are in retracted position, each ram head is just behind the rocket in either guide tube. When the unit functions, each piston is pushed forward by air under 1,000 psi pressure from the ship's supply, and the ram heads eject the rocket or rockets over the side into the water. (Jettisoning can, of course, be accomplished safely only when there are no ships or other obstructions close aboard.)

11B10. Safety precautions in firing 5.0-inch spin-stabilized rockets

General precautions pertaining to the firing of rockets, as partially outlined in article 11A7, are largely appropriate in the case of 5.0-inch spin-stabilized rockets as well. In addition, it may be reiterated that in the case of Mark 3 motors, front and rear closures of the motor tubes must remain intact at all times prior to firing. In Mark 8 common rocket heads, base fuzes must be in place before assembly. Note also that a 10-minute precautionary wait should be observed before unloading any misfired rounds. Mark 3 motors should not be allowed to stand on end for any considerable period of time (over an hour), and short-circuiting bands (on insulated contact rings) should be left in place until removed during the loading operation. Many special precautions must be observed in the operation of Mark 102 and Mark 105 launchers; these are detailed in appropriate ordnance pamphlets.

C. Aircraft Rockets

11C1. Rockets and aircraft

Aircraft rockets have been used primarily as forward-firing weapons, which supplement or take the place of forward-firing guns. The virtual absence of recoil in launching aircraft rockets makes possible the use of lightweight gear for such launching, and introduces no stresses inimical to the plane's structures. A modern rocket-firing plane armed with 5.0-inch rockets can deliver one salvo comparable to that of a destroyer, and a squadron of F9F planes carrying 11.75-inch rockets can fire a salvo similar to that of a cruiser division. In making such a comparison, however, it must be remembered that the ships can keep on firing, whereas the planes must return to base after delivering their pay loads. Generally speaking, rockets provide superior firepower with minimum added weight. The pay load of a rocket is less than that of a comparable bomb, but the rocket presents advantages related to accuracy of fire and greater penetration.

Rocket velocity is augmented by the velocity of the launching plane, with the result that actual velocities attained approach those of comparable projectiles, and this accuracy increases as the speed and stability of the aircraft at the time of release are increased. In antisubmarine use, the underwater trajectory of rockets is predictable, and this fact can be used to great advantage.

11C2. Aircraft rocket types

Basic types of aircraft rocket include a 2.25-inch training rocket (SCAR), the 2.75-inch air-to-air "Mighty Mouse" (FFAR), the 5.0-inch aircraft rocket (5.0-inch AR), the 5.0-inch high-velocity rocket (HVAR), the 7.2-inch antisubmarine rocket (VAR), and the 11.75-inch aircraft rocket (11.75-inch AR) or "Tiny Tim."

The "Mighty Mouse" is a 2.75-inch contact-fuzed air-to-air rocket with folding fins that open on launching. It is small enough to be carried in quantity, but with a direct hit, one round can destroy a plane.

The rockets are carried in streamlined cylindrical

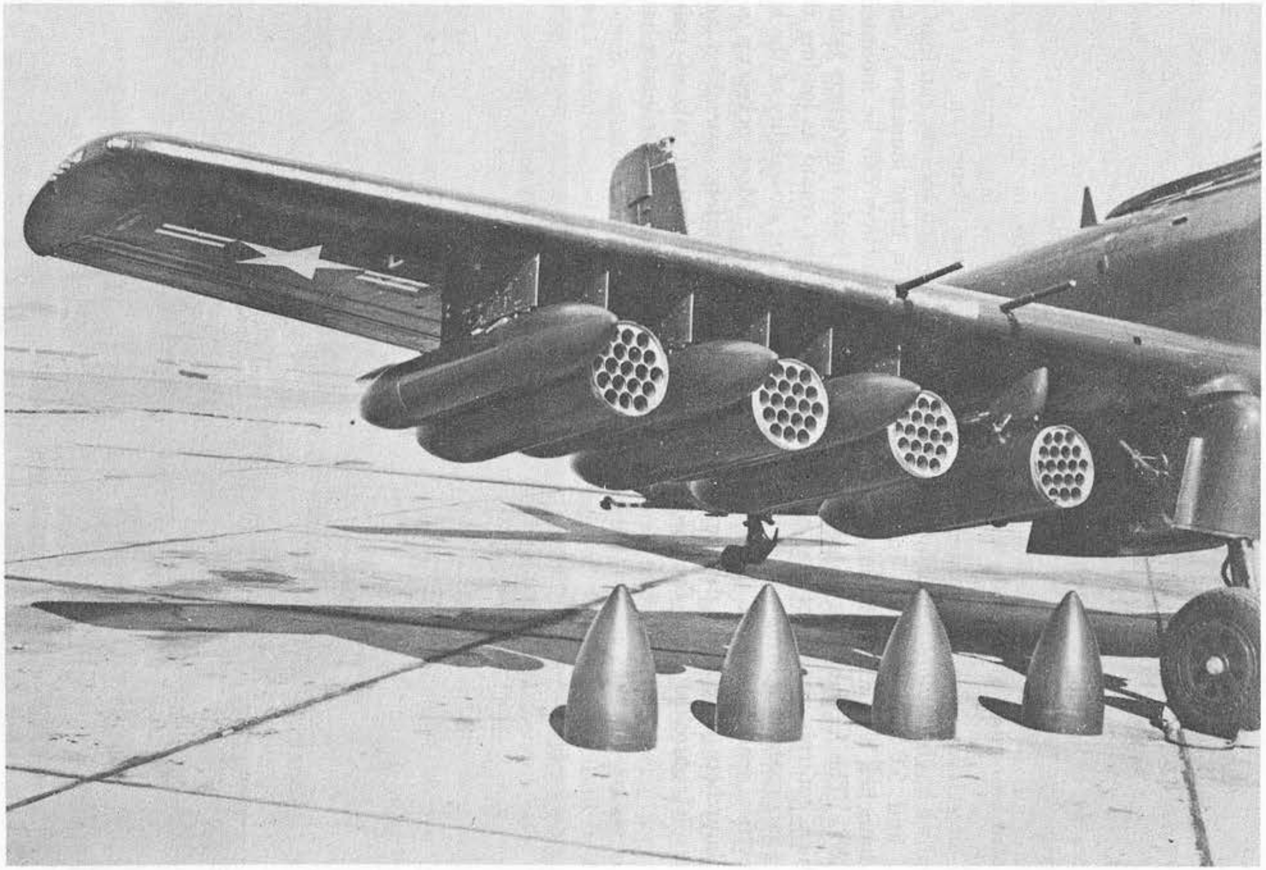

FIGURE 11C1.—2.75-inch 7- and 19-round launchers suspended from wing of aircraft. (Frangible noses removed from 19-round launchers.)

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jettisonable launchers, carrying up to 19 rockets each, which can be suspended under the wing of an aircraft. (Fig. 11C1.) The rockets are "ripple-fired" through the frangible nose of the launcher in quick succession.

The 5.0-inch high-velocity rocket (1,375 fps) can penetrate 6 feet of concrete. It is used against ships, pillboxes, locomotives, and tanks. Its head is a 5-inch Mark 35 common projectile, with nose and base fuzes and a 7.9-pound charge of TNT. The propellant is a 24-pound grain of ballistite. The 11.75-inch rocket (fig. 11C2) attains a velocity of 800 fps and has the explosive effect of a 500-pound bomb. Its head contains about 150 pounds of TNT. The motor contains 148 pounds of ballistite.

11C3. Suspension and launching of aircraft rockets

The conventional aircraft launcher for forward firing is the *post type,* which has been employed to launch 2.25-inch, 3.5-inch, and 5.0-inch rockets. In the Mark 5 zero-length launcher, a pair of posts supports the rocket, (fig. 11C3). The forward post houses an arming solenoid which controls arming of the nose fuze. The rear post incorporates a firing socket into which the rocket electrical lead is plugged. Retractible types of post launchers have been developed. Firing of the rockets is controlled from the pilot's station.

To increase the rocket firepower of aircraft there have been developed *self-contained jettisonable multiple launchers* for 2.75-inch FFAR's. These are at present made in 2 standard sizes—a large one with a capacity of 19 rounds (the 4 with noses removed, shown to the right in figure 11C1), and a smaller 7-round unit(the outboard unit in figure 11C1). These launchers are aluminum-clad paper tubes (which shield against radar and other electromagnetic radiation) with frangible nose and tail pieces, and a central aluminum beam which serves as the "backbone." The rockets are fired serially in "ripple" fire; the launcher's frangible nose and tail collapse upon firing. When the ammunition load is exhausted, the launcher is jettisoned. Among the advantages of this type of launcher are the large number of rounds that can be stowed on the plane (an AD–6, which used to carry only 12 5-inch rockets, can load 156 of the 2.75-inch FFAR's in these launchers), the rapidity with which the launchers can be mounted on the plane (mounting the loaded launchers takes only 5 percent as much time per round as loading the rockets individually), and the stowability of the loaded launchers as complete units. Most rockets up to now have been, for the sake of safety, assembled and loaded individually at the aircraft takeoff point. Exhaustive analysis by the Bureau of Ordnance has, however, veri-

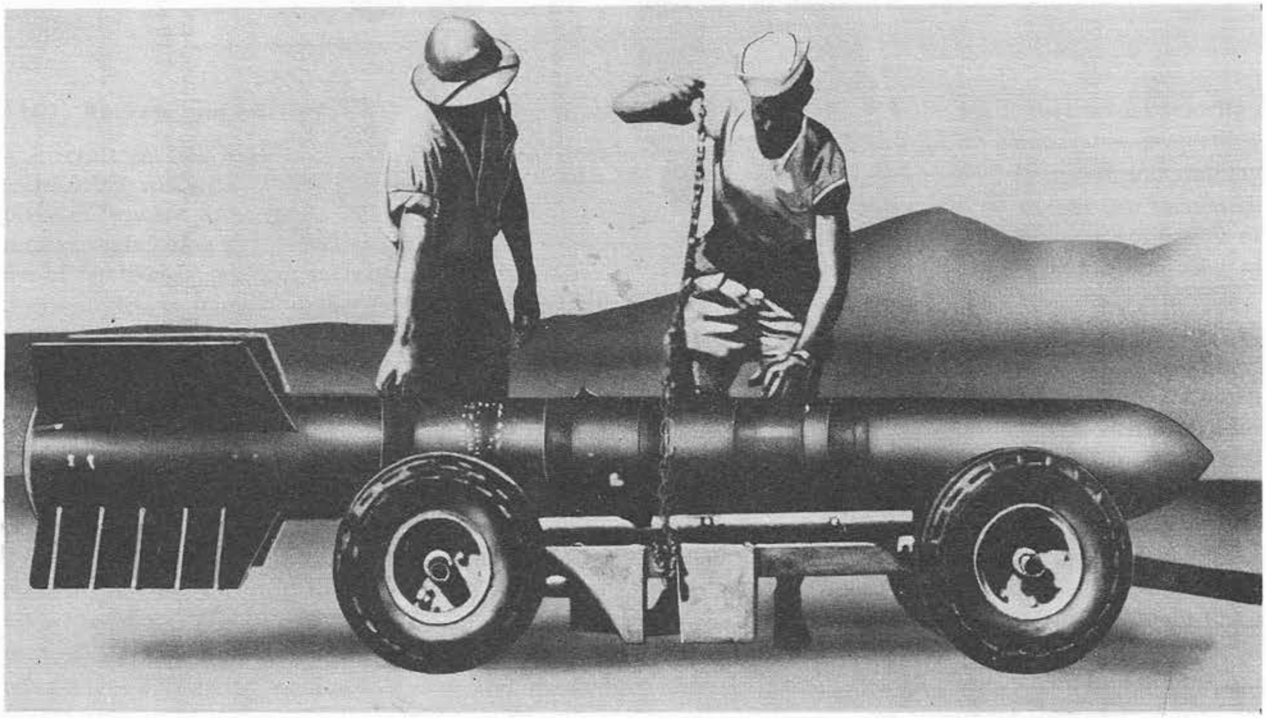

FIGURE 11C2.—An 11.75-inch aircraft rocket on a trailer.

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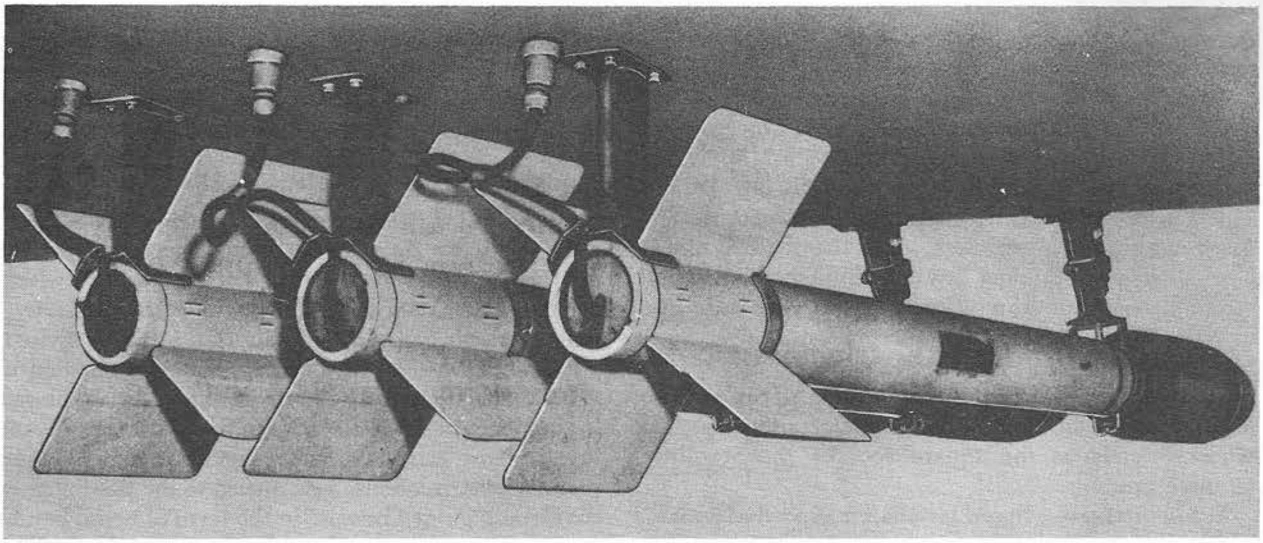

FIGURE 11C3.—Zero-length launchers for 5.0-inch aircraft rockets.

fied that completely assembled 2.75-inch FFAR's in these launchers are as safe as the disassembled components stowed in a canister. And a further advantage of these launchers is that, unlike previous types which would fit only one type of aircraft, they can be mounted on several types.

A *rearward-firing launcher* has also been developed for firing 7.2-inch antisubmarine rockets. This launcher provides a metal channel 8 feet long, 7 inches wide, and 2 inches deep; 12 of these launchers are mounted on each wing panel of a PBY, and 4 on each wing panel of the TBF. A magnetic submarine-detection device gives a peak signal when the plane is directly over a submarine; at this moment a rocket may be fired rearward with sufficient velocity to nullify the effect of the plane's speed. The rocket follows a substantially vertical path to the target.

A *drop launcher* has been perfected for firing the 11.75-inch Tiny Tim. This installation consists of a Mark 51 bomb rack, and a lanyard and lanyard-operated switches. The rocket is suspended from the bomb rack, and falls away from the plane when released. As it falls the rocket pulls out the 8-foot lanyard, which unreels until two micro switches are actuated and current flows through the lanyard to ignite the rocket propellant. Use of the lanyard makes it possible to delay firing of the rocket motor until the plane is safely out of the potential zone of rocket blast.

Further information on aircraft rockets may be found in *Naval Airborne Ordnance,* NavPers 10826.

D. Guided Missiles

11D1. Definition of guided missiles

The term "guided missile" has been defined by the Joint Committee on Guided Missiles as: "An unmanned vehicle moving above the earth's surface, whose trajectory or flight path is capable of being altered by a mechanism within the vehicle." This is a broad definition, but it limits the term to missiles in or above the atmosphere, and excludes such things as the guided torpedo. When we consider the guided missile as a weapon, we must qualify the above definition by adding that the missile must carry some lethal or useful military load.

Guided missiles are designed for special purposes. The German V–2 rocket, for example, was designed for surface launching against surface targets. Several types of guided missiles are now under development. Among the missions assigned to such missiles are the following:

Air-to-air (AAM).

Air-to-surface (ASM).

Air-to-underwater (AUM).

Surface-to-air (SAM).

Surface-to-surface (SSM).

Surface-to-underwater (SUM).

Underwater-to-air (UAM).

Underwater-to-surface (USM).

A number of special terms are encountered frequently in the study of guided missiles. Some of these terms and their meanings are as follows:

Drone. A remotely controlled aircraft.

Glide bomb. A winged missile powered by gravity.

JATO. An auxiliary rocket device for applying thrust to some structure or apparatus.

Mach number. Ratio of speed of an object to the speed of sound in air through which the object is moving. A missile climbing upward through the earth's atmosphere at constant velocity has a constantly increasing Mach number, because sonic speed decreases with decrease in temperature.

Sonic speed. The speed of sound. This is 766 mph under standard atmospheric conditions. It varies directly as the square root of the absolute temperature.

Subsonic speed. Speed less than the speed of sound.

Supersonic speed. Speed greater than the speed of sound.

11D2. History of guided missiles

Guided missiles have come into being because of developments in several engineering fields. Part of this history begins with the development of air-duct engines within the present century. Guillaume of France outlined the principles of the modern turbojet engine in 1909, and the Italian Campini used the same sort of propulsion system in the first jet-propelled airplane, which he designed in 1932. In 1933 Leduc of France detailed the possibilities of the ram-jet engine, and in the same year Bleecker of the United States experimented with a pulse-jet engine.

Meanwhile, the Wright brothers had begun the study of aerodynamic design at the turn of the century. Thereafter, a number of European scientists turned their attention to the various problems involved. In 1928 active study of flow phenomena got under way in the United States at the Langley Field Laboratory. At first thought, these early experiments may seem to have little relationship to modern guided missiles; but in fact all of them made some contribution, as did the various experiments with powder rockets reaching back to the 13th century.

The Navy and the Army Air Corps initiated experiments concerned with flying bombs and aerial torpedoes in 1916. An aerial torpedo, launched from a catapult at the Naval Proving Ground in 1920, flew for about 15 minutes. Such early experimental models, however, were scarcely guided missiles, since they were not subject to control after launching. Then in 1924 a pilotless seaplane under radio control was launched successfully, although it crashed in landing. For a time thereafter, military experimentation in this area lagged, because of lack of funds and unsolved problems of devising suitable controls. But in 1926, Goddard of the United States perfected and tested the first successful liquid-fuel rocket. He also developed the first system of automatic rocket design by using vanes in the exhaust blast for steering. In addition, Goddard was the first to fire a rocket at supersonic speed.

In 1936 the Navy initiated a project designed to produce a radio-controlled, pilotless aircraft which could be used as a target in gunnery training. Systems of radio control and stabilization were devised, and successful flight of a drone plane was effected in 1937. Shortly thereafter a drone plane was employed in gunnery exercise at sea. Radio control also came into use for purposes of testing new, experimental planes. Attention also was turned to the possibility of developing guided missiles in the form of aerial bombs or assault drones, and radio-controlled gliders. The latter were known as *glombs,* and were tested successfully in 1943, but their production was soon discontinued. However, several types of glide bombs were soon perfected, and used effectively in combat in World War II. The Navy also began experiments with a series of jet-propelled guided missiles in 1943; several types were brought into being but not employed tactically in World War II. Since the end of that war the Navy program of experimentation with guided missiles has been greatly expanded.

11D3. German long-range missiles

During World War II the Germans achieved considerable success in the use of long-range missiles, including the V–1 pulse-jet missile (buzz bomb) and the V–2 rocket. Both of these weapons served to effect area bombardment. About 15,000 buzz bombs and 2,600 V–2 rockets were launched against England and the channel ports. The external appearance of a buzz bomb is shown in figure 11D1. Overall length was a little over 25 feet, and weight at takeoff was 4,750 pounds. Speed attained in flight was about 360 mph, and maximum range was 150 miles.

The V–2 (fig. 11D2) was radically different, being a true rocket of the liquid-fuel type. It had a takeoff weight of 30,000 pounds; which included 19,800 pounds of alcohol, liquid oxygen, and auxiliary fuels; a warhead of 2,200 pounds; and rocket structures weighing 8,000 pounds. Maximum velocity attained by this rocket was approximately 5,000 fps; exhaust velocity was 7,000 fps, and range was 200–300 miles. The V–2 rocket was stabilized by graphite vanes in the exhaust blast, and by the external fins. Earlier models were guided in flight by an auto-pilot set to maintain a predetermined course.

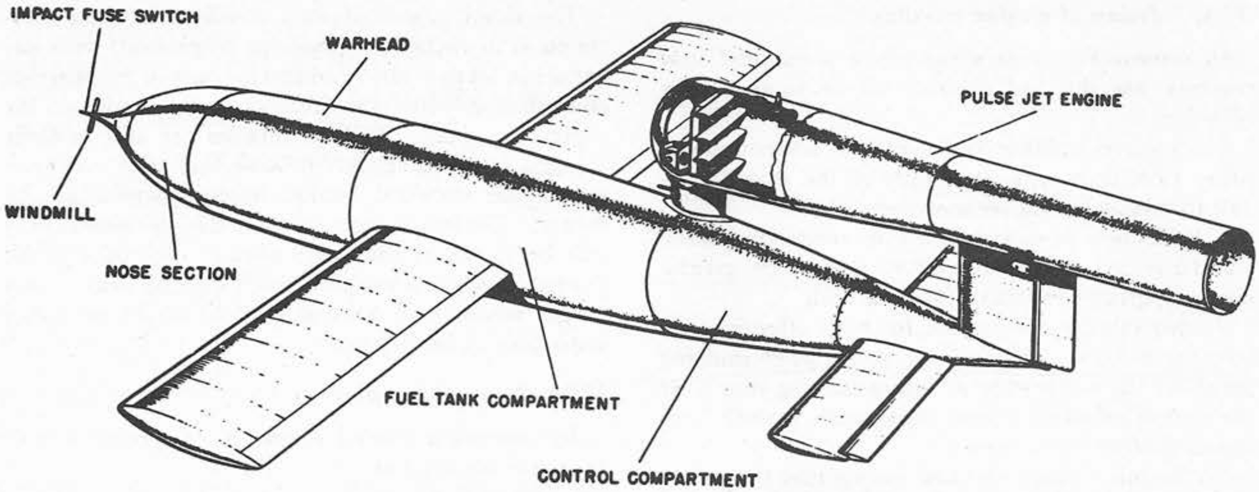

FIGURE 11D1.—The German V–1 pulse-jet missile (buzz bomb).

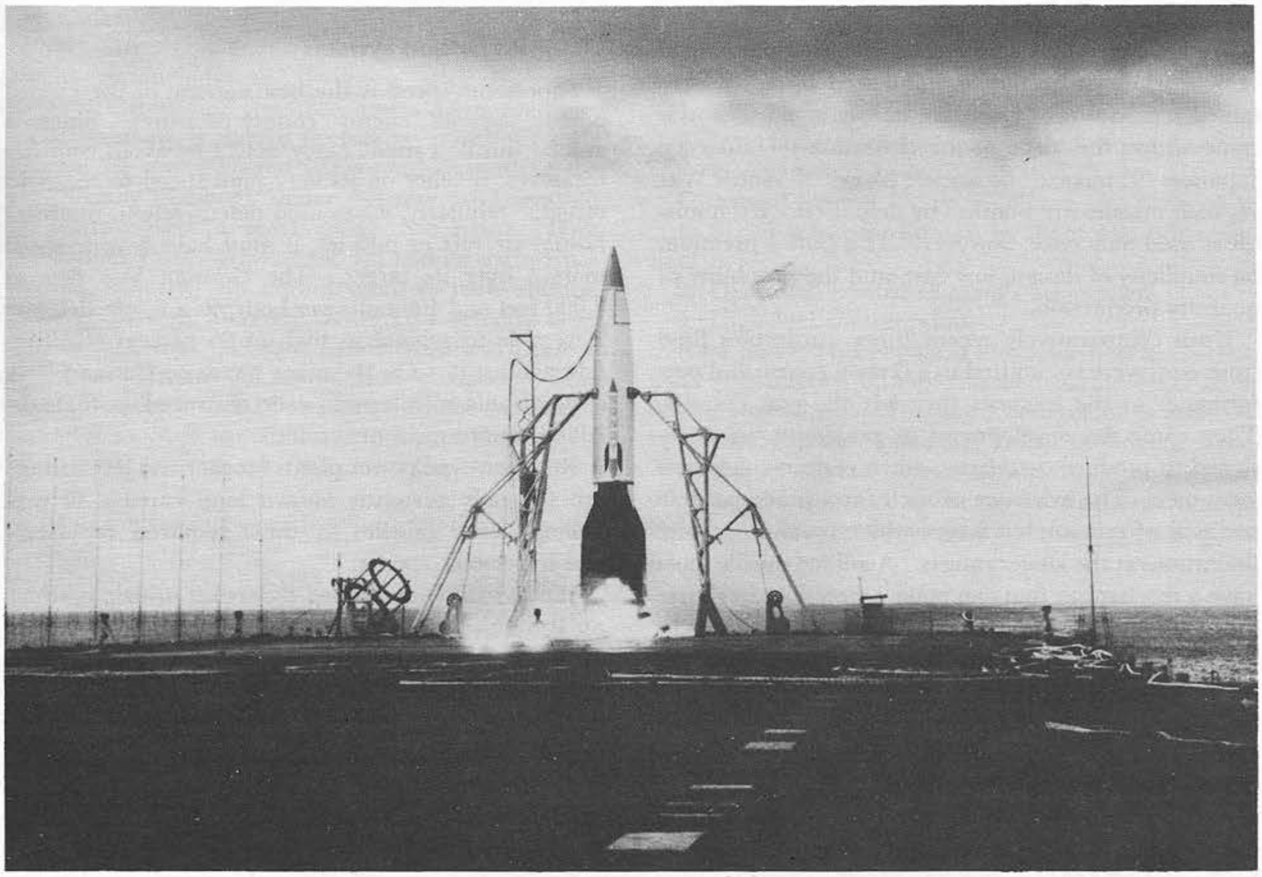

FIGURE 11D2.—V–2 rocket fired from deck of USS *Midway*.

11D4. Mission of guided missiles

All improvements in weapons, or attempted new weapons, are directed toward one or more of the following:

1. Increased striking range of the weapon itself, rather than increased range only of the ship or aircraft that launches the weapon.
2. Reduction in susceptibility to countermeasures.
3. Increased destructive effect gained by greater accuracy, greater explosive force, or both.

Guided missiles are needed for both offensive and defensive reasons. A little imagination when studying the above list will lead to an understanding that if we can perfect missiles in these three ways, we will have powerful offensive weapons.

On the other hand, we must assume that the enemy will also perfect guided missiles. To defend ourselves against these enemy weapons, we must have guided missiles capable of seeking out and destroying the enemy missiles in flight. It is essential that we gain and maintain supremacy in this new field.

11D5. The guided-missile principle

We have seen that a guided missile is an unmanned vehicle whose trajectory is influenced by a self-contained mechanism. Quite a number of missiles now come within the scope of this definition. Unlike the Japanese "kamikaze" or suicide planes of World War II, such missiles are pilotless by definition. Each missile is used only once, however. This puts a premium on simplicity of design, low cost, and the possibility of quantity production.

Until comparatively recent times, projectiles fired from guns were committed to a certain course and performance at the moment they left the gun muzzles. Then came the development of *proximity fuzes,* designed to produce detonation when certain conditions were met. The existence of such fuzes made possible one type of control, but a type which involves definite limitations at the longer ranges. A guided missile must have a mechanism that can make corrections in course during flight to compensate for initial errors in launching, deviation from course due to wind or other effects, and target motion.

To be effective, then, a long-range guided missile clearly must have a propulsion system capable of producing high and sustained speed; must be able to traverse a considerable range; must incorporate a mechanism adequate for purposes of guidance; must have control surfaces capable of effecting necessary changes in flight path; and must carry a "pay load" appropriate to its mission.

The development of such missiles has been associated with rocket development in general, with advances in jet propulsion and techniques of guidance or control, and with perfection of airframe design for supersonic speed. Guided missiles are still in their infancy, and it is entirely possible that they may constitute the standard bombardment weapons of the future. Great advances in their design undoubtedly will be made in the years ahead. Potentially, the guided missile is a weapon which may be used at long range, where conventional gunfire would be either impossible or ineffective.

11D6. Component parts

In general, a guided missile is composed of four principal components:

1. Propulsion system.
2. War head and fuze.
3. Guidance system.
4. Air frame.

In this volume, only the first two components will be considered. The various systems of missile guidance will be discussed in volume 3.

11D7. Propulsion systems

Supersonic speed is the best defense of the guided missile against enemy countermeasures. Since a guided missile cannot easily detect or avoid countermeasures, it relies on its very high speed to reach its target. Similarly, when used defensively to intercept hostile aircraft or missiles, it must have a wide speed margin over its target. The German V–1 flew at 3,000 feet and 400 miles per hour; as a result, defenses were able to achieve as high as 95 percent effectiveness against it. On the other hand, no German V–2, a supersonic missile, was ever destroyed in flight by Allied countermeasures.

Reaction-type power plants (rocket and jet engines) are the only presently known kind capable of propelling aerial missiles at these required supersonic and hypersonic speeds.

We have already studied the rocket principle, which applies also to jet engines. Jet propulsion is defined as motion resulting from ejection of matter from within the propelled body to create momentum. To develop thrust, a means of ejecting matter must be found. This may be done in two ways.

1. *Mechanical jets.* Pumps or fans can be used to produce a jet of air, water, or other fluid. A rotating lawn sprinkler is mechanically jet propelled.

2. *Thermal jets.* A thermal reaction, usually oxidation, produces great volumes of gases at high temperatures and pressures, which expand through a

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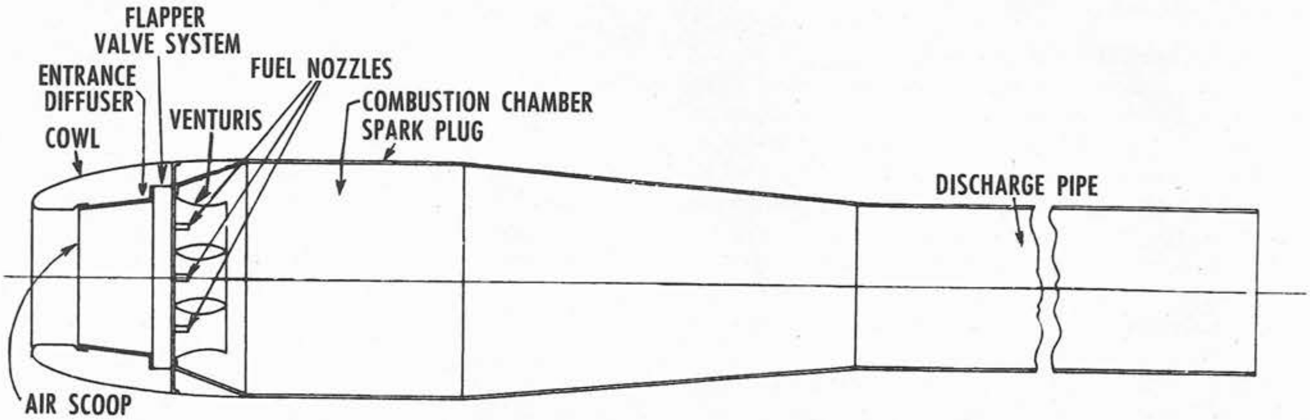

FIGURE 11D3.—A pulse-jet engine.

ducted outlet, producing a jet. All practical jet engines work on the thermal principle.

There are four varieties of reaction-type power plants:

1. Pulse jets.
2. Ram jets.
3. Turbo jets.
4. Rockets.

Pulse jets. This engine, also known as an intermittent jet, includes an air scoop, a flapper valve system, a combustion chamber, and a discharge pipe.

The pulse jet is started by forcing compressed air through the spring-loaded flapper valves, adding the fuel (usually gasoline) under pressure, and igniting this mixture with a spark plug. See figure 11D3. The flapper valves prevent the expanding gases from escaping forward, but permit gases to rush out the discharge pipe at high velocity. This velocity is so high, in fact, that the gases overexpand and cause a partial vacuum in the combustion chamber. This action, plus the inrush of air caused by the motion of the motor through the atmosphere, opens the flapper valves and permits air to enter the combustion chamber.

Part of the exhaust gases flow back up the discharge pipe and meet the air coming through the valves, compressing the new air slightly. This compression, plus residual burning fuel, plus the heat of the walls of the combustion chamber, ignites a new charge of fuel which enters at this time, and the cycle is repeated. It was this intermittent cycle, about 40–50 times per second, which gave the name of "Buzz Bomb" to the German V–1. The pulse jet is not used for manned flight.

Advantages:

1. Light, economical, and easy to construct.
2. Uses atmospheric oxygen so needs no oxidizer.
3. Uses common fuels.

Disadvantages:

1. Speed subsonic; limited to about 450 miles per hour.
2. Operation limited to earth's atmosphere.
3. High fuel consumption.

Ram jets. This engine is also known as an "athodyd" (contraction of aero-thermodynamic duct) or a "flying stovepipe." The latter designation is inspired by the shape of the engine and its lack of moving parts. The ram-jet engine consists of a diffuser or inlet air duct, a combustion chamber, and a discharge nozzle. Figure 11D4 is a sectional diagram of a ram-jet engine.

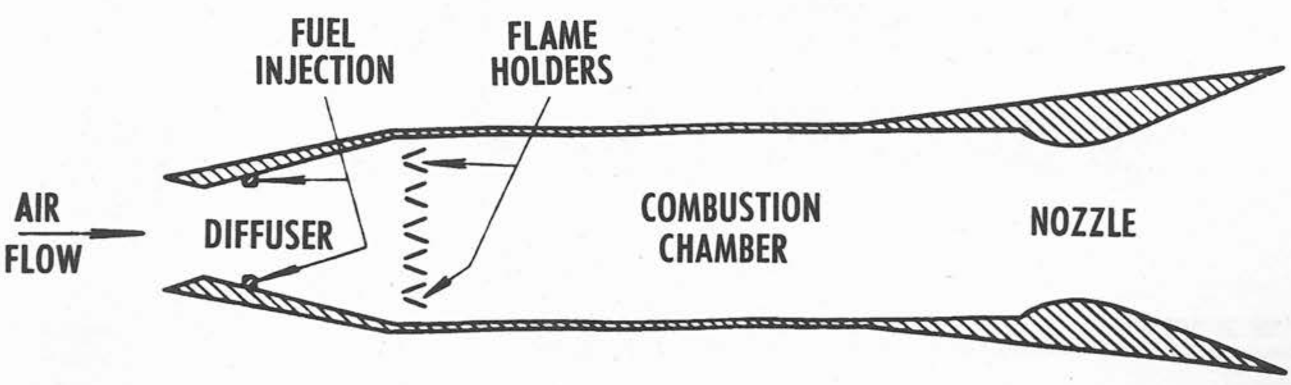

FIGURE 11D4.—A ram-jet engine.

Consider a piece of straight stovepipe at rest. If fuel were ignited in the middle of the pipe, the hot expanding gases would escape from both ends. Now consider the pipe moving along its axis at 400 miles per hour. Rammed air is traveling through the pipe at 400 miles per hour without combustion. When the heat of fuel combustion is added at a point near the forward end of the pipe, the gases seek to expand in all directions. Obviously, this expansion will be opposed by the "head" of air at the duct of the pipe. The only point of escape is at the rear. The pressure and heat produced by combustion are so great that the gas leaves the rear at 1,400 miles per hour. The mass of air entering at the front is thus rapidly accelerated to the rear, and produces thrust.

In actual operation the ram jet has a divergent inlet nozzle. This raises the pressure of the air "head" by decreasing its velocity inside the pipe, and allows more heat to be added. The discharge nozzle is convergent, and thus increases the velocity of the jet stream. Entry head becomes still greater, and makes the acceleration greater; you can say of the ram jet that "the faster it goes, the faster it goes!"

However, the ram jet must be boosted to a high speed before it will operate. This requires a booster that is larger and heavier than the ram jet itself. At low speeds—500 to 800 miles per hour—the ram jet uses fuel rapidly. As it reaches extremely high speeds at very high altitudes, however, the ram-jet unit itself gets hot from "skin friction." This heat increases the pressure of the ejected gases, and relatively little fuel is required.

There is a limit to this, however, for at extremely high speeds skin friction makes the metal of the ram jet white hot, and it soon collapses. Research will have to create metals to withstand this temperature if the advantages of the ram jet are to be fully used in guided missiles. In the near future, it may be possible to construct a ram jet limited in range only by the amount of fuel carried.

Advantages:

1. Simple—no moving parts.
2. Light and cheap.
3. Easy to manufacture.
4. Uses common fuel.
5. Efficient at high speeds and altitudes.
6. Supersonic.

Disadvantages:

1. Must be boosted to high speed before it will operate.
2. Limited to earth's atmosphere.
3. Speed presently limited to about 2,700 miles per hour.

Turbo jets. The turbo-jet engine includes an air scoop, a mechanical compressor driven by a turbine, a combustion chamber, and an exhaust nozzle. See figure 11D5. It does not require a booster. A turbo-jet engine provides good fuel economy at both high and low subsonic speeds.

Turbo-jet propulsion has been used extensively in airplanes, since it is readily controllable in manned flight. It has also been used for the propulsion of long-range missiles. Velocities approximating Mach 1 are attained. One objection to the use of turbo-jet propulsion in expendable missiles, however, is that the mechanism is relatively complex and costly.

In operation of the turbo-jet engine, the compressor, driven by the gas turbine, supplies air under high pressure to the combustion chamber, and the turbine absorbs only part of the jet energy. The result is an open-cycle gas turbine combined with a jet stream.

The turbo jet is limited to less than the speed of sound. When it approaches the speed of sound, shock waves develop on the compressor blades and interfere with their operation. A recent development may permit turbo jets to operate up to Mach 1.2. But such jets would be relatively inflexible, and very inefficient at low speeds.

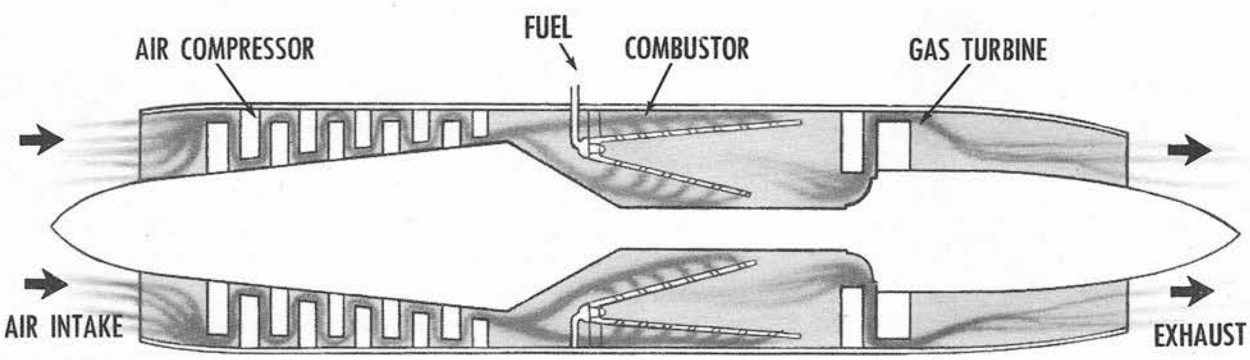

FIGURE 11D5.—A turbo-jet engine.

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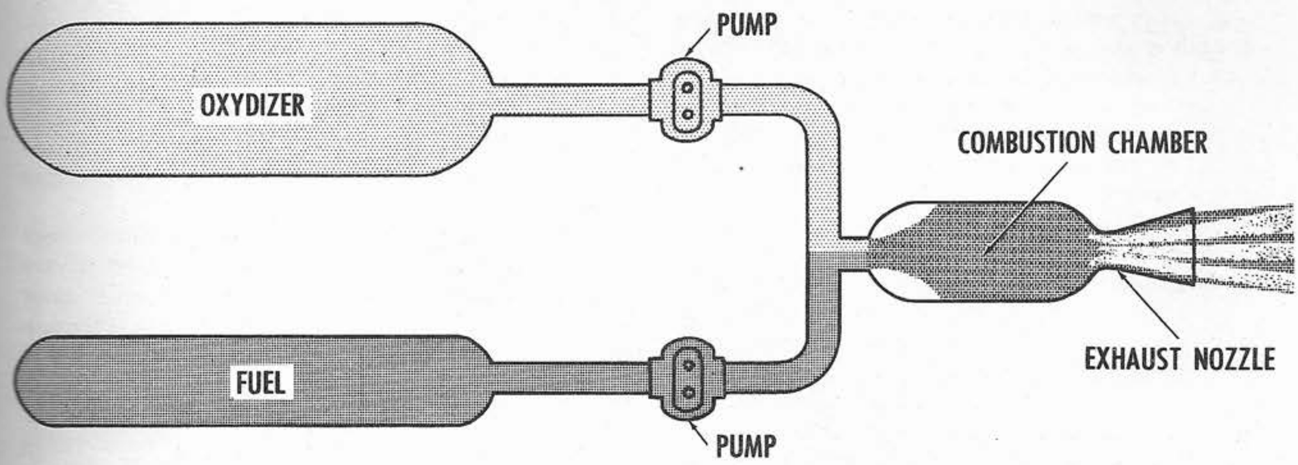

FIGURE 11D6.—Components of a liquid-propellant rocket motor.

Advantages:
1. Develops large static thrust.
2. Carries fuel only; gets oxygen from air.
3. Thrust practically independent of speed.
4. Burns common fuels.

Disadvantages:
1. Subsonic speeds at present.
2. Complicated engine with moving parts.
3. Power limited by stresses on turbine blades.
4. Must operate in earth's atmosphere.

Liquid-fuel rockets. To overcome the problems of weight and heat of burning for long-duration units, liquid-fuel rockets are used. The problems are alleviated by the fact that the combustion chamber may be made lighter and smaller than with a solid propellant. Fuel and oxidizer may be fed from their respective tanks to the motor by either the pressure feed system or the pump feed system. Figure 11D6 is a diagram of liquid-propellant rocket motor using the pump feed system.

Most liquid-fuel motors are of the regenerative type. Those are built as a double shell, with separate openings for injection of fuel and oxidizer. Fuel enters the rear of the motor, flows between the walls, cools the inner surface, and makes possible the use of a thin-walled combustion chamber. The fuel then enters the forward end of the combustion chamber. This not only permits longer burning, but because of the preheated fuel it also increases the heat energy released on combustion.

The fuel is ignited by a spark or a pyrotechnic device. Once initiated, combustion is self-sustaining, since fuel and oxidizer are continuously injected.

The source of power for the pumps is a turbine driven by a steam generating plant. Since pressure is developed only on the output side of the pumps, the fuel and oxidizer tanks can be of relatively lightweight construction.

The pressure feed system is similar to the pump feed system, except that pressure in the tanks takes the place of the pumps. The main disadvantage is that this pressure must be greater than the operating pressure of the combustion flask, which is 250–500 pounds per square inch. Consequently, the fuel, oxidizer, and pressure flasks must be of heavy construction.

Advantages:
1. Relatively simple.
2. Practically unlimited speed.
3. Operates in any medium or a vacuum.
4. Relatively few moving parts.
5. Develops full thrust at takeoff.
6. Has less need for a booster than air-breathing engine.
7. Can utilize multiple-step rockets in combination with solid-fuel rockets.

Disadvantages:
1. High rate of propellant consumption.
2. Short burning time.
3. Comparatively short range.
4. Cannot be stored fully fueled for long periods of time.

11D8. War heads and fuzes

War heads. The payload of a guided missile is its war head. There is an optimum position of burst to accomplish the desired effect on the target. Within limits, the closer the burst to the target, the smaller the war head required. On the other hand there is a limit to the maximum size of war head for a specific missile. Any increase in the effectiveness of guided missiles will require either that we launch larger num-

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bers of missiles against each target, or that we improve the guidance system. The latter is the most logical approach to the solution. Constant research is being devoted to improving methods of guidance.

At present, there is no reason to believe that the war heads used by other military weapons cannot be adapted to guided missiles. The following types of war heads might be used:

1. *Blast effect*. Depends on shock wave generated by explosive force to do damage.

2. *Fragmentation*. Depends on explosive force to eject numerous metallic fragments at high velocities.

3. *Shaped charge*. Used for maximum penetration.

4. *Explosive pellet*. Contains numerous separately fuzed pellets that withstand initial ejecting force from war head, but detonate on impact with target.

5. *Chemical*. Contains gases or incendiary material.

6. *Biological*. Releases living micro-organisms to cause sickness or death.

7. *Atomic*. Depends primarily on blast and heat resulting from atomic fission or fusion.

8. *Radiological*. Depends primarily on saturation of target with radioactive material.

The type of target is the most influential factor in the selection of war heads. It is emphasized that the war head, and the results it can achieve at the target, constitute the only justification for building and flying guided missiles.

Fuzes. One or more fuzes may be used in conjunction with any of the above-listed war heads. Here again, the type of target is the most important consideration in the type of fuze desired.

The fuzes used fall into three general categories: *impact, proximity,* and *ground-controlled*.

1. *Impact*. This fuze is actuated by inertia on impact, either at once or after a pre-set time delay.

2. *Proximity*. This fuze is actuated by some characteristic of the target, which causes the fuze to operate at a predetermined distance from the target. Following are five basic types of proximity fuzes:

a. Radio-proximity (similar to VT fuzes).

b. Pressure proximity.

c. Electrostatic proximity.

d. Photoelectric proximity.

e. Acoustic proximity.

3. *Ground-controlled fuzes*. This fuze does not contain the mechanism for determining the proximity of the target. When the missile gets close enough to its target, a signal to detonate the missile is sent from a station on the ground.

A fuze may appear to be a minor component of a guided missile, but a poorly designed or wrong-type fuze can render an otherwise powerful weapon useless.

11D9. Problems of guided-missiles design

A guided missile must withstand very heavy acceleration forces and inertia loads produced by rapid turns at high speed. Materials used in construction must also withstand very high temperatures produced by air resistance (external), and fuel combustion (internal). It is axiomatic that if the missile becomes misshapen, it will fall out of control.

From the aerodynamic standpoint, a long-range guided missile must have an *airframe* adaptable to very high speed and precise control. The missile must travel at supersonic speed to realize the full potentialities of jet propulsion and achieve greatest benefit of surprise at the target. One of the challenging needs is to reduce *drag*: resistance to motion through the air. Drag increases rapidly as missile velocity increases within the sonic range; within this range it is difficult to effect controlled flight as acceleration increases. The Germans met the problem in their V–2 rocket by installing graphite control vanes within the jet stream; these vanes effected control within the sonic range and were burned out when the V–2 attained supersonic speed. Thereafter, the surfaces in the air stream provided control.

The *range* attained by a long-range missile depends primarily upon *maximum velocity* of that missile. Maximum velocity, in turn, is conditioned by the amount of fuel, the exhaust velocity when the fuel is being burned, and the effect of drag upon rocket velocity. For example, one variable is the mass-ratio of the missile, which represents comparison of (1) takeoff weight with fuel load, and (2) weight without fuel load. The theoretical mass-ratio of the V–2 rocket was about 3:1; however, its actual performance was more nearly represented by a mass-ratio of 2.2:1.

In preceding discussions we have noted that many short-range rockets depend upon solid fuels for propulsion. The burning rate of solid fuels can be inhibited or delayed, but even so, solid-fuel rockets are not preferred as long-range vehicles. This is because their combustion chambers must be as large as the fuel charge, and must have relatively heavy walls to withstand the forces of combustion. In other types of long-range missiles it is possible to have small combustion chambers, into which fuels are drawn as needed from fuel tanks of much lighter construction.

Thus kerosene or gasoline carried in tanks has commonly been used as fuel for air-duct engines. In liquid-fuel rockets, however, where fuel consumption is relatively high, the development of superior fuels becomes a critical consideration. The Germans used liquid oxygen and alcohol in the V–2 rocket. They also developed a nitric acid and hydrocarbon combination, and a hydrogen peroxide and hydrazine mixture for use in rocket propulsion.

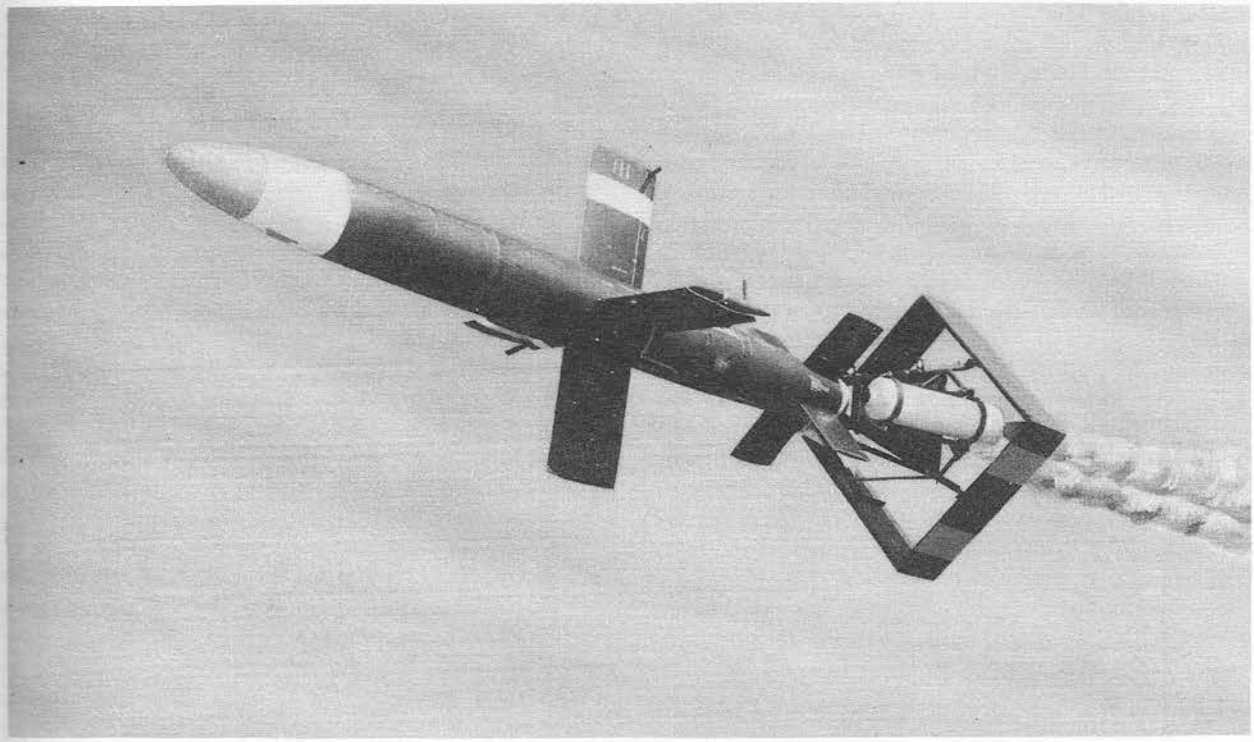

FIGURE 11D7.—Use of booster in launching rocket.

11D10. Single-step versus multiple-step rockets

A rocket missile which has a single propulsion unit containing a charge which burns continually to the point of exhaustion is a *single-step rocket*. Such a rocket has the inherent disadvantage that the weight of all structures (less weight of consumed fuel) must be retained throughout the period of acceleration. A *multiple-step* rocket, on the other hand, incorporates one or more propulsion units which are discarded as rapidly as they serve their purpose. Step 1 is fired initially and burns to exhaustion. Step 2 now carries on the work of acceleration until it, too, is exhausted, whereupon step 3 is ignited and step 2 is discarded. This process continues until all steps incorporated in the rocket are consumed. Figure 11D7 shows a simple two-step rocket, in which a booster is used to give the missile its initial acceleration. When the booster is exhausted the propellant of the larger rocket will be ignited, and the booster will fall away.

The potential superiority of a multiple-step rocket, from the standpoint of achieving high velocity, will now be apparent. This superiority stems from the fact that it is not necessary to accelerate the entire initial mass (less burned propellant) except during the burning of the first stage. It will also be seen that the proposed German A–9 and A–10 combination, previously mentioned, represented a sort of multiple-stage rocket. The A–10 rocket incorporated the first stage and the A–9 rocket incorporated the second stage.

11D11. Launching problems

The Navy problem with respect to the launching of long-range missiles is complicated by the fact that launchers must be compact for shipboard installation, and that decks of ships do not provide the relatively stable base for launching that is provided by a land area. Launchers may be either *fixed,* in which case the missile is dispatched in the fixed direction and subsequent control must be provided to guide the missile to the target, or *trainable,* so that the missile is initially dispatched in the direction of the target. A fixed launcher is comparatively simple, but necessitates employment of rather exacting guidance during flight for each missile, and can be effective only against long-range targets. A trainable launcher makes less demand upon guidance in flight at short range, but is a much more complex structure from an engineering standpoint.

Among the first guided-missile launchers to be used were *gravity* launchers for the release of short-range glide bombs. Essentially, such launchers are modified bomb racks. The launching thrust is provided by gravity, and initial train is effected by maneuvering the airplane. Early types of glide bombs such as the Bat were launched in this manner. *Pit* launchers were constructed to fire V–2 rockets. Within the pit the missile rested on its stabilizing fins in a vertical position; the rocket provided its own launching thrust. Such a pit launcher is an example of a fixed launcher.

Various types of *inclined-ramp* launchers, such as the one shown in figure 11D8, have been tested in experimental work. Such a launcher must provide for whatever control and initial propulsion are necessary to get the long-range missile on the way to the target, so that the missile's own propulsion and guidance systems may function effectively. Essential components may include a set of rails along which the missile slides in the launching process. Such a launcher must also provide stable and rigid support, meet general requirements of compactness, and withstand the blast of the missile or its auxiliary boosters.

Some long-range missiles, of course, have propulsion systems which do not function until the missiles have been accelerated to a requisite velocity. *Booster units* can be employed singly or in combination to supply the thrust necessary to produce this velocity. The thrust can also be provided by action of a *catapult,* which also gives support and direction during the launching period. The Germans used a catapult system to give initial acceleration to their V–1 bomb. A catapult is likely to be large, complex, and heavy; on the other hand, it may be used over and over again.

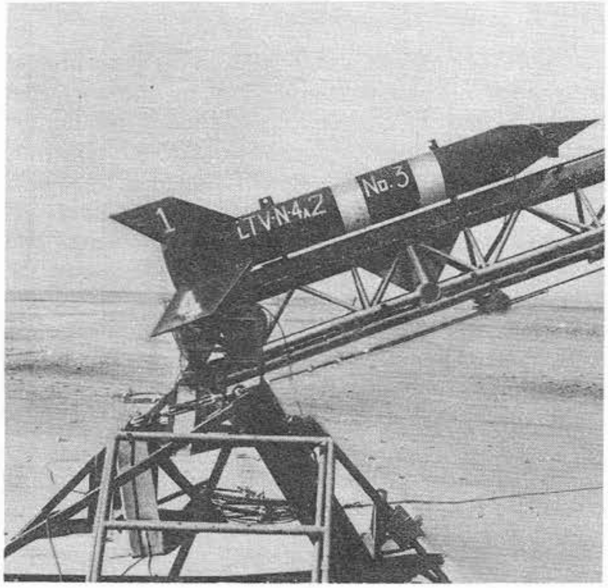

FIGURE 11D8.—Solid-fuel booster rocket on a launching ramp.

It is possible, moreover, to use a catapult and booster charges in combination. Special *gun types* of missile launchers have also been developed.

11D12. Missiles in use in the Fleet

Although it is not possible in this volume of this course to go into detail regarding guided missiles that are now operational in the Fleet or under development, chiefly because of security classification, it is possible to survey very briefly here a few important types of missiles concerning which unclassified information is available.

Missile types while under development are identified by code names rather than by descriptive nouns followed by mark and mod numbers.

The best known United States Navy missile at the present time is a surface-to-air (SAM) type known as the *Terrier*. *Terrier* is the chief armament of CAG ships. At least one DD is being modified to carry it, and it will also be mounted on some new frigates. It is a 9-foot-long rocket-propelled weapon, which starts its flight from a twin launcher on the ship's deck. The booster which gives the missile its start is nearly as long as the missile. The booster drops off after it burns out. The missile is guided electronically by the launching vessel.

The twin launchers on CAG vessels (the present two are former CA's) are mounted above ammunition hoists which mechanically lift the missiles into the launcher. Reloading can be done twice a minute. It has been stated that two *Terriers* are normally sufficient to bring down any aircraft. Figure 11D9 shows *Terriers* in their launchers aboard CAG 1.

An Army-developed missile similar in mission to *Terrier* is *Nike*, which is used in defense of ground installations and cities. *Nike* is not fired from naval vessels.

Talos is a newer naval SAM larger than *Terrier*. At least one light cruiser is being modified to carry it.

Regulus is one of several SSM's developed for naval use. It is a high-subsonic-speed pilotless bomber which can be launched from any of several types of ship, including submarines. It can be fired from demountable launchers or from steam catapults. Another SSM still under development is the *Loon*.

Sparrow is a rocket-propelled AAM now operational in the Fleet. (See fig. 11D10.) It is guided by a radar beam transmitted from the launching aircraft. *Sparrow* is about 12 feet long, weighs around 300 pounds, and can attain a speed of 1,500 knots within a few seconds after launching. It has proved effective against both high-and low altitude targets, even while they are taking evasive action.

Sidewinder is another rocket-propelled AAM. At this writing, details of this missile are classified.

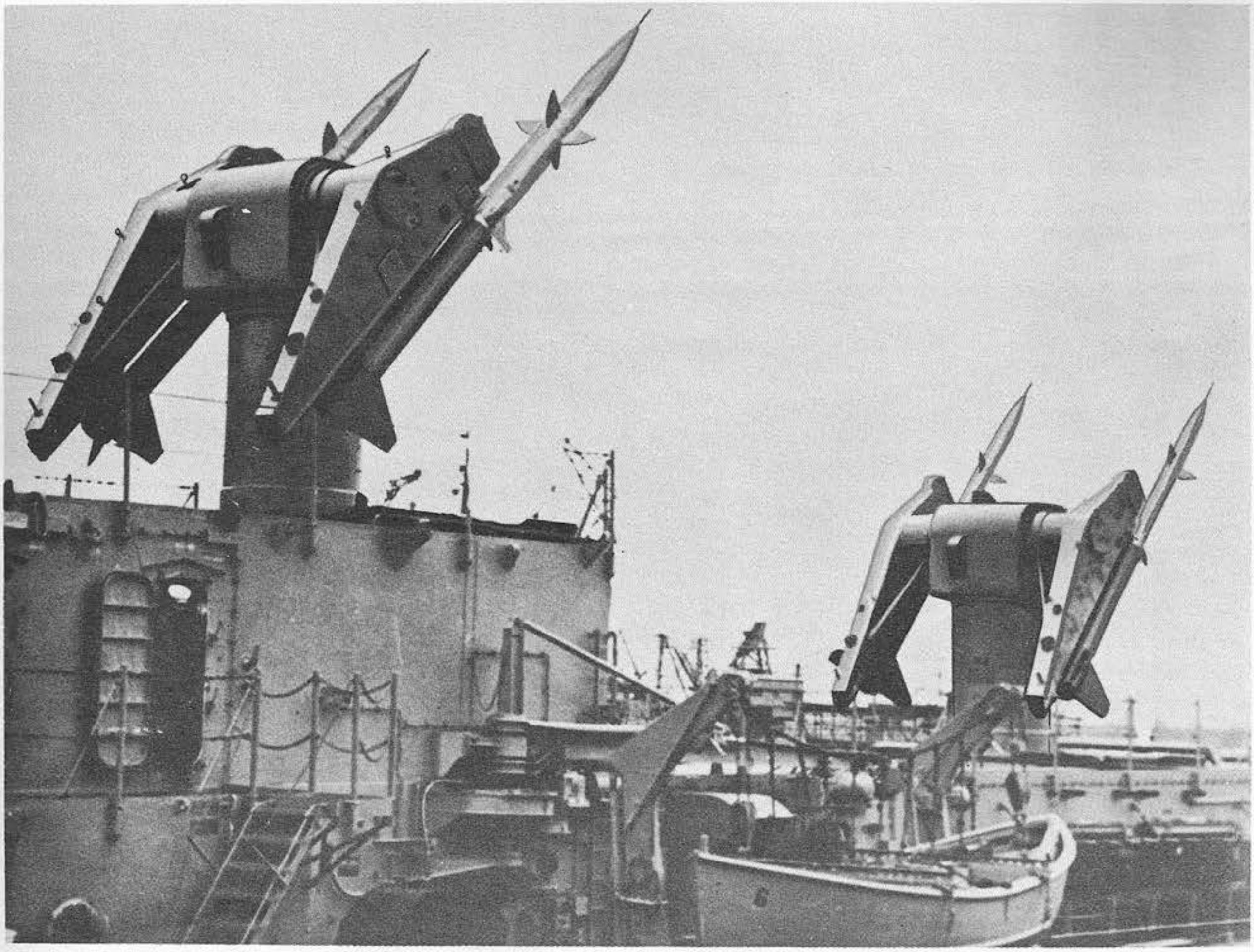

FIGURE 11D9.—Terrier missiles in launcher aboard CAG 1.

Development is close to completion on the *AUM Petrel.* This is essentially a homing torpedo mounted in an airframe with its own jet engine. It flies for some distance after launching, jettisons its airframe and engine when it strikes the water, and then functions as a homing torpedo against a submerged or partly submerged target.

Aerobee is a research vehicle. It is a rocket capable of speeds up to 2,000 knots and altitudes of 78 miles. It carries instruments rather than a war head.

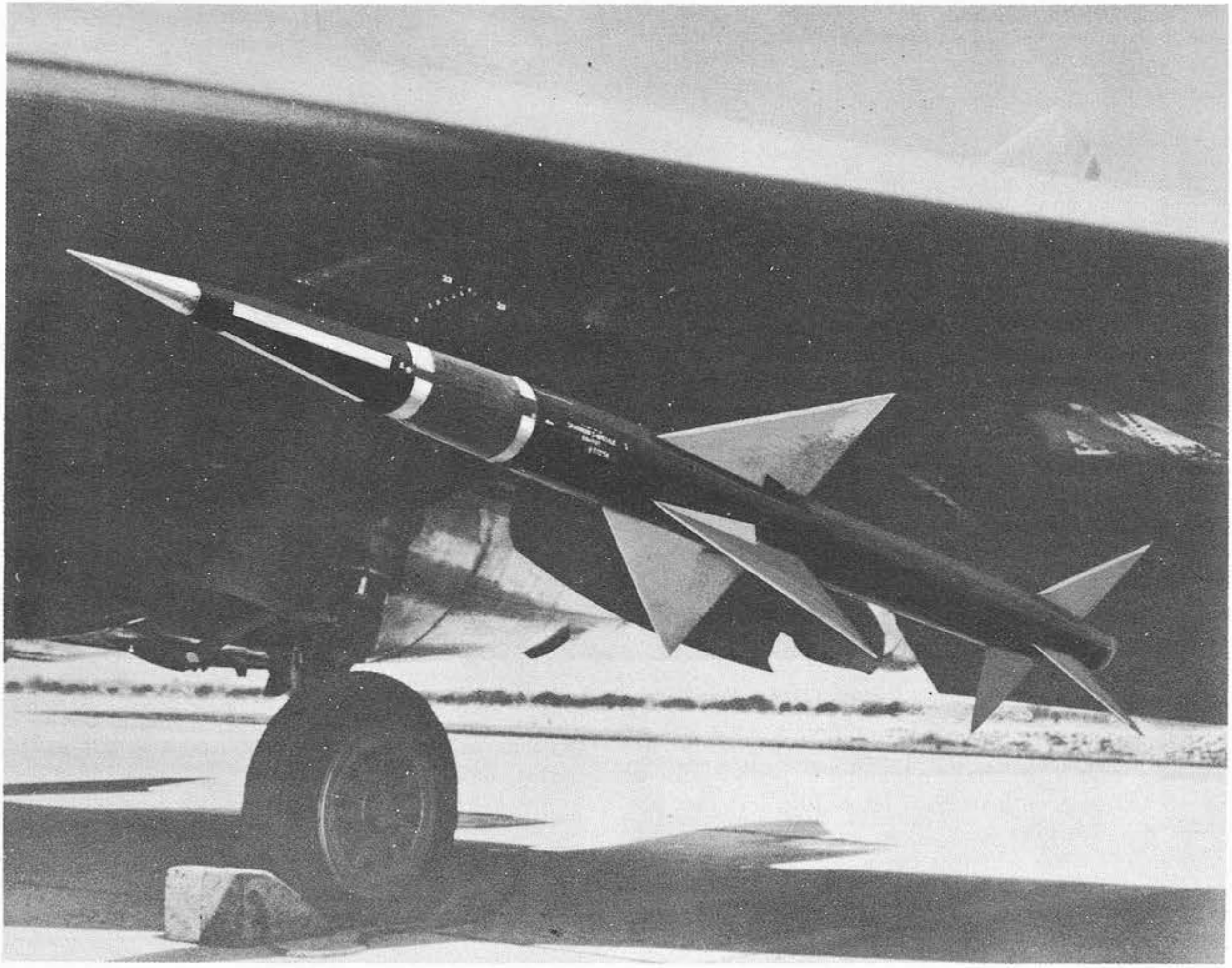

FIGURE 11D10.—Sparrow suspended from the wing of the launching aircraft.

TORPEDOES

A. Introduction

12A1. General

A torpedo is a self-propelled underwater weapon that carries a high-explosive charge to its target. A torpedo can do more damage than a projectile from the biggest guns on a battleship. There is more explosive in a torpedo war head than there is in any projectile.

The torpedo war head explodes under water, and that increases its destructive effect. When a projectile explodes, a part of its force is absorbed by the surrounding air. But when the torpedo war head explodes, the water transfers almost the full force of the explosion to the hull of the target ship. Thus, even if a projectile could carry the same amount of explosive, the torpedo would do more damage.

The torpedo makes it possible for small ships to carry heavy armament. But of course it can not make a small ship the equal of a large one in combat. A torpedo moves slowly compared to a projectile, and its effective range is much shorter.

12A2. Applications

The torpedo is an important weapon of destroyers, destroyer escorts, and frigates. Torpedoes are the principal armament of PT boats and submarines, and, under certain conditions, of aircraft. The tactical use of torpedoes is gradually changing; their use in surface engagements is less frequent than it was a number of years ago. The outcome of a battle is likely to be decided before the enemy is within torpedo range. Even so, the ability of a destroyer to launch torpedoes serves as a constant threat to the enemy, and thus limits the range of maneuver available to him.

When aircraft approaches a surface ship within torpedo-launching range, it is vulnerable to antiaircraft fire. In future warfare, it is likely that both destroyers and torpedo planes will use guided missiles against surface targets. The missiles will carry torpedoes to within launching range of the enemy.

While it is submerged, a submarine is not vulnerable to gunfire. A submarine can often approach within torpedo range of its target before its presence is detected. Torpedoes will therefore continue to be the principal armament of submarines in the foreseeable future.

Homing torpedoes are a relatively recent development; they have been perfected since the end of World War II. With homing torpedoes, a destroyer can attack a submerged submarine, even when its exact position and depth are unknown. The homing torpedo is becoming increasingly important as a weapon with which one submerged submarine may attack another.

12A3. Launching methods

There are two principal ways to launch a torpedo—by firing it from a tube, or by dropping it from a rack.

PT boats launch torpedoes from racks at the sides of the boat. A PT boat may carry from 2 to 4 torpedoes. Aircraft drop torpedoes from launching racks; usually, an aircraft carries only a single torpedo.

Older destroyers carry 5 torpedoes, in a tube mount that consists of 5 barrels side by side. The tube mount is carried amidships. It can be trained through a wide arc, so that torpedoes may be fired from either side of the ship. *Impulse charges* of black powder are used to expel the torpedoes from the tube mount with enough force to clear the firing ship.

Newer destroyers, destroyer escorts, and frigates are fitted with fixed, non-trainable tubes—usually four of them. The tubes are located below the weather deck with their muzzles extending through the sides of the deck house. Torpedoes are expelled from these tubes by compressed air.

Submarines fire torpedoes from fixed, below-water tubes. The fleet-type submarine is fitted with 10 tubes—6 in the bow and 4 in the stern. On firing, the torpedoes are expelled from the tubes by compressed air. Spare torpedoes are carried in ready racks near

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the tubes. A submarine on war patrol will usually put to sea with a load of 28 torpedoes aboard.

12A4. Requirements of a torpedo

As previously stated, a torpedo is a self-propelled weapon. Its principal requirements are, therefore, a charge of explosive and a power plant. As a practical weapon, a torpedo must have a number of other features. These include the following:

A shell, or housing, strong enough to support the explosive charge, power plant, and related mechanisms, and strong enough to withstand the shock of launching.

A source of energy for the power plant, and for the torpedo control mechanisms.

An exploder that will detonate the explosive charge when the torpedo reaches its target, but which will remain inoperable while the torpedo is close to the firing ship.

Control mechanisms that hold the torpedo on a preset course, at a preset depth.

One or more propellers to drive the torpedo through the water.

Tail vanes and rudders, to control course and depth.

Sections B through G of this chapter will show how these requirements are met in a typical torpedo—the Mark 15 type.

12A5. Types of torpedoes in service

All torpedoes are similar in general appearance; they are typically cigar-shaped, as shown in figure 12A1. Torpedoes may be classified in several ways:

1. By their *power plants* (gas-steam or electric). Electric torpedoes are powered, of course, by electric motors; the energy source may be either a dry battery or a lead-acid storage battery. The power plant of a gas-steam torpedo consists of a pair of turbines and a gear-reduction engine. In most of the gas-steam torpedoes, energy is provided by compressed air and alcohol. In the Mark 16 type, the energy source is alcohol and a concentrated solution of hydrogen peroxide.

2. By the *craft* from which they are launched (destroyer, submarine, or aircraft).

3. By their *speed* and *range*.

4. By the type of *exploder*. The *impact* exploder operates only when the torpedo actually strikes its target. The influence exploder (which will not be described in this volume) operates when the torpedo passes *near* its target.

5. By the type of *control mechanism*. In the older torpedoes, the control mechanism holds the torpedo on a previously calculated collision course with the target. The *homing* torpedo (which is described briefly in article 12I6) can steer itself toward its target and, if necessary, chase it.

The following list summarizes the characteristics of the *non*homing torpedoes now in the Fleet.

Mark 13 type. The Mark 13 torpedo, compared with the others, is short and thick: its length is 13½ feet, and its diameter, 22½ inches. (The others all have the same diameter—21 inches—so they will fit the standard torpedo tubes.) The Mark 13 is designed for launching from aircraft and PT boats. Its range is 6,000 yards at an average speed of 33½ knots, and it carries 600 pounds of high explosive.

Mark 14 and 23 types. The Mark 14 torpedo is fired from submarines. Its length is about 20½ feet. It offers a choice of two speeds. At the high-speed setting it has a range of 4,500 yards, at an average speed of 46 knots. At the low-speed setting its range is 9,000 yards, and its average speed is 32 knots. It carries 600 pounds of high explosive.

The Mark 23 torpedo is exactly like the Mark 14, except that it has no speed-change mechanism. It operates only at high speed.

Mark 15 type. The Mark 15 torpedo is launched from the deck tubes of surface ships. It is 24 feet long, and carries an explosive charge of about 800 pounds. It has three speeds: 26½ knots (range 15,000 yards); 33½ knots (range 10,000 yards); and 45 knots (range 6,000 yards).

Mark 16 type. The Mark 16 is a "chemical" torpedo. It uses a strong solution of hydrogen peroxide, rather than compressed air,.to support the combustion of its fuel. This feature gives the Mark 16 a relatively high speed and long range, and enables it to carry a relatively heavy charge of explosive.

Mark 18 type. The Mark 18 is the only nonhoming

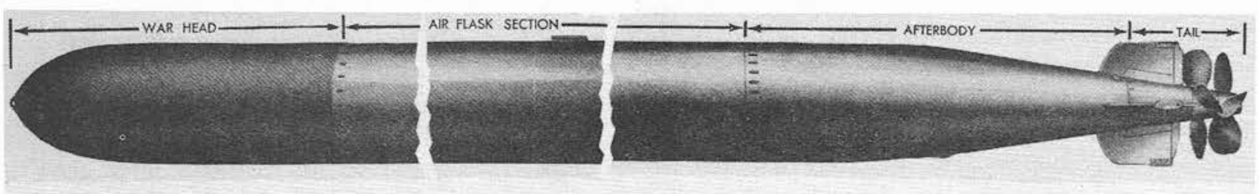

FIGURE 12A1.—Torpedo Mark 15 Mod. 3 with war head.

electric torpedo now in the Fleet. Its principal source of energy is a large lead-acid storage battery. It has a length of about 20½ feet, and an effective range of 4,000 yards at an average speed of 29 knots.

12A6. Construction of the gas-steam torpedo

A gas-steam torpedo is made up of five sections—the *head, air-flask section, midship section, afterbody,* and *tail.* Figure 12A1 is an external view of a Mark 15 type torpedo, showing the four principal sections. The midship section, which is not indicated in the figure, is very short; it is located at the after end of the air-flask section. Because it is permanently joined to the air flask, it is not always counted as a separate section.

When a torpedo is issued to the Fleet it consists of three main units:

1. The head.
2. The air-flask and midship sections (permanently joined).
3. The afterbody and tail (assembled together with joint screws).

Figure 12A2 is a cutaway view of a Mark 15 type torpedo, showing the principal contents of the various sections.

The *war head* contains the charge of high explosive, and the exploder mechanism that detonates it.

The *air-flask section* contains the air flask, fuel flask, and water compartment.

In the *midship section* are a number of valves and fittings for transferring fuel, air, and water between the air-flask section and the afterbody, and for recharging the air flask. Also in the midship section, but attached to the afterbody, is the combustion flask. In this flask, compressed air and fuel are mixed and burned, and provide a high-speed stream of exhaust gases to spin the turbines. Water is sprayed into the combustion flask to increase the volume of gases that go to the turbines, and to prevent overheating.

The contents of the afterbody include the turbines and gear-reduction engine, and their lubrication system; the starting gear; and the mechanisms that control the course and running depth of the torpedo. The depth mechanism includes a diaphragm and pendulum, which determine the torpedo's depth and the inclination of its axis, and a depth engine to control the depth rudders. The steering mechanism includes a gyro to determine the torpedo's actual course with respect to the preset course, and a steering engine to control the action of the steering rudders.

The mark of a gas-steam torpedo applies to the air flask, afterbody, and tail. The war head, exercise head, and gyro have individual marks.

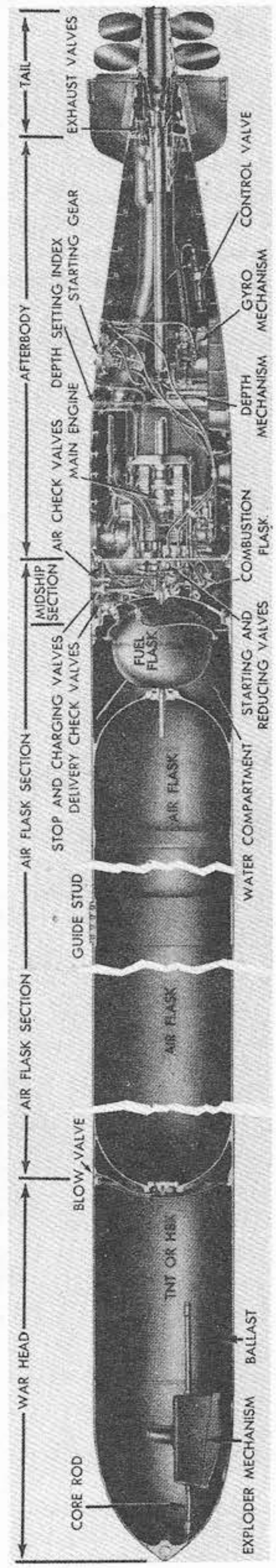

FIGURE 12A2.—Cutaway view of Torpedo Mark 15 Mod 3.

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B. Head Section of a Mark 15 Type Torpedo

12B1. General

The head section may be either a *war head* or an *exercise head*. The war head is almost entirely filled with high explosive. The exploder is mounted in a cavity on the lower surface of the war head shell. For a test shot, or for firing practice, an exercise head is used in place of the war head. The exercise head contains no explosive charge, and no exploder mechanism. For an exercise shot, the exercise head is filled with a liquid ballast—either water or a solution of calcium chloride. At the end of an exercise run, the liquid ballast is automatically expelled. When the head is empty, the torpedo has enough buoyancy to float until it can be recovered.

12B2. Functional description

The war head shell serves simply as a container to house the high-explosive charge and the exploder mechanism. Since the main charge of explosive is relatively insensitive to shock, an exploder mechanism is needed to detonate the main charge when the torpedo strikes the target. The exploder mechanism is so designed that, on impact with the target, it explodes a small detonator charge. The detonator then explodes a booster charge, which in turn detonates the main charge.

When the torpedo is launched, the exploder mechanism is in a "safe" condition. It cannot explode the booster charge, even if its detonator explodes accidentally. During the first few hundred feet of the torpedo's run, the exploder mechanism arms itself. When the torpedo reaches a safe distance from the firing ship, the exploder is completely armed. It will then detonate the main charge when the torpedo strikes any solid object.

The exercise head simulates the war head during test firing. It has the same shape as the war head, and when filled with liquid ballast it has approximately the same weight. Thus an exercise torpedo has the same trim and running characteristics it will have when fired with a war head.

At the end of the exercise run, compressed air from the torpedo's air flask expels the liquid ballast through a discharge valve. An air-releasing mechanism releases the compressed air into the exercise head automatically when the pressure in the air flask drops to a predetermined value.

12B3. War head

The Mark 15 type torpedo is provided with a Mark 17 war head. It is ogival in shape at its forward end, and cylindrical in its after part. A nose ring is provided at the forward end of the shell to facilitate handling. The shell itself is made of phosphor bronze. Although the Mark 17 war head uses only an impact exploder at the present time, the use of phosphor bronze rather than steel makes it possible to use an influence exploder when necessary.

The high-explosive charge consists of more than 800 pounds of HBX. The lead ballast weight, mounted in the bottom of the war head shell, helps to control the trim of the torpedo and to minimize rolling.

A joint ring at the after end of the war head shell is drilled and tapped for the joint screws that secure the head to the air-flask section. The after end of the shell is closed by a bulkhead, which is bolted to a flange on the inner side of the joint ring. A gasket between the bulkhead and flange forms a watertight seal.

The exploder mechanism fits in a cavity in the bottom of the forward end of the war head. The exploder is mounted on a base plate, which is secured to the war head shell with screws. The base plate is curved to match the curvature of the war head.

12B4. Exploder construction

Any one of several different exploder mechanisms may be used in the war head of the Mark 15 torpedo. The following discussion applies to the impact-operated Exploder Mechanism Mark 6.

Figure 12B1 shows the location of the exploder in the war head. The booster charge is shown in outline, mounted above the exploder in the top of the exploder cavity. The arming action of the exploder mechanism is brought about by the impeller. The impeller is turned by the flow of water through the impeller channel in the exploder mechanism base plate. The horizontal shaft to which the impeller is keyed passes into the exploder cavity through a watertight packing.

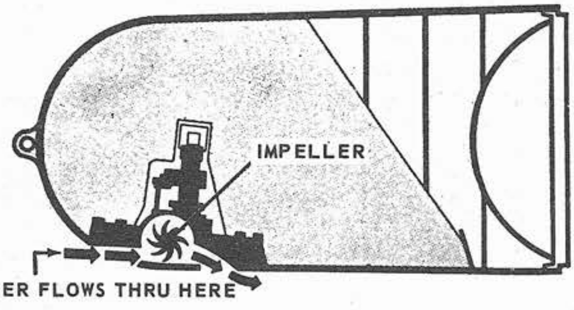

FIGURE 12B1.—Impeller action.

Figure 12B2 shows the Mark 6 exploder in both the unarmed and armed condition. The exploder's principal safety device is the safety chamber, which may be seen at the top of the pictures. When the exploder is unarmed, the detonator is housed within the safety chamber. If the detonator should explode prematurely within the safety chamber, it could not detonate the booster charge. As the exploder arms, the detonator rises out of the safety chamber to its position within the booster cavity.

On impact with the target, the detonator of the Mark 6 exploder is fired by a charge of electricity stored in a large condenser. During the first part of the torpedo run, the condenser is charged by the output of a direct-current generator driven by the impeller shaft. The generator output passes through a voltage-regulator tube, which keeps its voltage nearly constant regardless of generator speed.

A second safety feature is provided by the delay device indicated in figure 12B2, part A. A spring-loaded contact grounds the generator output through the delay wheel. As the torpedo moves through the water, the delay wheel is turned by a worm on the vertical shaft (at the left in figure 12B2). After a short time, a hole in the delay wheel reaches the spring-loaded contact. The contact falls into the hole, and the generator output is no longer grounded. At the same time, a blank sector on the wheel reaches the

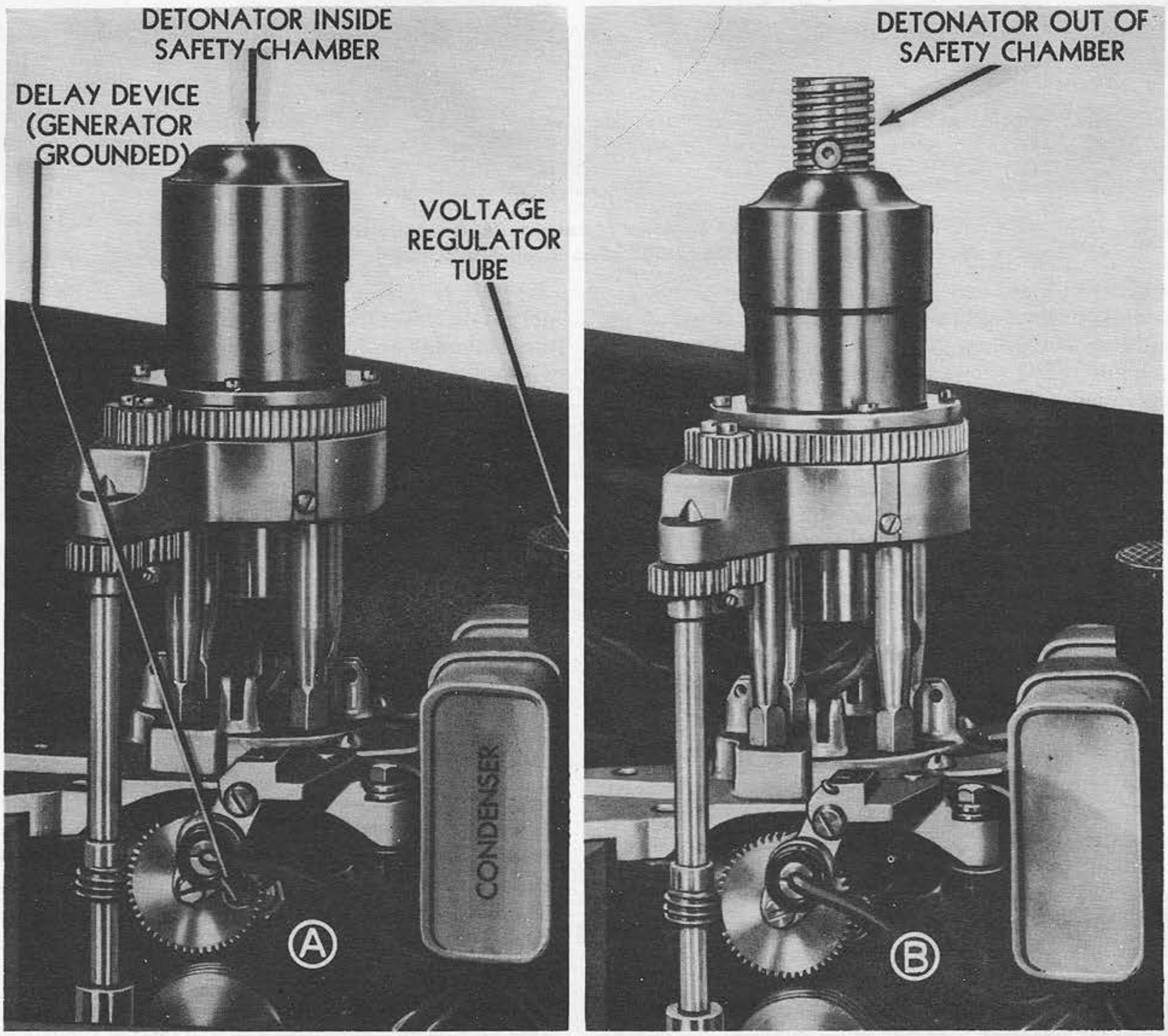

FIGURE 12B2.—A: Exploder Mechanism Mark 6, unarmed.
B: Exploder Mechanism Mark 6, armed.

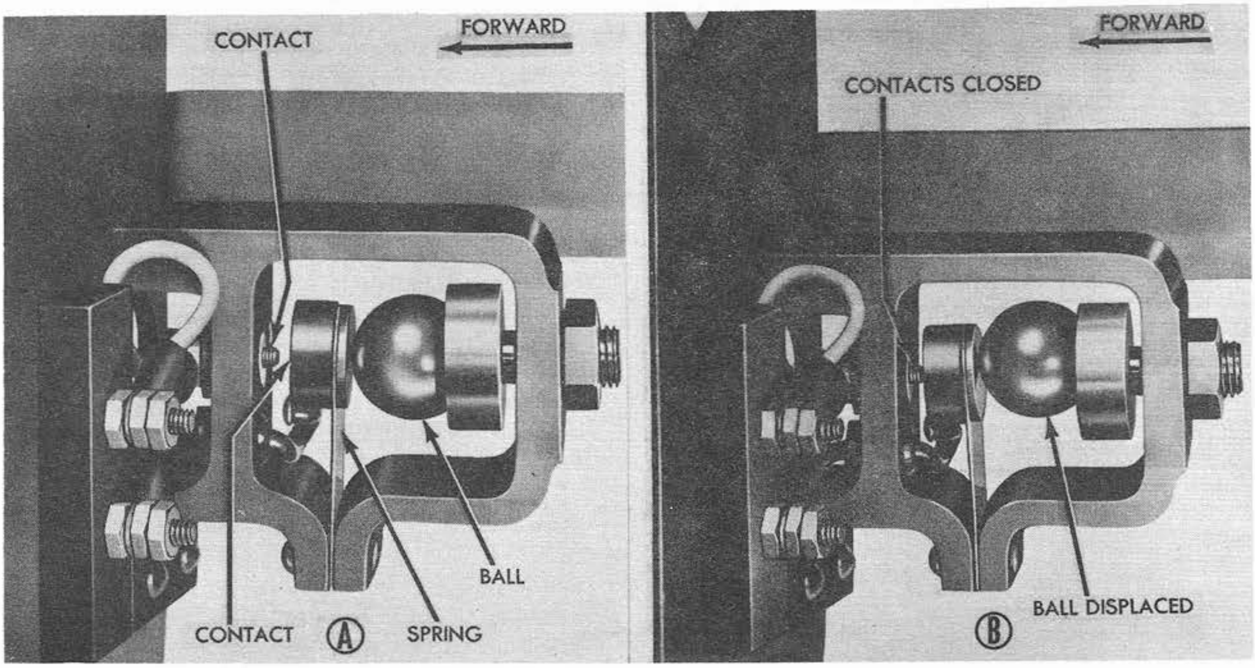

FIGURE 12B3.—A: Exploder Mechanism Mark 6 ball switch, open.
B: Exploder Mechanism Mark 6 ball switch, closed (fired).

worm on the vertical shaft, and the wheel stops turning.

Figure 12B3 shows the ball switch through which the detonator is fired on impact. Note that the left side of the pictures is forward; when the torpedo is under way the switch, as shown here, is moving from right to left. The ball is held in a cup-like depression by the force of the spring on the movable contact. When the torpedo strikes its target, the inertia of the ball carries it forward (to the left), overcoming the resistance of the spring and closing the contacts. The ball switch will operate even when the torpedo strikes the target a glancing blow. A sideways force on the ball will cause it to climb out of the cup, thus forcing the movable contact forward.

12B5. Exploder operation

At the instant of firing, the exploder is in its unarmed condition. The detonator is completely housed within the safety chamber. The generator output is short-circuited to ground through the delay wheel. The inertia switch is open.

As the torpedo moves through the water, the impeller wheel turns. The impeller shaft, through the gear train shown in figure 12B2, turns both the delay wheel and the safety chamber. The upper rim of the safety chamber is threaded on its inside, to match the threads of the detonator. The detonator is free to move up and down, but is so mounted that it can not rotate. Rotation of the safety chamber thus lifts the detonator up into the booster cavity. The delay wheel, meanwhile, unshorts the generator. The generator, through the voltage regulator tube, charges the condenser. The exploder mechanism is then completely armed, both electrically and mechanically.

On impact with the target, the inertia ball closes the switch contacts. The condenser discharges through the switch, and through the electric detonator. The detonator fires, exploding the booster. The booster detonates the main charge of high explosive.

12B6. Exercise head construction

At the present time, Exercise Head Mark 31 is used with Mark 15 torpedoes. Figure 12B4 shows a sectional view of this exercise head.

The exercise head has the same shape and size as the war head. And, like the war head, it is closed at its after end by a concave bulkhead. The exercise head, however, is made of steel rather than phosphor bronze. The war head is strengthened by the high-explosive charge, which completely fills it. Since the exercise head contains no explosive, it is reinforced by a series of nine strengthening rings.

In the bottom of the exercise head shell, near the after end, is the discharge valve. This is a one-way valve, which keeps sea water from entering the head but permits the liquid ballast to be blown out at the

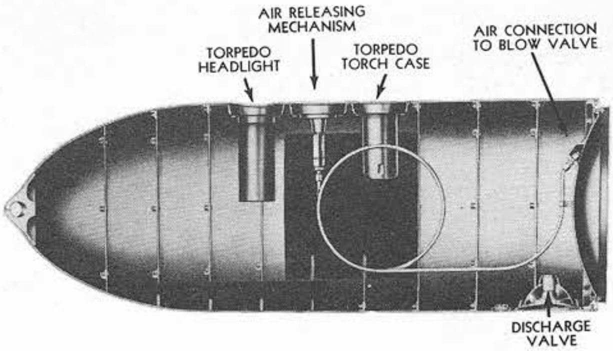

FIGURE 12B4.—Exercise Head Mark 31.

end of the run. The air-releasing mechanism is mounted on a flange at the top of the exercise head shell, and connected by a length of pipe to a fitting in the bulkhead. The pipe is always provided with one or more loops, to prevent any danger of breakage due to fatigue. Two additional flanges, on which various accessories may be mounted, are provided at the top of the head.

12B7. Exercise head accessories

One or more accessories are mounted on the flanges in the top of the exercise head, according to the conditions under which the exercise torpedo is fired.

The *headlight* helps the recovery crew to locate a torpedo that has been fired at night. It contains a bulb and a set of flashlight batteries. An inertia switch in the headlight case turns the light on when the torpedo is fired.

A *torch pot* helps in locating an exercise torpedo in the daytime. The torch pot contains a chemical that gives off smoke when it gets wet. A metal seal on the torch pot case is removed shortly before firing. When the torpedo is fired, water seeps into the case, and the torch pot begins to smoke.

The *depth and roll recorder* is a mechanical device that helps in the evaluation of the torpedo's performance during an exercise run. Throughout the run, it makes a continuous graphic record of the torpedo's running depth and angle of roll.

A *pinger* is a sound-making device. It is sometimes used when an exercise torpedo is fired in relatively shallow water. If the head fails to blow and the torpedo sinks, the noise of the pinger makes the torpedo easier to find.

12B8. Exercise head operation

When an exercise torpedo is fired, the exercise head is filled with liquid ballast. The air-releasing mechanism is connected to the air flask through the fitting in the exercise head bulkhead, and through the blow valve on the flask. The blow valve is opened when the torpedo is prepared for firing. This allows compressed air, at full flask pressure, to reach the air releasing mechanism. Air pressure overcomes the pressure of a spring inside the mechanism, and closes its valve so that no air can enter the head section.

During the torpedo run, the torpedo constantly uses air from its air flask, and the flask pressure slowly falls. When it reaches a certain predetermined level, it can no longer overcome the spring pressure in the air-releasing mechanism. The valve opens, and releases compressed air into the exercise head. Air pressure then forces the liquid ballast out through the discharge valve.

12B9. Exercise firing and recovery

Every torpedo is given at least one proof run before it is issued to the Fleet. In the Fleet, it will make one or more practice runs before it is returned to a tender for overhaul.

An exercise torpedo is recovered from a boat that approaches from the lee side, to prevent any danger of drifting down on the torpedo. The torpedo is nearly vertical in the water, because of its empty head section. A noose is passed over the torpedo's nose, and a line secured to the nose ring. The torpedo is towed slowly until it is nearly level in the water. The noose can then be worked aft and secured around the tail section. As a safety precaution, to keep the torpedo engine from starting up again, the stop valve is closed and a lock installed on the propellers as soon as these parts are accessible. The torpedo is then towed back to the firing ship.

After hoisting an exercise torpedo aboard, the torpedo crew will perform a prescribed lubrication and maintenance routine to prevent corrosion and deterioration because of salt water.

C. Air System of a Mark 15 Torpedo

12C1. General

The inside volume of the Mark 15 air flask is 23 cubic feet, and the flask is charged to a pressure of 2,800 psi. Obviously, a great deal of energy is stored in the air flask. Compressed air alone could be used to spin the turbines, and to drive the torpedo for a considerable distance. But both the speed and range of the torpedo are increased by passing the compressed

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air through a *superheater* before it reaches the turbines. The superheater increases both the volume and the speed of the gas that strikes the turbine blades.

The main part of the superheater is a closed chamber—the *combustion flask*. A mixture of compressed air and alcohol is forced into the combustion flask, where it burns. The products of burning alcohol—carbon dioxide and steam—add to the volume of the exhaust gases. Because of the extreme heat generated in the combustion flash, water is sprayed in with the air and fuel to prevent damage to the superheater and turbines. In cooling the flask, the water is turned to steam and adds to the volume of gases that spin the turbines.

Because compressed air and alcohol are the only sources of energy in the Mark 15 torpedo, compressed air is used for several things. Besides spinning the turbines, it also does the following:

1. At the end of an exercise run, it blows the liquid ballast out of the exercise head.
2. It forces fuel and water into the combustion flask.
3. It operates the igniter that starts the air-fuel mixture burning.
4. It operates the starting valve, which puts all the propelling and control mechanisms of the torpedo into operation.
5. It operates the gyro-spinning mechanism, which gives the gyro its initial spin and brings it up to full speed.
6. It keeps the gyro spinning during the whole torpedo run.
7. It supplies energy for the depth and steering engines, which operate the depth and steering rudders.

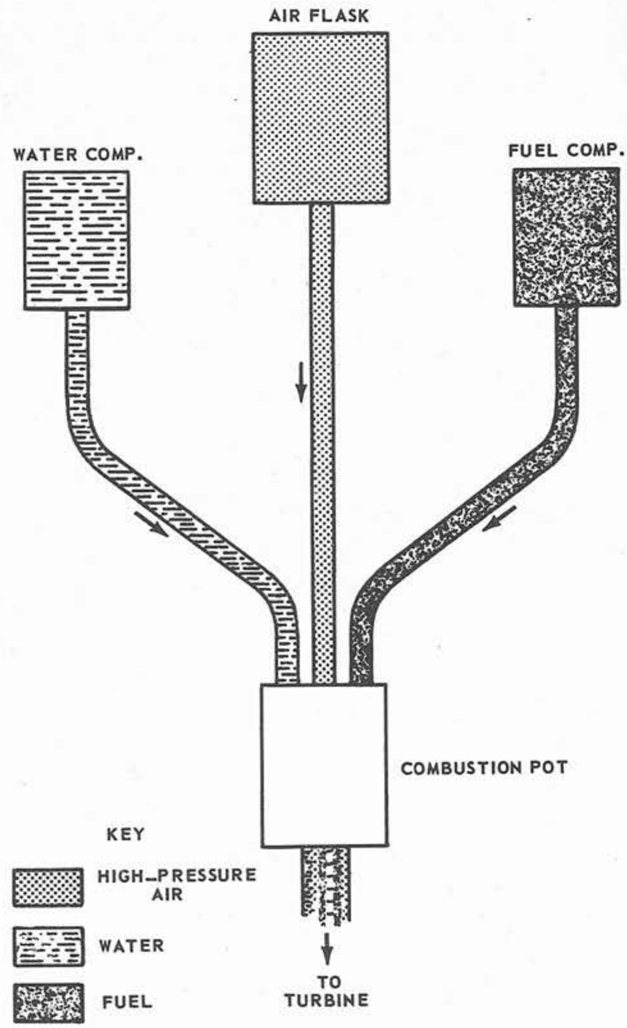

FIGURE 12C1.—First diagram of the air system.

12C2. Functional description

The air system of the Mark 15 torpedo is complex. It can best be explained by developing a diagram of it gradually, adding a few features at a time. Figure 12C1 shows the simplest possible type of air system. The supplies of air, fuel, and water must be kept in separate compartments. A pipe from each of these compartments goes to the combustion flask. The exhaust gases leave the flask and go to the turbines.

The air system shown in figure 12C1 has several obvious defects. First, there is nothing to keep the air flask from exhausting into the combustion flask before the torpedo is fired. A *starting valve* must therefore be placed in the air pipe. This valve will open when the torpedo is fired, and release air from the flask into the rest of the air system.

It is also desirable to have a *stop valve* in the main air line. This will make it possible to shut off the air flask from the rest of the torpedo during testing and repair. The stop valve is located between the air flask and the starting valve.

In figure 12C1, fuel and water can reach the combustion flask only by gravity. An efficient system requires that fuel and water be forced out of their compartments by compressed air. But this should take place only after the starting valve has opened. The air lines that go to the fuel and water compartments will therefore join the main air pipe between the starting valve and the combustion flask. The air system has now been developed to the point shown in figure 12C2.

But the system shown in figure 12C2 can easily be improved. First, a means for recharging the air flask is necessary. This calls for a *charging valve*, located

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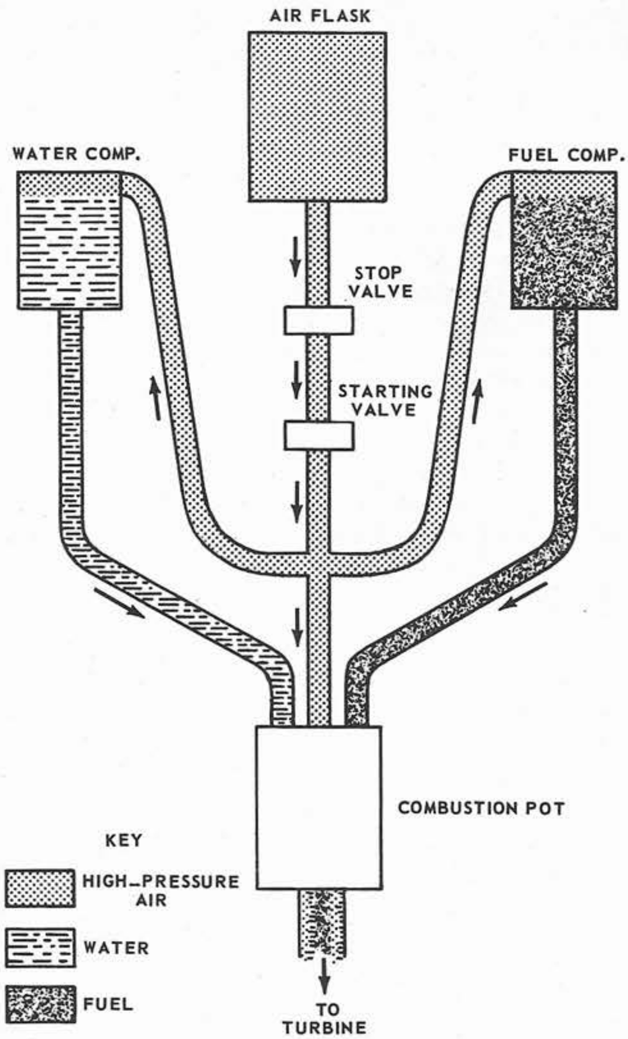

FIGURE 12C2.—Second diagram of the air system.

between the stop valve and the starting valve. The air flask may now be recharged, as follows:

1. Close the stop valve (if it is open).
2. Connect the charging line to the charging valve. (Figure 12C3.)
3. Open the stop valve.
4. Open the valve in the charging line, and charge the flask to full pressure. (The starting valve is closed, and keeps air out of the rest of the system.)
5. Close the stop valve.
6. Close the valve in the charging line, and disconnect the line.

The pressure in the air flask—2,800 psi—is much too high for most of the torpedo mechanisms. A *reducing valve* is therefore added, between the starting valve and the lines that go to the fuel and water compartments. The *starting gear* is connected to the

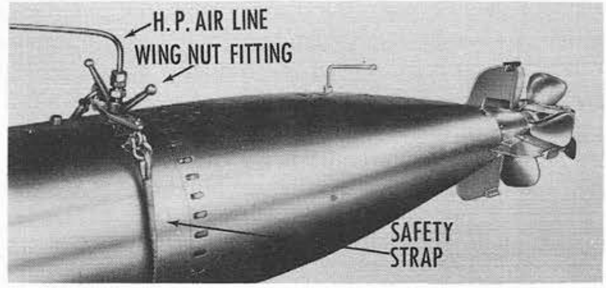

FIGURE 12C3.—Charging the air flask.

starting valve by an air pipe. It allows the starting valve to open by venting the pressure in this pipe. When these features have been added, the air system has reached the stage shown in figure 12C4.

A number of desirable features can still be added. For example, the starting gear begins to vent air from the starting valve as soon as the torpedo is fired. To prevent waste, this air should be carried back into the air system. Because there is a drop in pressure as

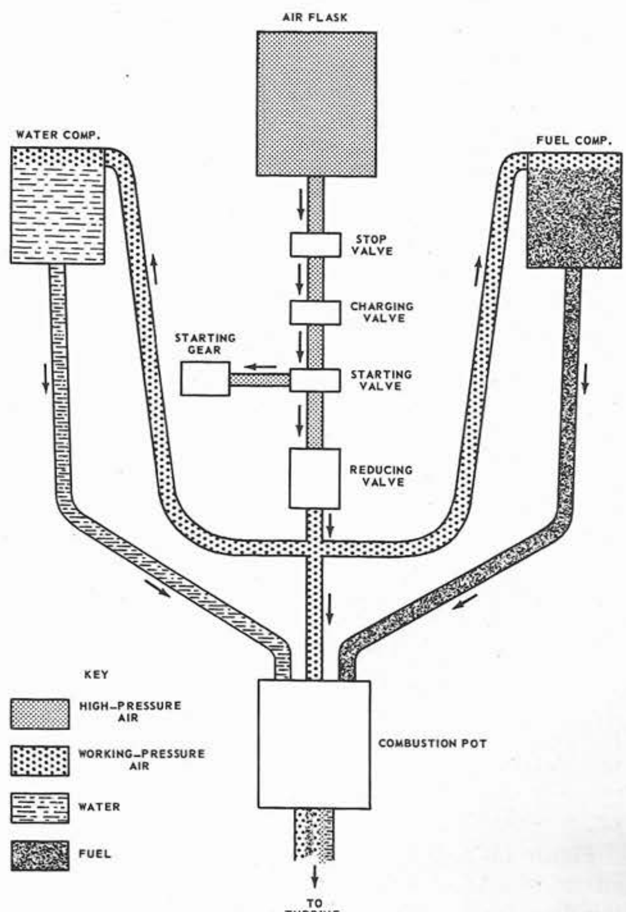

FIGURE 12C4.—Third diagram of the air system.

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the air passes through the starting gear, the pipe that returns the air from the starting gear will be connected to the low-pressure side of the reducing valve.

Flask-pressure air is used to blow the exercise head at the end of an exercise run. We therefore need a pipe extending from the flask, which can be connected to the fitting in the exercise head bulkhead. A *blow valve* must be added in the pipe, so that it can be closed off at all times except when an exercise head is in place.

In the system shown in figure 12C4, there is nothing to keep fuel and water from trickling and sloshing into the air system and combustion pot before the torpedo is fired. This can be prevented by putting check valves in both air lines, and in the fuel and water delivery pipes. The check valves are closed by low-pressure springs. As soon as the torpedo is fired, working-pressure air overcomes the spring pressure, and forces the check valves open.

The air system has now been developed to the stage shown in figure 12C5. It is nearly complete. Only a few refinements are needed.

As the air expands in the reducing valve, its temperature drops. But the reducing valve works more efficiently when it is warm than when it is cold. This difficulty can be overcome by preheating the air before it reaches the reducing valve. The *preheater* consists simply of one or more loops in the main air pipe, located between the charging valve and the starting valve. The preheater is mounted in the afterbody, where the hot exhaust gases from the turbine can flow over it.

High-pressure air is used to bring the gyro up to speed. The *gyro-spinning mechanism* is therefore connected to the main air pipe at a point between the starting valve and the reducing valve. The *igniter,* mounted in the combustion flask, is connected to the air system on the working-pressure side of the reducing valve. As soon as the torpedo is fired, working-pressure air will operate the igniter.

Working-pressure air is also used to operate the control mechanisms. Because of the close tolerances in these mechanisms, the air is first passed through an *air strainer body.* From there, it goes to both the *steering engine* and the *depth engine.* Air from the strainer body is also used to sustain the speed of the gyro, after it has been brought up to speed by the gyro-spinning mechanism. But because the full working pressure is too high for this purpose, the air first passes through a *gyro reducer,* which decreases its pressure to about 125 psi.

Figure 12C6 shows the diagram of the completed air system of a Mark 15-type torpedo. (Remember that this diagram is not intended to show the relative size or location of the parts. It merely shows how they are connected together.) Figure 12C7 is a schematic diagram that shows the actual appearance of the parts.

The operation of the air system can be reviewed by showing what happens during a war shot. At the instant before firing, with torpedo loaded in the tube, the following conditions exist. The stop valve is open. The charging valve will let air flow to the starting gear; but its charging fitting is closed so that no air can leak outboard at that point. Because this is a war shot, the blow valve is closed. There is flask-pressure air in the preheater. There is flask pressure on the flask side of the starting valve and in the line from the starting valve to the starting gear. But the air is blocked off at the starting valve and starting gear, and there is no pressure in the system beyond those points.

When the torpedo is fired the following things happen. (The operations are listed here in numbered steps. But remember that as soon as the starting valve opens, all the rest of the operations happen almost simultaneously.)

1. As the torpedo begins to move forward in the tube, the tripping latch in the tube strikes the torpedo's starting lever, and throws it aft.
2. The starting gear vents the line from the starting valve, and the pressure in this line drops.
3. The starting valve opens.
4. Flask-pressure air goes to the gyro-spinning mechanism, which spins the gyro and quickly brings it up to full speed. The mechanism then shuts itself off, and uses no more air.
5. Flask-pressure air passes through the reducing valve, which drops it to working pressure—about 500 psi.
6. Air from the starting gear passes back into the system on the low-pressure side of the reducing valve.
7. Working-pressure air flows into the combustion flask through a restriction valve and an air whirl.
8. Working-pressure air opens the air check valve in the line to the fuel compartment. The pressure in the fuel compartment opens the fuel check valve, and fuel flows into the combustion flask through a restriction valve and a fuel spray.
9. Working-pressure air flows to the igniter, and starts it burning. The igniter ignites the fuel-air mixture.
10. Working-pressure air opens the air check valve in the line to the water compartment. The pressure in the water compartment opens the water check valve, and water flows into the combustion flask through a restriction valve and a water spray.
11. A mixture of hot compressed air, combustion gases, and steam strikes the turbine blades, and spins the turbine. The turbine, through the gears and shafts of the main engine, spins the propellers.

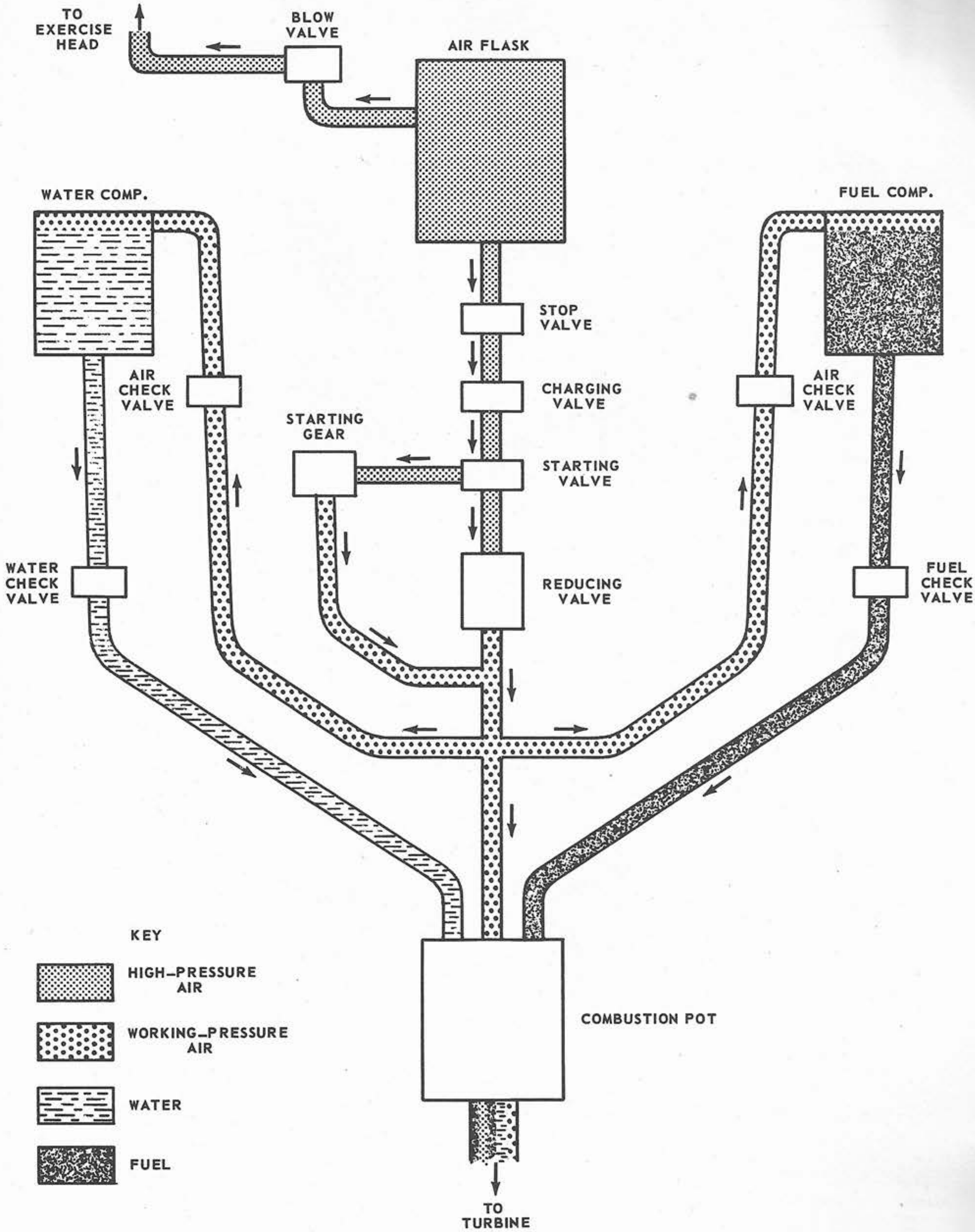

FIGURE 12C5.—Fourth diagram of the air system.

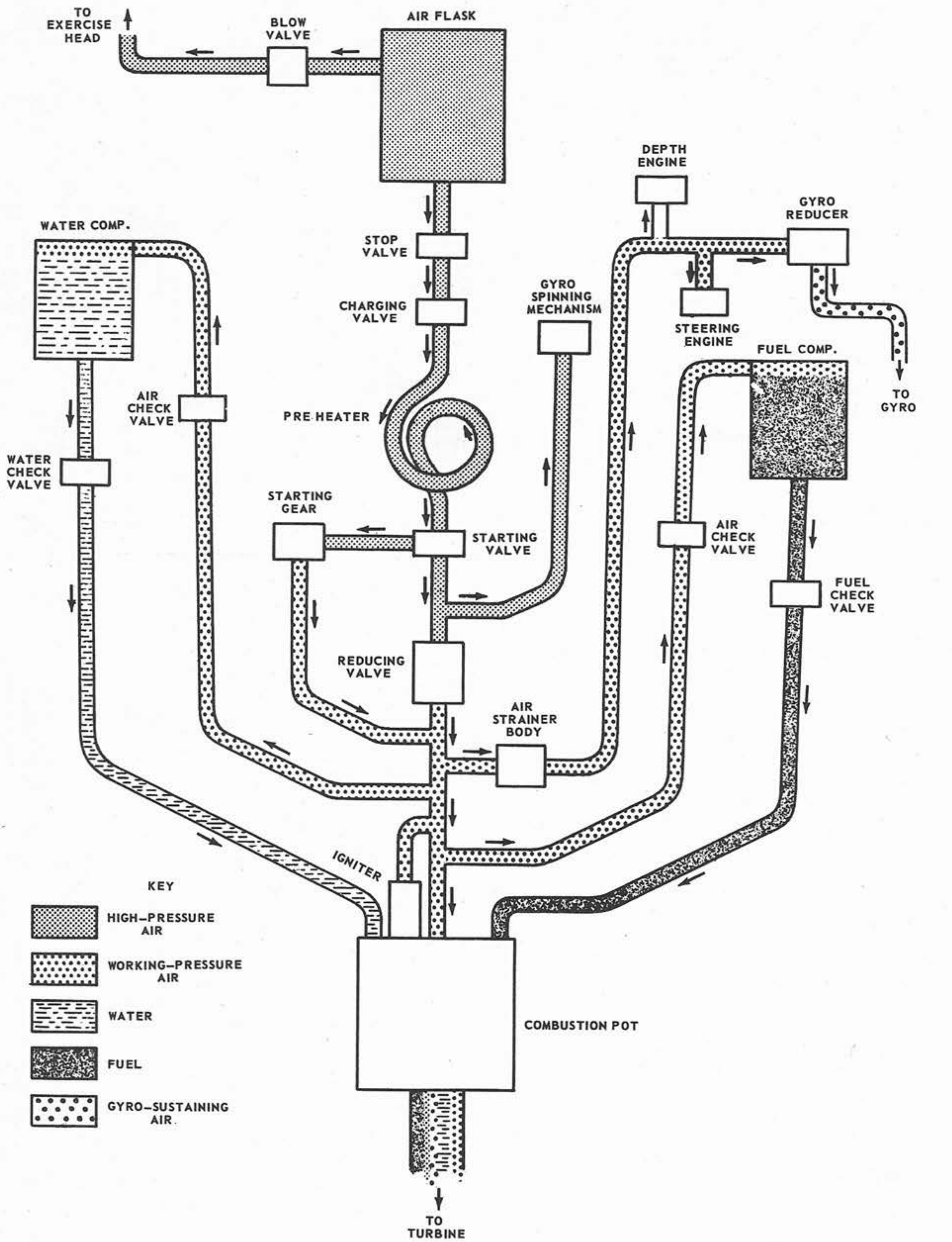

FIGURE 12C6.—Final diagram of the air system.

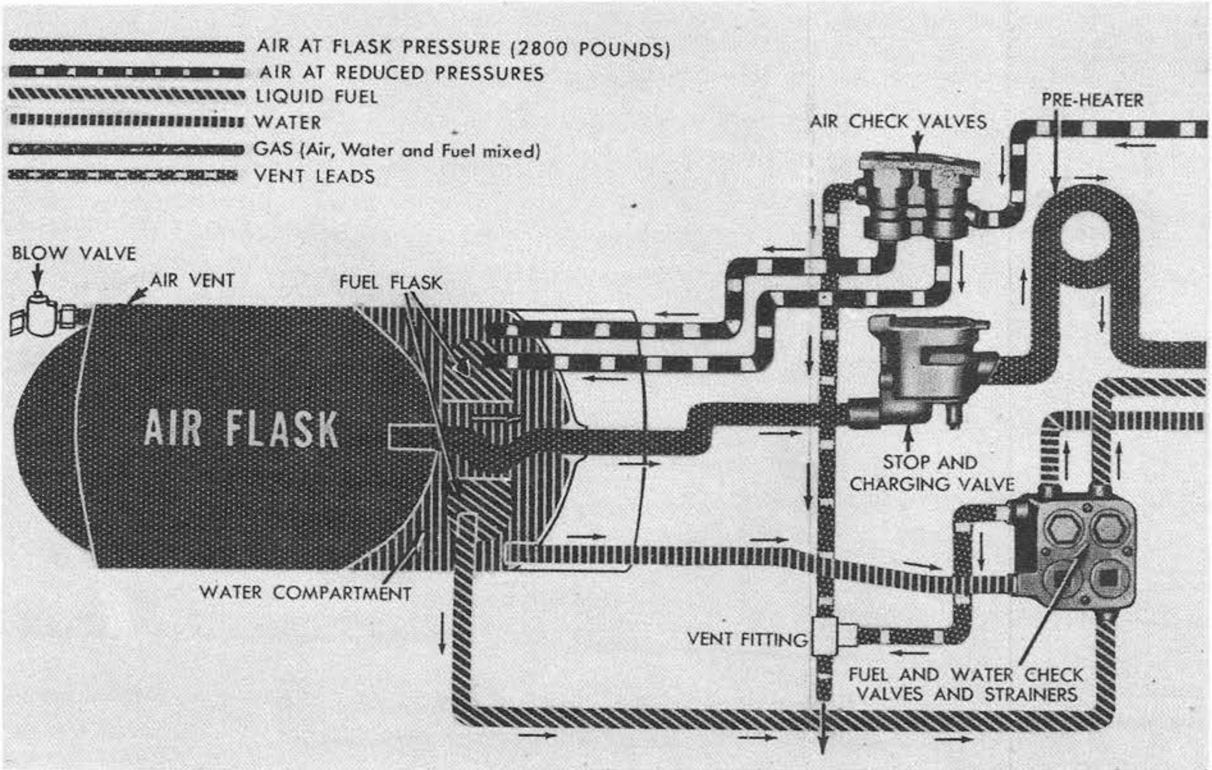

FIGURE 12C7.—Torpedo Mark 15 type, schematic diagram of the air system.

12. Working-pressure air passes through the air strainer to the depth engine. The depth engine will then operate the depth rudders as soon as it gets an order from the depth mechanism.

13. Air from the air strainer body goes to the steering engine. The steering engine will then throw the steering rudders as soon as it gets an order from the steering mechanism.

14. Air from the air strainer body goes through the gyro reducer, which drops its pressure to 125 psi. This low-pressure air keeps the gyro spinning.

12C3. Air-flask section

The air-flask section includes the air flask and the fuel and water compartments; the midship section is permanently attached to its after end. The air-flask section is by far the longest section of an air-steam torpedo; in the Mark 15 type, it makes up more than half the total length. Figure 12C8 shows a sectional view of the air-flask section; the left-hand end of the picture is forward. Note that part of the flask has been cut out; it is relatively longer than it appears in the illustration.

The air flask is made up of several forgings welded into a unit. It is closed at both ends by dome-shaped bulkheads, permanently welded in place. In the center of the forward bulkhead is a small, removable bulkhead, which gives access to the inside of the flask. A clamp and lock nut hold the small bulkhead in place, and the pressure inside the flask forces it firmly against its seat.

A short length of pipe connects the removable bulkhead to the blow valve. As previously explained, the blow valve is opened for an exercise shot, and closed for a war shot.

A nut and nipple connect the *main air pipe* to the after bulkhead of the air flask. The pigtail shape of this pipe allows the air flask bulkhead and the water compartment bulkhead to expand and contract when the temperature changes, without putting any strain on the nipples. The *dry pipe* goes straight into the flask from the main air pipe. At the end of an exercise run the torpedo floats almost vertically, with its tail down. The dry pipe keeps any water that may be in the flask from running down through the main air connection.

The *water compartment* is enclosed by the outer

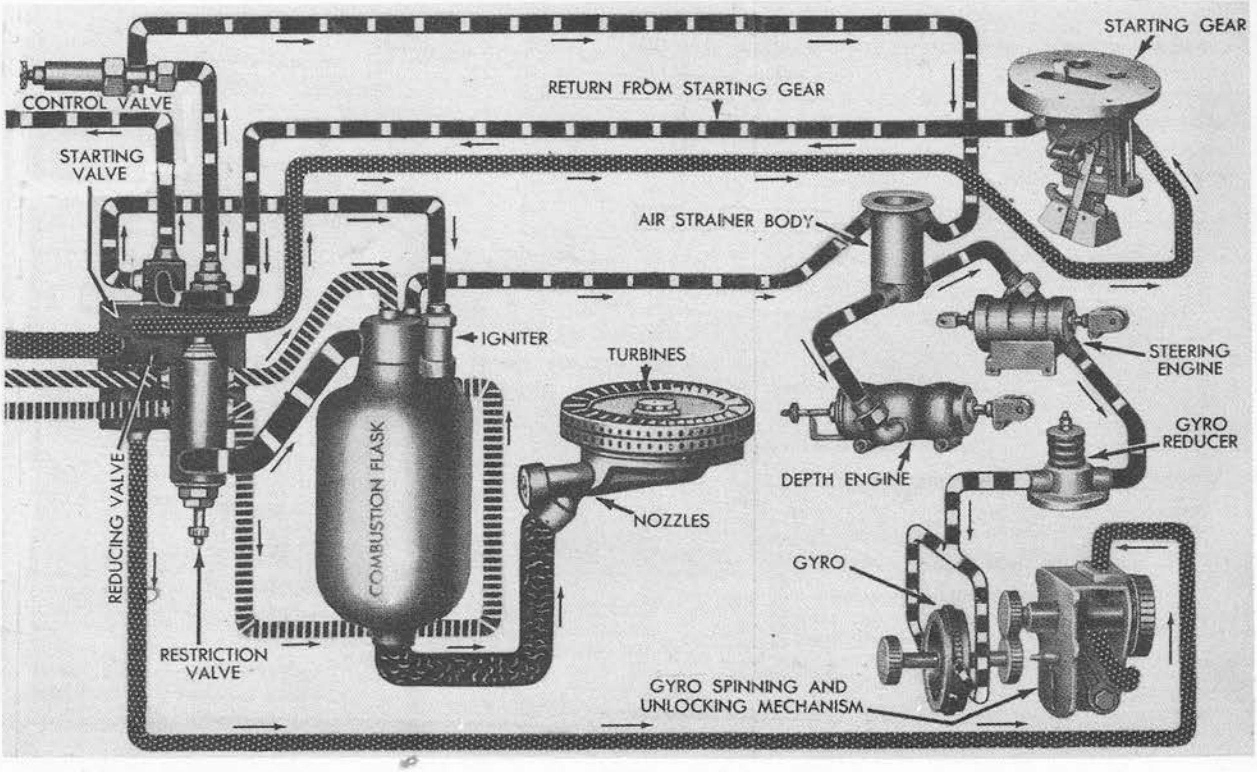

FIGURE 12C7.—Torpedo Mark 15 type, schematic diagram of the air system—Continued.

shell of the torpedo. It is closed at its forward end by the after bulkhead of the air flask, and at its after end by the water compartment bulkhead. This bulkhead fits against a ground seat, and is held in place by screws.

On its forward face, the water compartment bulkhead supports the doughnut-shaped *fuel flask* on four brackets. In the top of the fuel flask is a filling plug. When the torpedo is assembled, this plug lies directly under a second plug in the outer shell of the torpedo. This makes it possible to fill both the water compartment and the fuel flask through a single opening in the torpedo shell.

In the rim of the water compartment bulkhead are four clamping nipples. To these are connected the two pipes that pressurize the fuel and water compartments, and the fuel and water delivery pipes. A safety feature—the *blowout plug*—is also mounted in the water compartment bulkhead. If, through mechanical failure, flask-pressure air should enter the water compartment, a copper disc in the blowout plug would give way. The high pressure would then be vented through the plug and into the midship section, without serious damage to the water compartment or fuel flask.

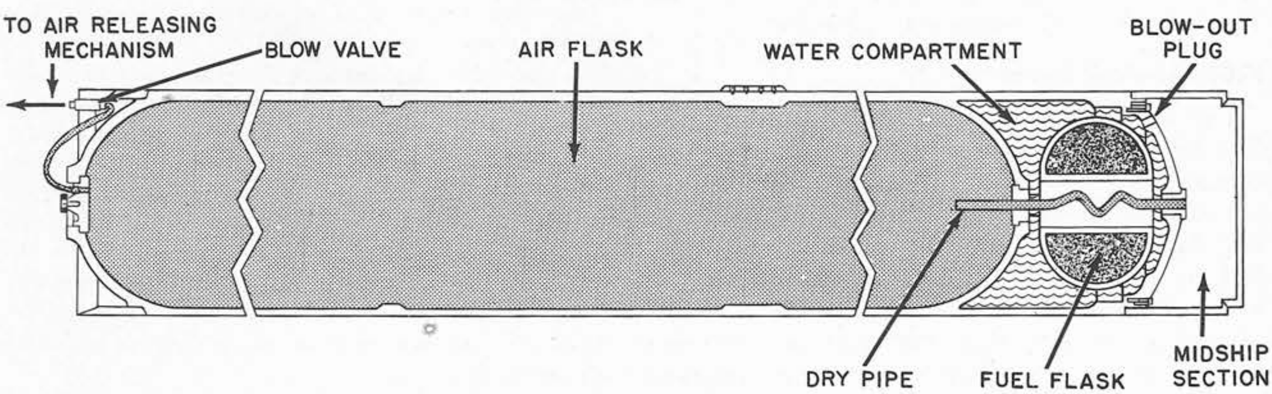

FIGURE 12C8.—Air-flask section.

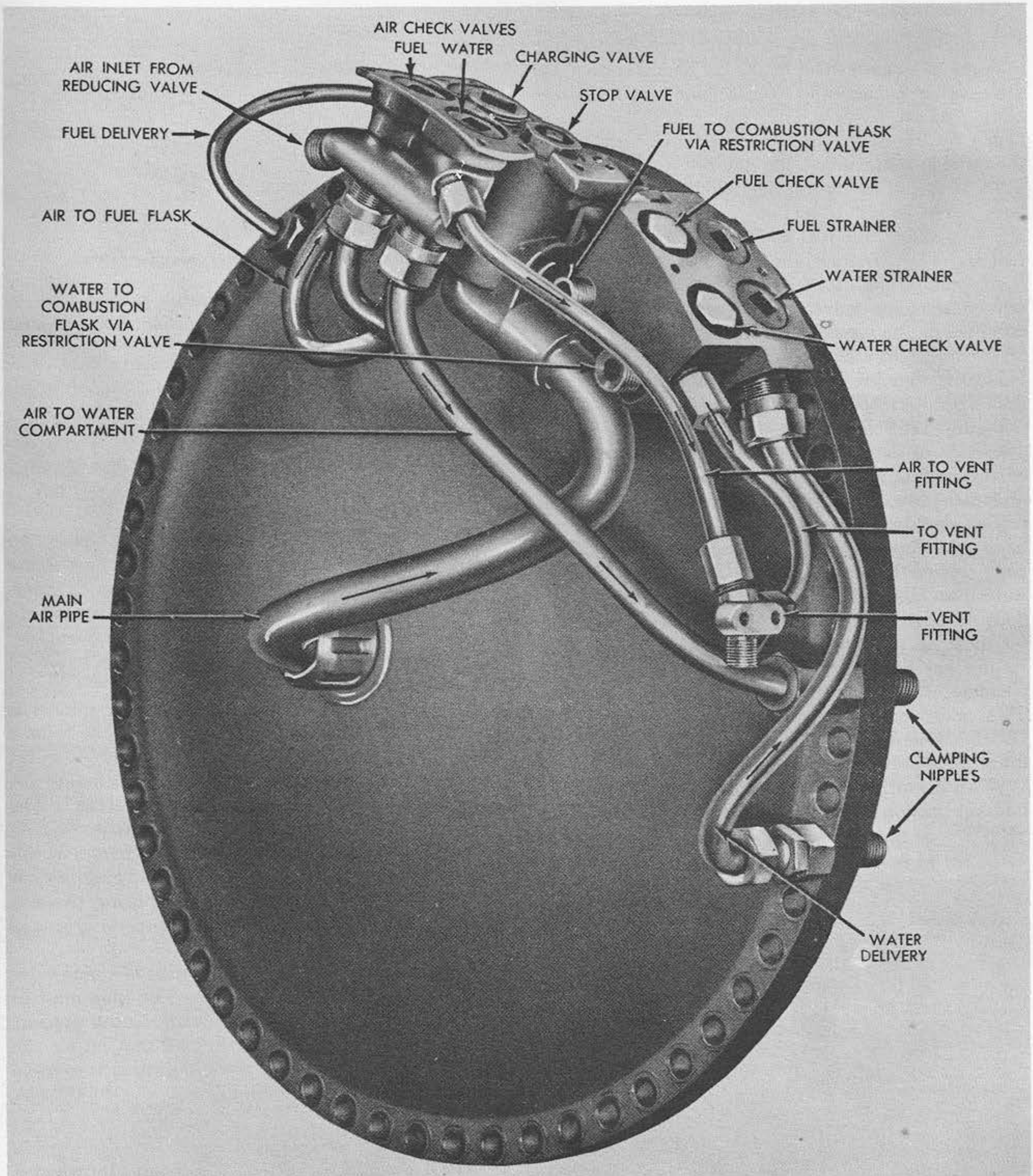

FIGURE 12C9.—Valves and fittings on the water compartment bulkhead.

12C4. Fittings of the midship section

The midship section is a short steel ring, riveted and soldered to the after end of the air flask section. Its after end is machined to form a joint with the afterbody. At its forward end, the midship section is closed by the water compartment bulkhead. When the torpedo is assembled, the midship section is closed at its after end by the turbine bulkhead of the afterbody. The midship section carries the stop and charging valves, the fuel and water check valves, the fuel and water strainers, the two air check valves, and the speed-setting socket. The combustion flask, igniter, reducing valve, and several other parts are mounted on the forward face of the turbine bulkhead, and are therefore considered parts of the afterbody. However, they are enclosed by the midship section shell when the torpedo is assembled.

Figure 12C9 shows the fittings attached to the after side of the water compartment bulkhead. All of these parts are enclosed by the midship section, and the valve housings are secured to the midship section shell by screws. Figure 12C10 shows the top of the midship section of an assembled Mark 15 torpedo. Note the openings in the shell. Fuel, air, and water pass between the air-flask section and the afterbody through five separate lines. The connections for these lines can be secured only after the air-flask section has been assembled to the afterbody. The openings in the midship section make this possible. Two additional openings are not shown in figure 12C10. One of these provides access to a vent fitting, the other to the igniter.

When the torpedo is under way, sea water floods the midship section through the openings in its shell.

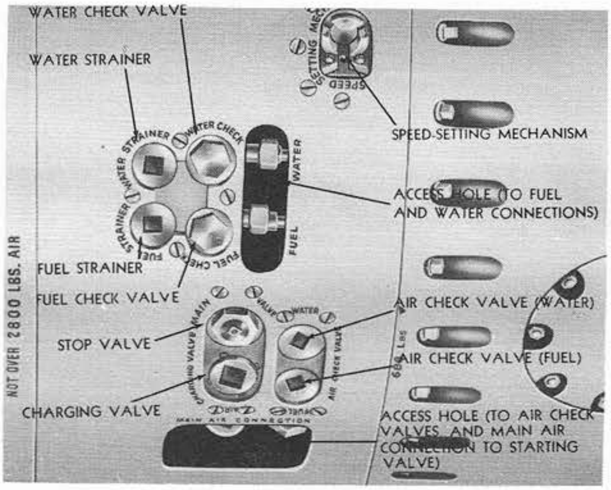

FIGURE 12C10.—Midship section of a Mark 15 torpedo; top view.

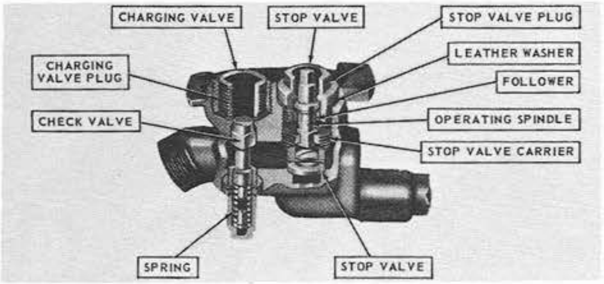

FIGURE 12C11.—Stop and charging valves.

Some of the fittings in the midship section have to carry hot gases. The sea water that flows around them keeps them from overheating.

12C5. Stop and charging valves

The stop and charging valves are contained in a single housing, as shown in figure 12C11. The opening at the right is connected to the air flask through the main air pipe; from the opening at the left, a pipe takes air to the starting valve.

The stop valve plug makes an airtight connection against a washer on its seat. Inside the plug is the operating spindle. The small threaded follower screws into the inside of the plug. The shoulder on the operating spindle makes an airtight seal between the plug and the follower, so that no air can leak outboard through the stop valve.

To open the stop valve, the operating spindle is turned manually with a socket wrench. The spindle can not rise, because its shoulder is bearing against the plug. But the square shank at the bottom of the spindle turns the threaded stop valve carrier. The carrier rises, and lifts the stop valve off its seat.

The stop valve must be opened to charge the air flask. It is closed again as soon as charging is completed. During final preparations for firing, the stop valve is opened shortly before the torpedo is loaded into the tube.

The charging valve assembly consists of a plug valve and a spring-loaded check valve. The plug must be removed before charging the flask. Spring pressure on the check valve holds it shut, so that no air can leak outboard. When the charging fitting is screwed in, its tip unseats the check valve.

12C6. Check valves

The 2 air check valves—1 for fuel and 1 for water—are identical, and are housed in a single casting. Figure 12C12 shows the air check valve housing, with the fuel air check valve partially cut away.

Before the torpedo is fired, spring pressure holds both of the air check valves on their seats. The valves thus serve to isolate the fuel and water compartments

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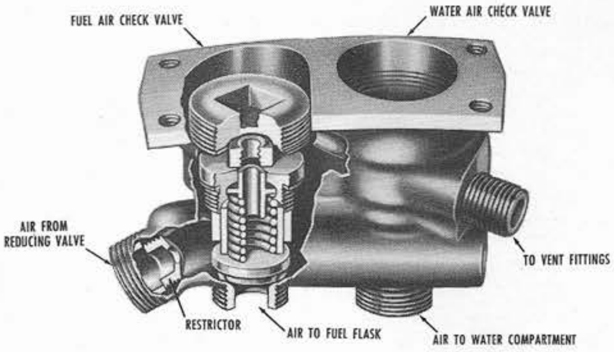

FIGURE 12C12.—The air check valves.

from each other, and to keep fuel and water out of the air pipes. When the torpedo is fired, air from the reducing valve enters the housing through the nipple shown at the left in figure 12C12. It surrounds both valve stems, overcomes the spring pressure, opens the valves, and flows to the fuel and water compartments. The restrictor serves to smooth out any surges of pressure that might pressurize the fuel and water compartments unequally, with resulting damage to the fuel flask. The spaces above the valves are vented through a common opening. The venting feature prevents any air that may leak up past the valve stems from cushioning the action of the valves.

The water air check valve will also serve as a safety device in the event that air leaks from the main air pipe into the water compartments before firing. If the pressure exceeds 5 psi, it will unseat the valve and exhaust into the combustion flask.

The fuel and water check valves and strainers are mounted in a single housing, as shown in figure 12C13. The strainers remove any foreign matter that may be present in the fuel and water. The two check valves are similar in principle to the air check valves. Before

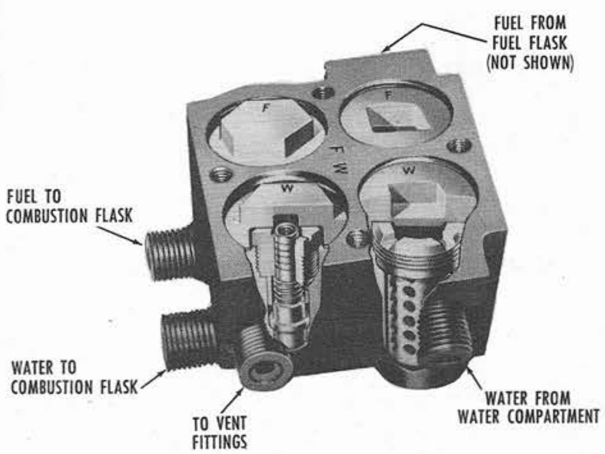

FIGURE 12C13.—Fuel and water strainers and check valves.

firing, spring pressure keeps the valves closed, and thus keeps fuel and water out of the combustion flask. On firing, pressure builds up in the fuel and water compartments, and unseats the valves. Fuel and water then flow through the strainers and check valves. The fuel and water check valves, like the air check valves, are vented through a common opening.

The location of the four check valves in the midship section may be seen in figure 12C9. This figure also shows the location of the vent fitting. When the torpedo is assembled, a pipe carries any air vented through this fitting into the afterbody.

12C7. Restriction valves

Before entering the combustion flask, both fuel and water flow through restriction valves, which control the speed of flow. Working-pressure air, before it enters the combustion flask, also flows through a restriction valve. The restriction causes a small decrease in air pressure; as a result, the pressure in the fuel and water compartments is higher than that in the combustion flask. It is this differential pressure—from 40 to 75 psi—that forces fuel and water into the flask.

12C8. Starting valve

The starting valve, reducing valve, and restriction valve are located in a single housing, as shown in figure 12C14.

When the stop valve is closed, there is no pressure on either side of the starting valve. Its spring holds it shut. When the stop valve is opened, flask-pressure air flows in through the passage marked "1" in the illustration, and surrounds the bottom part of the valve. A deep groove runs around the bottom of the valve. Flask-pressure air fills this groove, pushing up against the top of it and down against the bottom.

(NOTE: In this discussion, the terms "up" and "down" refer only to figure 12C14—not to the actual valve as assembled in the torpedo.)

Because the area of the top of the groove is larger than that of the bottom, the total pressure on the top of the groove is greater, thus tending to overcome the spring pressure and open the valve. But, while the stop valve is being opened, air leaks up through a small passage in the starting valve and fills the space above it. This air goes through the connection at "2" (figure 12C14), to the starting piston of the starting gear. But, until the torpedo is fired, this passage is blocked off at the starting gear. By the time the stop valve is fully open, the space above the starting valve is filled with flask-pressure air. Since flask-pressure air

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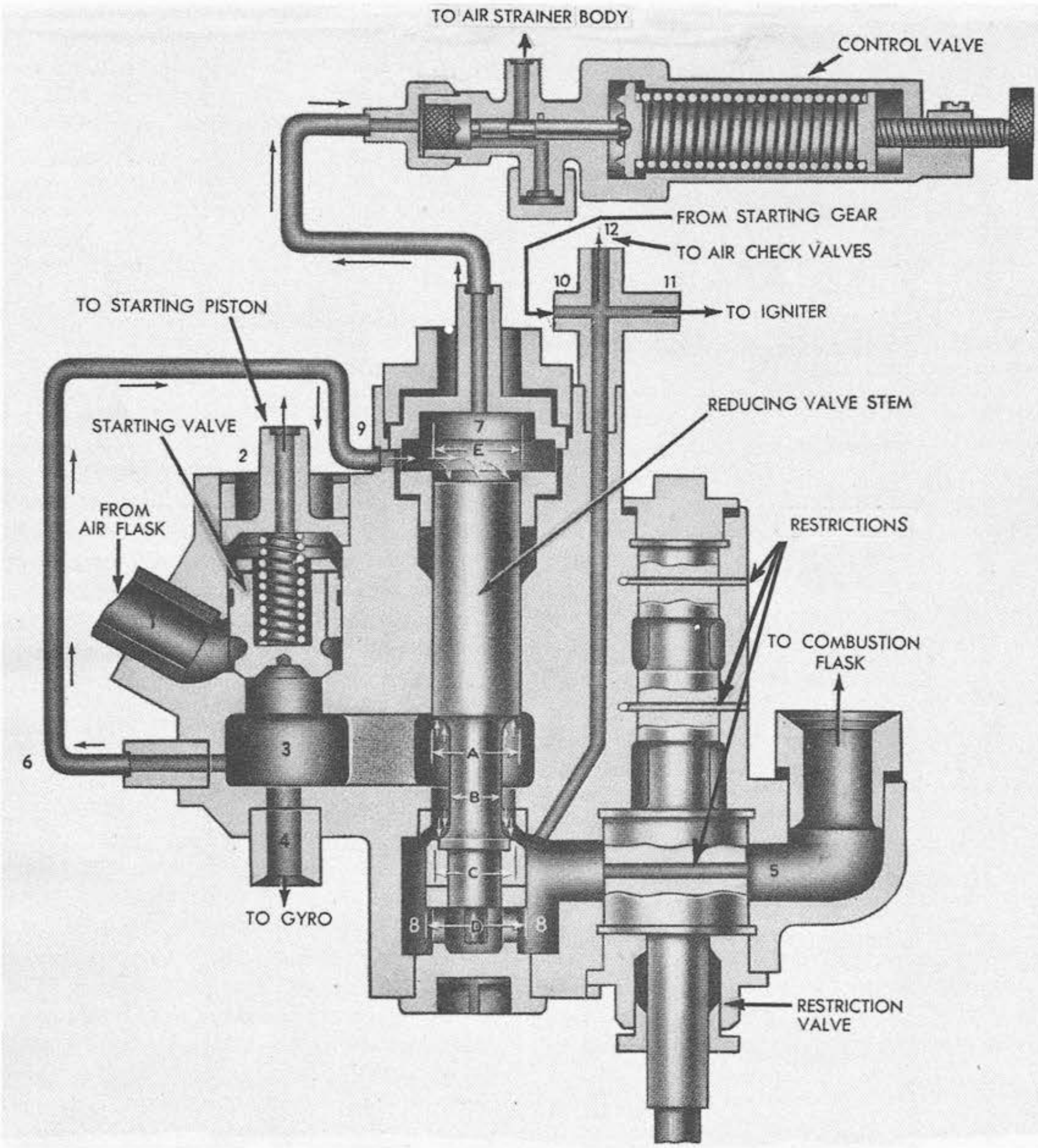

FIGURE 12C14.—Starting and reducing valve groups with control valve.

is now pushing down on a much larger area than it's pushing up on, air pressure helps the spring keep the starting valve closed.

When the torpedo is fired, the starting gear vents the air line and the pressure above the starting valve drops. The pressure at the bottom of the valve forces it open, and flask-pressure air flows into chamber "3". From there it goes to three places. It goes to the right, and flows around the bottom end of the reducing valve stem. It goes through the control pipe (6), through a small restriction at "9", and into the control chamber (7). And it goes through outlet "4" to the gyro-spinning mechanism.

12C9. Reducing and control valves

In figure 12C14, note the letters A, B, C, and D on the lower part of the reducing valve stem. These letters refer to the different cross-sectional areas that the air pressure acts on. In the picture, the valve is partly open. Imagine the valve stem in a higher position, with the valve completely closed. Flask-pressure

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air will then be pushing upward on the area A minus B, and downward on the area C minus B. Since A minus B is bigger than C minus B, the net force is upward, and the valve stays closed.

But air is also going through the control pipe (6) and the restriction (9), into the control chamber (7). There it pushes down on area E, and forces the valve open. As soon as the valve is open, air flows into the reduced-pressure chamber (8). And there it pushes up against area D, and tends to close the valve again. So the valve stem moves up and down until it finds a point at which the upward forces exactly balance the downward forces.

The control valve (figure 12C14) is a spring-regulated leak-off for the control chamber. As air pressure builds up in the control chamber, it moves the control valve against the pressure of its spring. Because the restriction at "9" is small, pressure builds up rather slowly in the control chamber. When it reaches a certain preset valve, the piston of the control valve uncovers a groove in the control valve housing, and some of the air leaks out. The control valve serves to keep the pressure in the control chamber constant. The actual pressure on the working-pressure side of the reducing valve depends on the pressure in the control chamber. Thus the working pressure can be adjusted, to some extent, by adjusting the pressure on the control valve spring.

As the torpedo uses up the air in the air flask, the flask pressure gradually drops. But the working pressure remains constant. If the pressure in chamber "8" should start to drop, the upward pressure on area D would also drop. The valve would open wider; letting more air into "8". If the pressure in "8" should get too high, it would tend to close the valve and bring the working pressure back to normal.

From the reduced-pressure chamber (8), the working-pressure air goes to three places. It goes through passage "11" to the igniter. It goes through "12" to the two air check valves. And it goes through the restriction in the restriction valve, into chamber "5", and from there to the combustion flask.

The two upper passages in the restriction valve stem (figure 12C14) are for fuel and water. The three passages through the restriction valve stem control the rate at which fuel, air, and water enter the combustion flask. Thus the delivery rate, and therefore the running speed of the torpedo, can be changed by turning the restriction valve stem on its axis. Turning the valve stem will bring other passages, of different diameter, into position.

12C10. Starting gear

When the torpedo is fired, the starting gear vents the pressure above the piston of the starting valve. The starting valve will then open, and release air to the reducing valve.

Figure 12C15 represents the starting gear of a Mark 15 torpedo. Note that the right-hand side of the illustration is forward. The upper half of the illustration shows the condition of the starting gear before the torpedo is fired. The starting gear valve and piston may be seen in the small diagram at the upper right. The valve is seated, and spring pressure holds it in place. High-pressure air enters the valve housing through the opening at the left, which is connected by a pipe to the space above the starting valve piston. This high-pressure air pushes downward on the valve, and aids the spring pressure in keeping it shut.

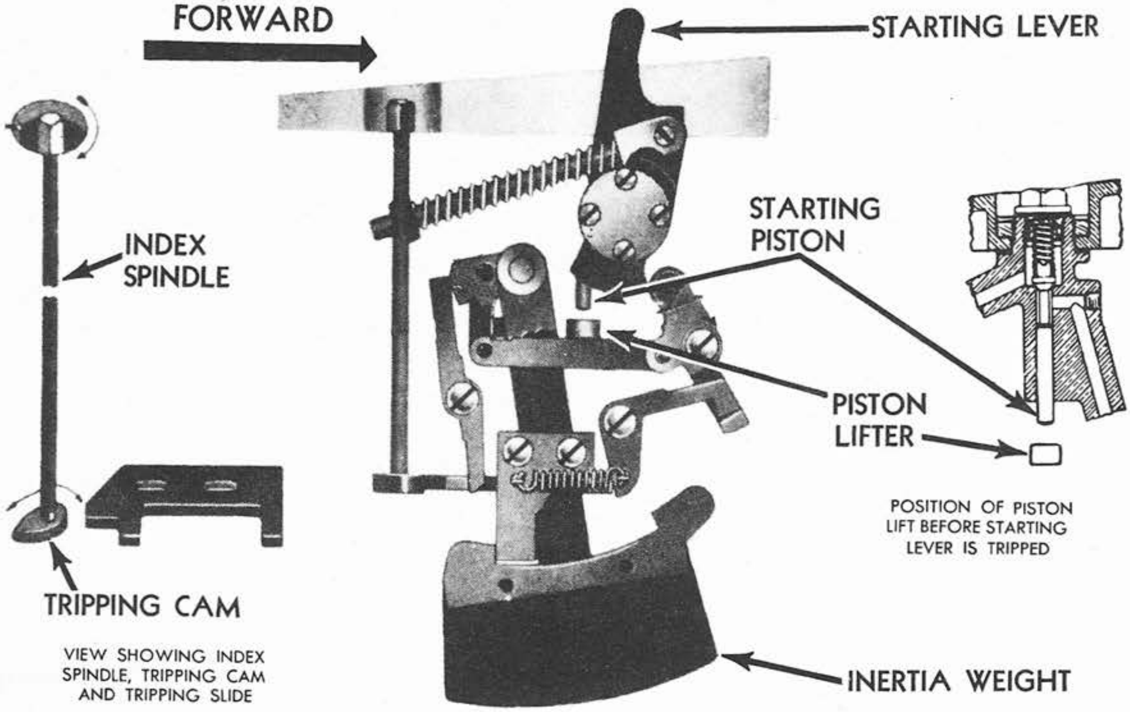
The starting gear operates when the torpedo is fired. The piston lifter then forces the piston upward, opening the valve. The high-pressure air above the valve is vented through the right-hand passage, permitting the starting valve to open.

The starting gear of a Mark 15 torpedo is operated by two separate devices—the starting lever and the inertia weight. The starting gear is mounted in the top of the afterbody, with the starting lever projecting upward through an opening in the afterbody shell. When the torpedo begins to move forward in the tube on launching, a tripping latch in the tube engages the starting lever and throws it aft. The starting lever, through a mechanical linkage, moves the piston lifter upward toward the starting piston, but it does not lift the piston.

As the torpedo gains momentum in the tube, the inertia weight trends to lag aft. The weight, through a second linkage, completes the upward movement of the piston lifter, and opens the valve. A spring-loaded latch holds the starting gear in this position, so that its valve can not close again during the torpedo run. Throughout the run, a small flow of air continues to pass through the starting gear, and is returned to the low-pressure side of the air system.

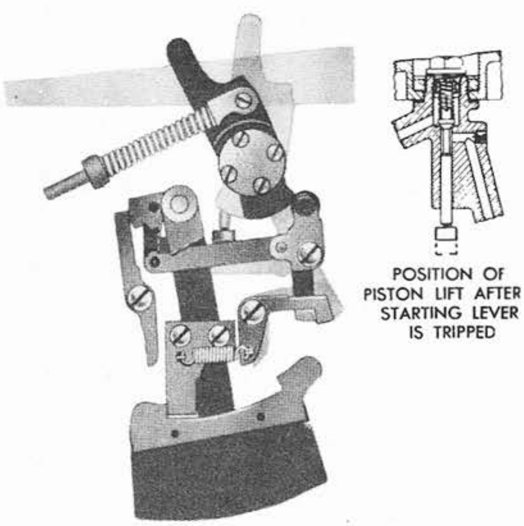
As shown in the lower half of figure 12C15, neither the starting lever nor the inertia weight can operate the starting gear alone. Both must act together before the valve can open. This safety feature prevents the possibility of accidentally starting the torpedo before it is fired.

The index spindle is operated manually with a socket wrench. Turning the spindle releases the latch, and permits the starting lever and inertia weight to return to their original positions. The index spindle is used to stop the torpedo after a test run on deck, and to reseat the starting piston before the air flask is charged.



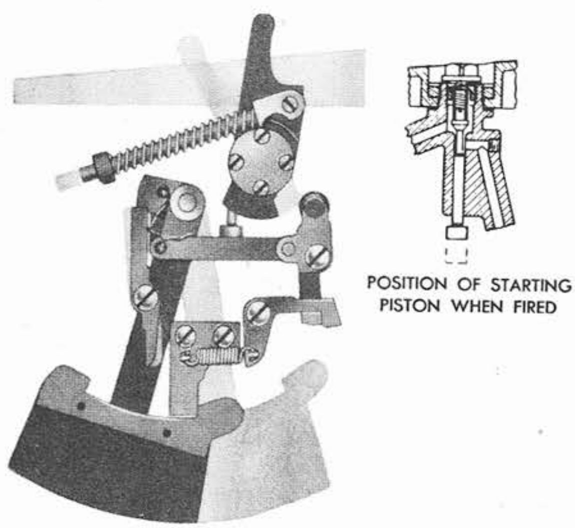
NORMAL POSITION BEFORE FIRING

A—Before firing—piston seated, valve lift in lowest position.



OPERATION BY STARTING LEVER

B—Starting lever tripped, but torpedo not fired from tube. Inertia weight not operative. Piston seated, valve lift in partially raised position, just below piston.



OPERATION BY INERTIA WEIGHT

C—Torpedo fired from tube. Inertia weight operative. Piston open, valve lift in raised position lifting piston.

Figure 12C15.—Operating positions of inertia starting gear.

D. Superheating System of a Mark 15 Torpedo

12D1. General

Figure 12D1 is a diagram of the superheating system of a Mark 15 torpedo. The system consists of the combustion flask, the devices through which air, fuel, and water enter the flask, the igniter, the nozzles through which combustion gases flow to the turbine blades, and the nozzle valve. All of these parts are mounted on the forward face of the turbine bulkhead.

12D2. Functional description

As previously explained, the compressed air in the torpedo's air flask has enough energy to propel the torpedo for a short distance at moderate speed. But both speed and range are increased considerably by superheating the compressed air. This is done in the combustion flask, where fuel is burned in a stream of working-pressure air. In burning, the liquid fuel is converted to gases, which add their volume to that of the compressed air. The heat of combustion increases the pressure, and therefore the speed at which the combustion gases strike the turbine blades. The water that is sprayed into the flask to cool it turns to steam, and adds to the volume of gases. The water, of course, contributes no energy to the system. But it does take energy that would otherwise be wasted as heat, and makes it do useful work.

When the torpedo's starting valve opens, air passes through the reducing and restriction valves, and into a fitting at the end of the combustion flask. A part of this air passes out through a pipe to the air strainer body, to operate the depth and steering engines. The rest of it enters the flask through a *whirl* or *premixer,* which gives it a spinning motion. Air from the reducing valve also flows to the fuel and water compartments, and forces fuel and water into the flask. As previously explained, the air pressure drops slightly as the air passes through the restriction valve. The pressure in the fuel and water compartments is therefore higher than that in the combustion flask, thus insuring a continuous flow of fuel and water into the flask.

The fuel spray, mounted in the center of the air whirl, delivers fuel in the form of a fine mist. The fuel and the whirling air mix thoroughly, and the igniter starts them burning. Once ignited, the fuel and air mixture continues to burn without any further help from the igniter. The igniter burns out after about 6 seconds.

Water is delivered to the combustion flask through two water sprays. (Only one of them is visible in figure 12D1.) The water spray holders are longer than the fuel spray holder, and are set deeper into the combustion flask. That gives the air-fuel mixture a chance to burn before water is sprayed into it.

The hot combustion gases pass at high velocity from the combustion flask to the nozzle unit. They strike the blades of the first tubine wheel, and start it spinning. The gases are deflected from the blades of the first turbine wheel and strike those of the second, and spin it in the opposite direction.

The nozzle valve (figure 12D1) is a part of the speed-change mechanism. Note, in the illustration, that combustion gases pass through five separate nozzles before they reach the first turbine wheel. When the nozzle valve is raised a short distance it closes 3 of the nozzles, leaving only 2 of them open. When raised all the way, the valve closes all of the nozzles but one.

12D3. Igniter

The igniter may be seen in figure 12D1, screwed into place in a threaded opening in the combustion flask. During transportation or overhaul of the torpedo, a dummy igniter is used in this opening to keep out drift and moisture. During preparations for firing, the dummy is removed and replaced by the real igniter. A protecting nut and lead disc are then removed from the outer end of the igniter, and an air pipe from the reducing valve is connected to it.

Figure 12D2 shows a cutaway view of the igniter. When the torpedo is launched, air from the reducing valve enters through the reduced-pressure air inlet at the outer end. Air pressure, acting through the rubber diaphragm, presses down on the housing. The sheer nibs hold the housing in place until pressure in the igniter builds up to about 250 psi. Then they suddenly give way. The housing and the firing pins snap down, and fire the primer caps. Flame from the caps spurts down through the two ignition tubes, blows out the end seal, and lights the ignition charge. The ignition charge burns from the bottom upward.

12D4. Speed-change mechanism

The speed change mechanism is not a part of the superheating system, but is closely associated with it. The mechanism is so designed that the torpedo tube crew can change the speed at which the torpedo will run by turning a single shaft accessible from outside the torpedo. The torpedo tube barrel is provided with a spring-loaded spindle for this purpose. This spindle can be forced down into the socket of the speed-setting shaft of the torpedo. The torpedo speed

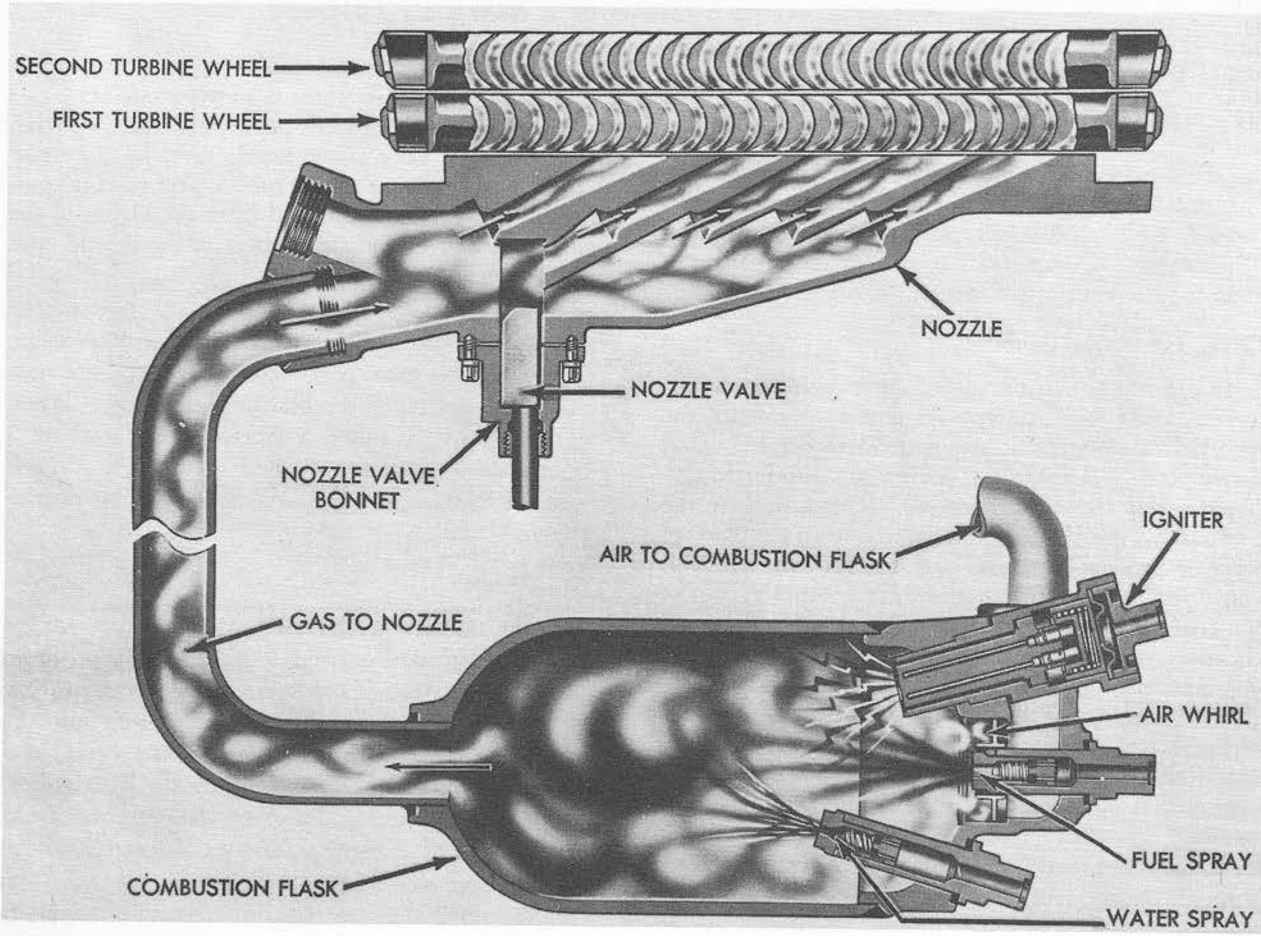


FIGURE 12D1.—Combustion flask and nozzle unit.

can thus be changed at any time up to a few seconds before launching.

Figure 12D3 is a diagrammatic view of the speed-change mechanism of a Mark 15 torpedo. The operating shaft is at the left of the figure, and the setting socket at the top of the shaft. Turning the shaft does three things:

1. It changes the size of the restrictions in the restriction valve.

2. It changes the number of nozzles covered by the nozzle valve.

3. It changes the gear ratio of the main engine.

The operating shaft, through its associated gear train, turns the restriction valve stem. One of the gears in this train meshes with a rack on the lower end of the nozzle valve stem, so that turning the operating shaft will raise or lower the nozzle valve. A cam is

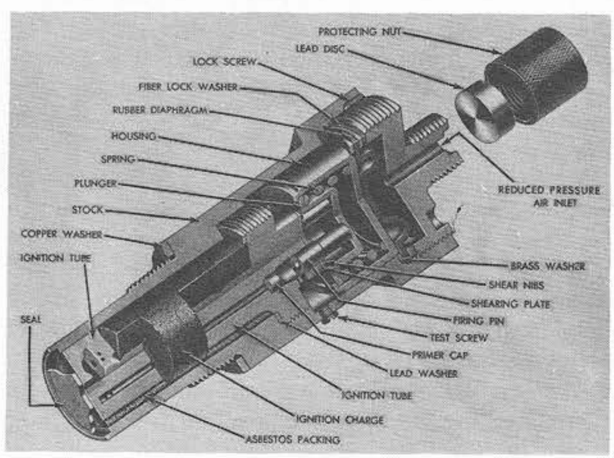


FIGURE 12D2.—Igniter Mark 6.

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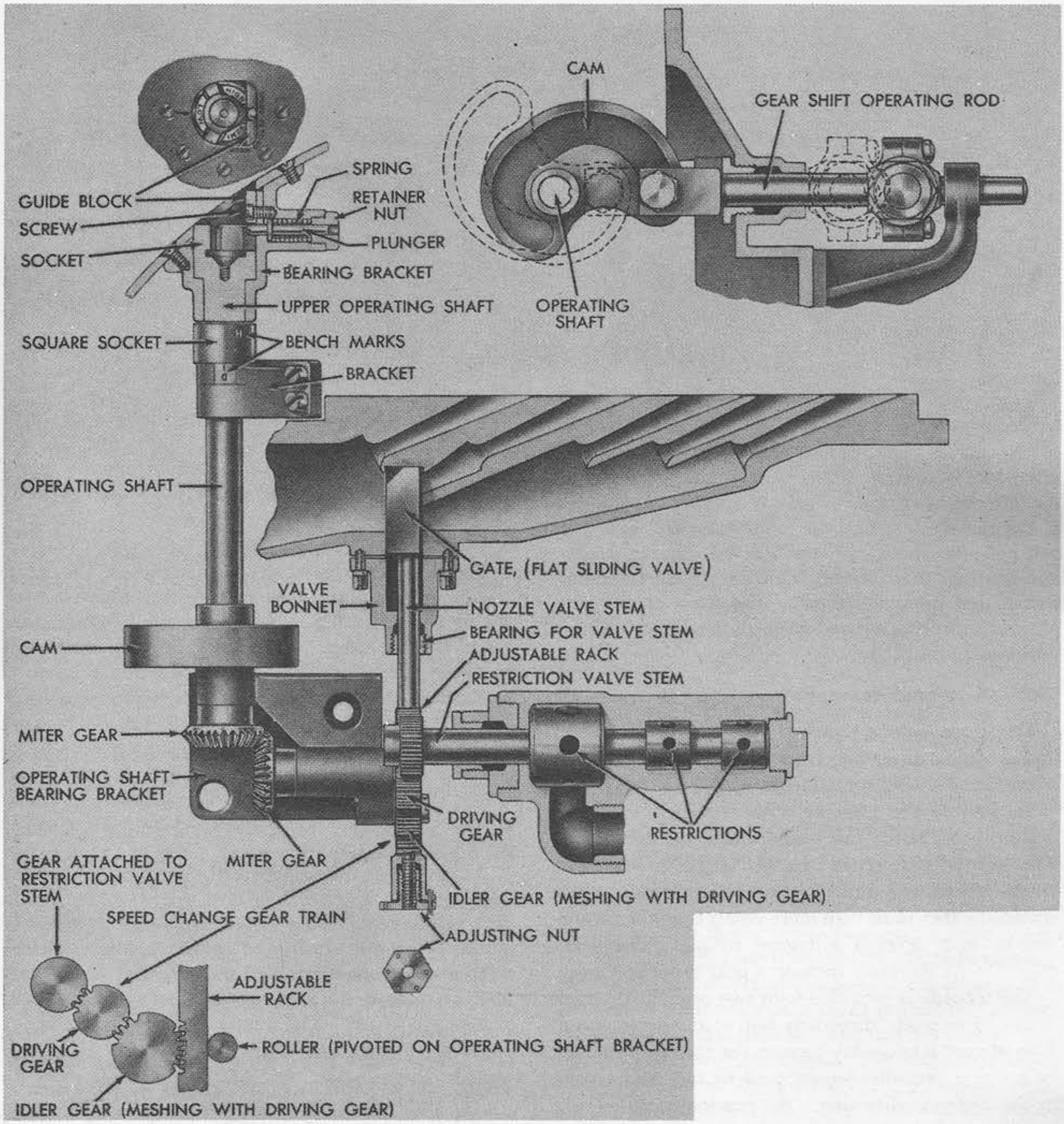

FIGURE 12D3.—Speed-change mechanism and nozzles (in low-speed setting).

mounted on the operating shaft near its lower end. The insert at the upper right of figure 12D3 shows how the cam changes the rotary motion of the shaft to a fore-and-aft motion of the gear shift operating rod. (The gear-shift mechanism will be described later.)

Speed-setting data for the Mark 15 torpedo is summarized in the following table.

SPEED-SETTING DATA

Spindle Setting	*Restriction Valve*	*Rear Ratio*	*Number of Nozzles*	*Standard Speed*	*Designed Range*
HIGH...........	Large Opening.........	High..........	5	46.0 knots......	6,000 yds
INT.............	Intermediate Opening....	High..........	2	33.5 knots......	10,000 yds
LOW............	Small Opening..........	Low...........	1	26.5 knots......	15,000 yds

E. Main Engine of a Mark 15 Torpedo

12E1. General

The main engine is located entirely within the afterbody, and is supported by A-frames secured to the after side of the turbine bulkhead. It consists of the turbine wheels, gear reduction train, and propeller shafts, along with the frames, spindles, shafts, and bearings that support these parts, and the oiling system that lubricates them. The main engine of a Mark 15 torpedo, viewed from the starboard side, is shown in figure 12E1.

12E2. Functional description

The main engine converts turbine-wheel rotation into propeller rotation. In order to do this effectively, it must have several special features.

Because of the high velocity at which the combustion gases strike the turbines, the turbine wheels must turn at high speed in order to use the available energy efficiently. But, if the propellers are to operate efficiently, they must turn more slowly than the turbine wheels, and develop a higher torque. The main engine must therefore include a gear reduction train.

The torpedo is provided with two propellers, which rotate in opposite directions but at the same speed. This feature is necessary because the torque developed by a single propeller would tend to roll the torpedo in the opposite direction. As previously stated, the two turbine wheels also turn in opposite directions. But it is not possible to drive each propeller with a different turbine wheel, because the first turbine wheel develops a much higher torque than the second. The main engine must therefore combine the two unequal torques developed by the turbine wheels, and then divide this force equally between the two counter-rotating propellers.

Finally, the main engine must continuously lubricate its moving parts throughout the torpedo run.

12E3. Gear train

Figure 12E2 is a schematic diagram of the main engine. This illustration should be compared with figure 12E1, bearing in mind that the two views are from opposite sides. (The side gears are not shown in figure 12E2; they will be described later.)

Each of the two turbine wheels is mounted on a separate spindle. The first turbine spindle is short and hollow, and carries the first turbine pinion at its lower end. The second turbine spindle is longer, and passes through the opening in the first spindle. The second turbine pinion is mounted at the bottom of the second turbine spindle.

As they pass through the nozzles, the hot combustion gases expand and reach a high speed—about 4,000 feet per second. They strike the blades of the first (lower) turbine wheel, and spin it counterclockwise (as viewed from the top of the torpedo). The first turbine turns its spindle, and the first turbine pinion, counterclockwise. The pinion meshes with the upper main drive gear, and turns it clockwise. The drive gear turns the upper bevel pinion clockwise.

The combustion gases are deflected from the blades of the first turbine, and strike the blades of the second (upper) turbine. The second turbine spins clockwise (still looking down from the top). The second turbine turns the second turbine spindle, and the second turbine pinion. The second turbine pinion turns the lower main drive gear counterclockwise.

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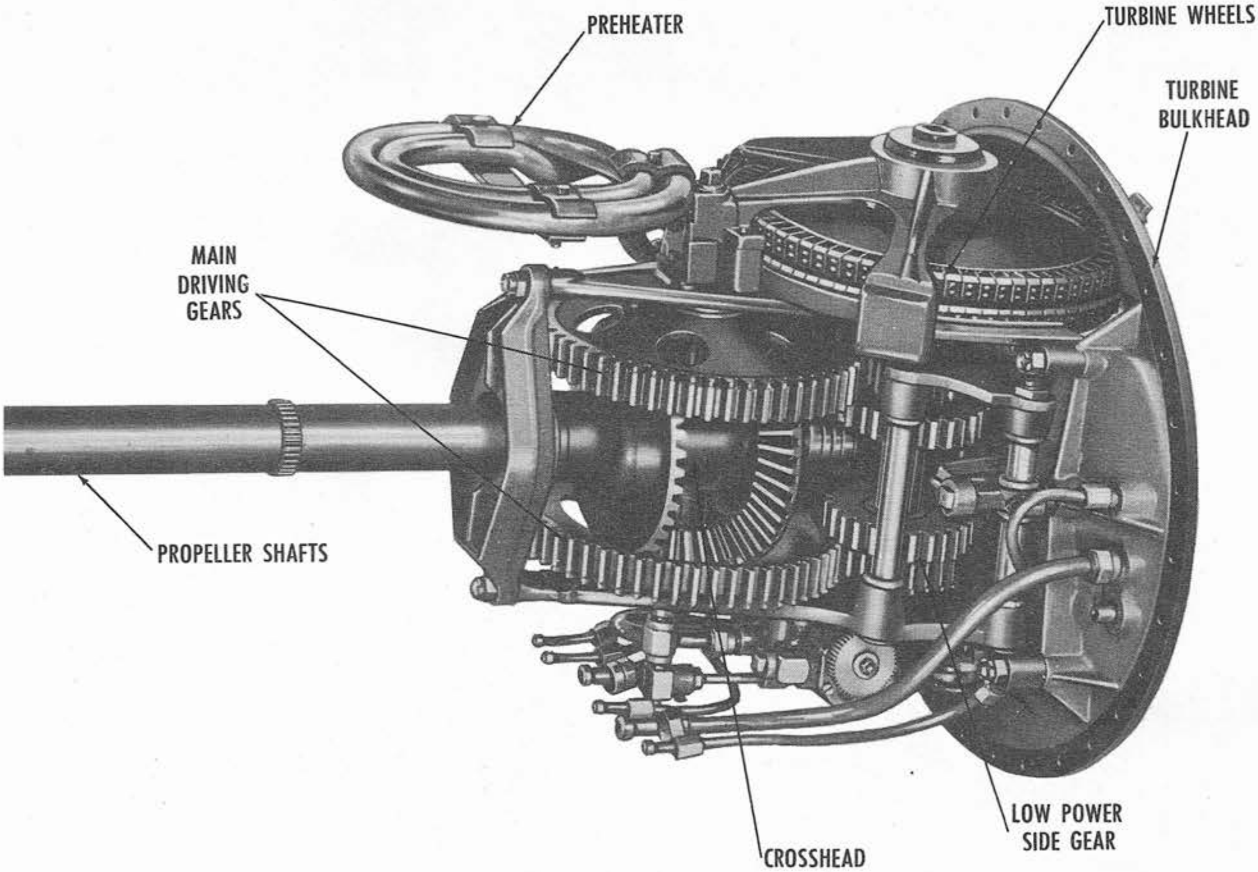

FIGURE 12E1.—Main engine.

Each of the 2 bevel pinions meshes with both bevel gears. Working together, the 2 pinions turn the 2 bevel gears. The forward bevel gear turns counterclockwise (looking aft from the forward end of the engine). The after bevel gear turns the forward (outer) propeller shaft, which turns the forward propeller. The forward propeller shaft is hollow; the after propeller shaft turns inside it. The forward bevel gear turns the after (inner) propeller shaft, which turns the after propeller. Because the two propeller shafts are linked together through the bevel gears and bevel pinions, they turn in opposite directions at the same speed.

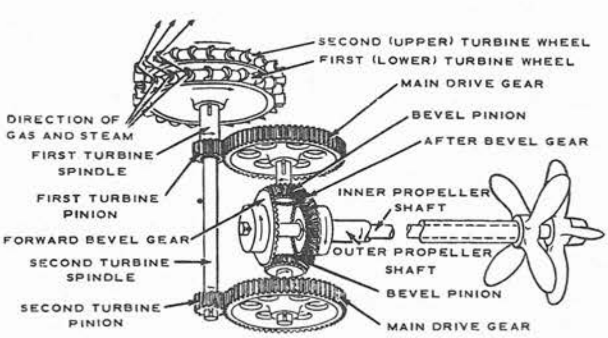

FIGURE 12E2.—Schematic diagram of the main engine.

12E4. Turbines and turbine spindles

Figure 12E3 shows the turbine and spindle assembly; the spindle casing is at the left. In both turbines, the blades are of crescent-shaped cross section. On the end of each blade is a small projection to which the turbine band is riveted. The turbine band is made up of overlapping segments. The clearance at the butt ends of the segments gives them room to expand when they get hot. The blades of the second turbine curve in the opposite direction from those of the first turbine. And the blades of the second turbine are slightly larger than those of the first, so that the gases can keep expanding as they pass through the turbine.

The upper and middle bearings support the first

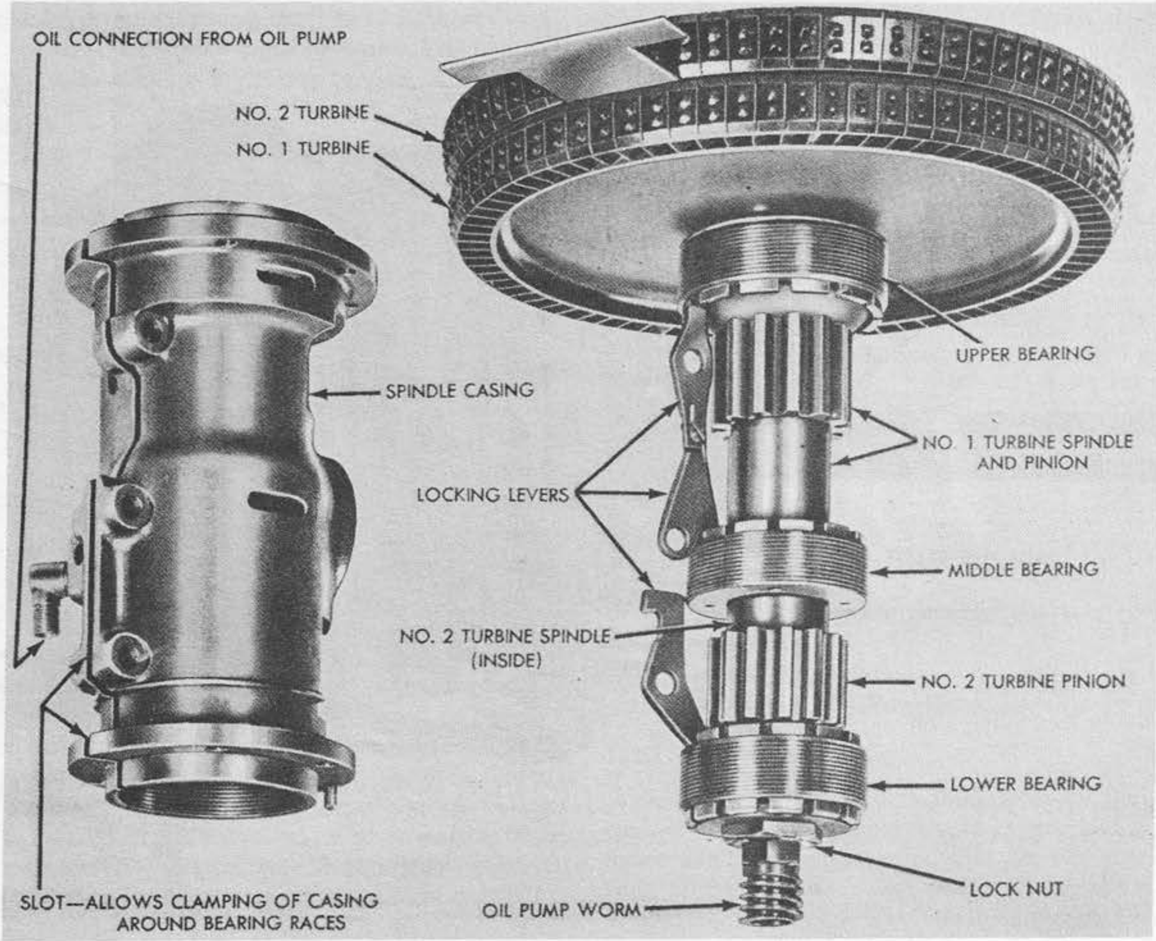

FIGURE 12E3.—Turbine and spindle assembly.

turbine spindle. The second turbine spindle, which passes through the first, is supported by the lower bearing and the top bearing. (The top bearing does not show in figure 12E3; it is located above the second turbine wheel.)

12E5. Crosshead assembly

The crosshead is shown in figure 12E4. Its outer ends are supported in the two A-frames. Bronze bushings fit over the two crosshead shafts. These bushings serve as bearings for the main drive gears and bevel pinions. (Each drive gear and pinion combination is machined from a single forging.) In figure 12E4 the bushings are in place on the crosshead. Note the spiral oil grooves on the surface of the bushings. Notice also, to the right of the strut, a small pinion gear machined on the outside of the forward propeller shaft. This pinion supplies the power that drives the steering mechanism.

The after propeller shaft passes through the crosshead in a floating bronze bushing. The forward bevel gear is keyed to the after (inner) propeller shaft; the after bevel gear is keyed to the forward (outer) propeller shaft. The outer propeller shaft turns in a bearing in the engine frame strut. This bearing supports the shaft radially; it prevents any motion at right angles to the torpedo axis. Between the after bevel gear and the crosshead are a bearing washer and a thrust bearing.

12E6. Engine thrust

As the propellers turn, they develop a thrust, or pushing force. They transmit this thrust to their shafts. To drive the torpedo through the water, this thrust must be taken from the propeller shafts and applied to the shell of the torpedo. This is done in three ways:

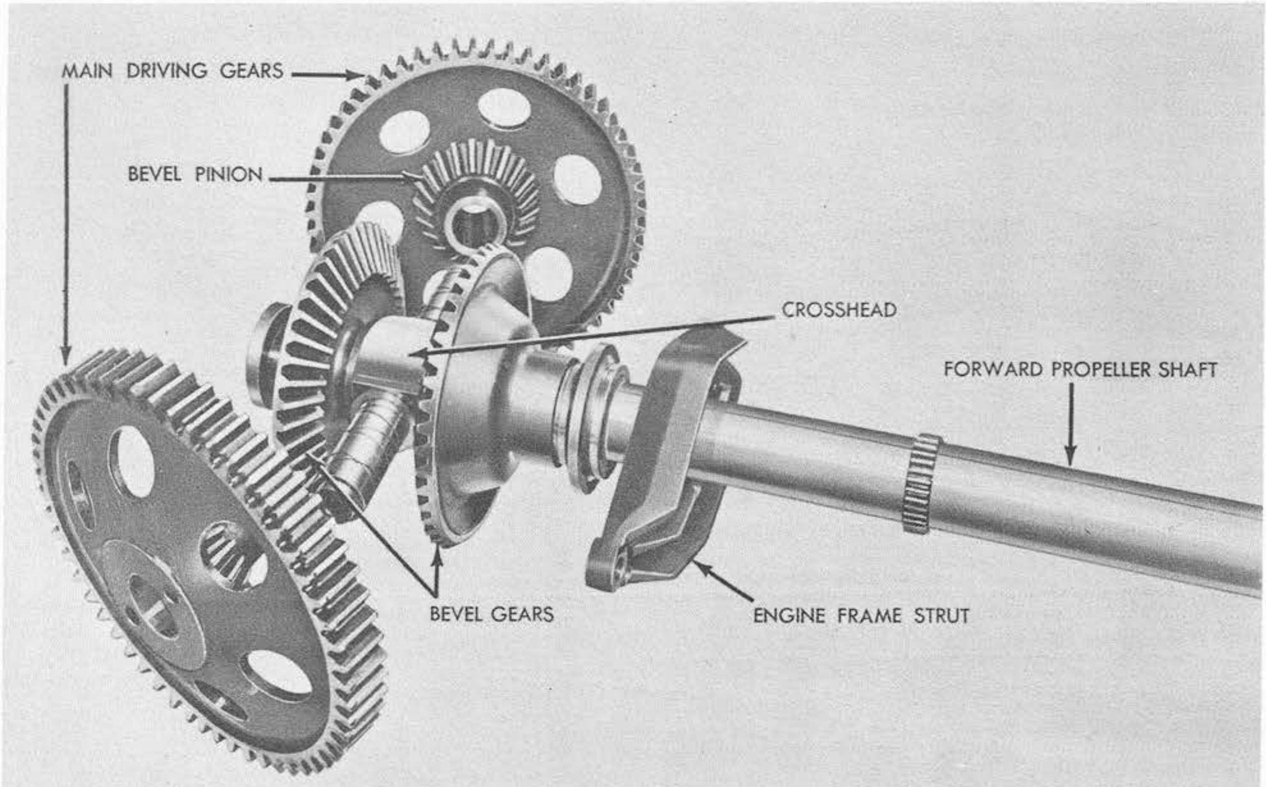

FIGURE 12E4.—Crosshead assembly.

The after bevel gear is driven by the two bevel pinions. Because of the slope of the gear teeth, the turning force of the bevel pinions tends to push the bevel gear aft. But the thrust of the forward propeller tends to push the bevel gear forward. The thrust of the propeller is stronger than that of the gears. A part of the thrust of the forward propeller therefore goes through the after bevel gear to the bevel pinions, and from there to the crosshead. The rest of the thrust from the forward propeller is applied to the crosshead directly, through a thrust bearing and washer.

The crosshead transmits the forward thrust through the A-frames and the turbine bulkhead to the shell of the torpedo. The after propeller shaft applies its thrust to a thrust bearing mounted on the after side of the turbine spindle casing. The spindle casing carries the thrust through the A-frames to the turbine bulkhead.

12E7. Engine balancing

Any rapidly rotating body develops a gyroscopic action, and resists any force that tends to turn its axis of rotation. The engine parts of a Mark 15 torpedo rotate fast enough to develop a considerable gyroscopic action. To keep this action from interfering with the steering mechanism of the torpedo, the main engine is *balanced*. The gyroscopic force of each of the principal rotating parts is balanced by the force of a similar part rotating in the opposite direction. For example, the gyro action of the first turbine wheel is balanced by that of the second. Other pairs of counterrotating parts include the turbine pinions, the main drive gears, the bevel pinions, and the bevel gears.

12E8. Side gear assembly

As previously explained, the speed-change mechanism of the Mark 15 torpedo includes a means for changing the gear ratio in the main engine. This is accomplished by interposing idler gears, called *side gears*, between the turbine pinions and the main drive gears. Figure 12E5 is a diagram representing the side gears in the low-speed setting (left) and the high-speed setting (right).

The side gear carrier is mounted on the turbine spindle casing. When the speed-setting socket is turned the cam rotates, moving the operating rod backward or forward. The operating rod turns the side gear carrier, so that either the high-power or the low-power side gear may be engaged with the main drive gear.

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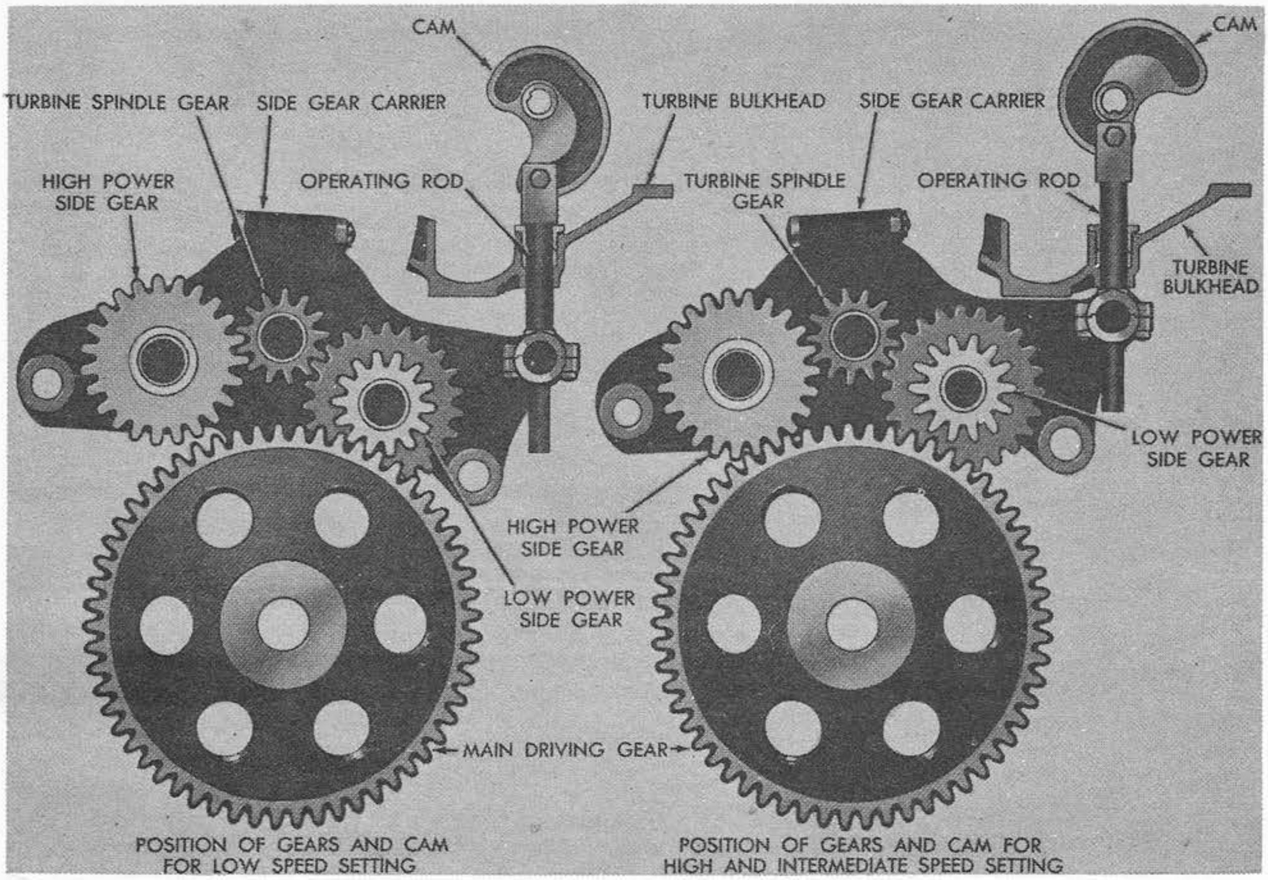

FIGURE 12E5.—Speed-change mechanism, showing positions of gears and cam.

The turbine spindle gear (turbine pinion) is engaged with both side gears at all times. In the left-hand diagram (figure 12E5), the high-power side gear is turning idly; the main drive gear is driven through the low-power side gear. The right-hand diagram shows the opposite condition.

Figure 12E5 shows only 1 set of side gears. There are, of course, 2 such sets—1 for each of the two turbine pinions and main drive gears. This can be seen in figure 12E1, in which the 2 low-power side gears are meshed with the 2 main drive gears.

12E9. Oiling system

The after propeller shaft bearings are lubricated by grease, which has been applied under pressure to seal the afterbody against entry of sea water. All other bearings associated with the main engine, as well as all the gear teeth, are supplied with oil throughout the torpedo run.

Figure 12E6 is a diagram of the oiling system of a Mark 15 torpedo. Oil flows from the two oil tanks to the reservoir. The reservoir ensures a steady supply of oil for the pump. The pump which is driven by a worm on the bottom of the second turbine spindle, operates at constant pressure. Excess oil is bypassed, and returns to the reservoir. The pump forces oil through 2 separate outlets—1 for the turbine spindle bearings and 1 for the crosshead. The oil that flows to the crosshead lubricates the crosshead bushing, the driving pinion bushings, and the top bearing of the second turbine.

The pump does not force oil directly to the gear teeth, or the strut bearing, or the propeller shaft thrust bearing. But oil leaks out constantly past the main driving gear washers, and past the crosshead bushing. The turning gears whip this oil into a spray, or fog. This oil fog lubricates all the parts that aren't supplied directly by the oil pump.

12E10. Exhaust system

Figure 12E7 shows the exhaust system of a Mark 15 torpedo, looking down from the top. The two tubes

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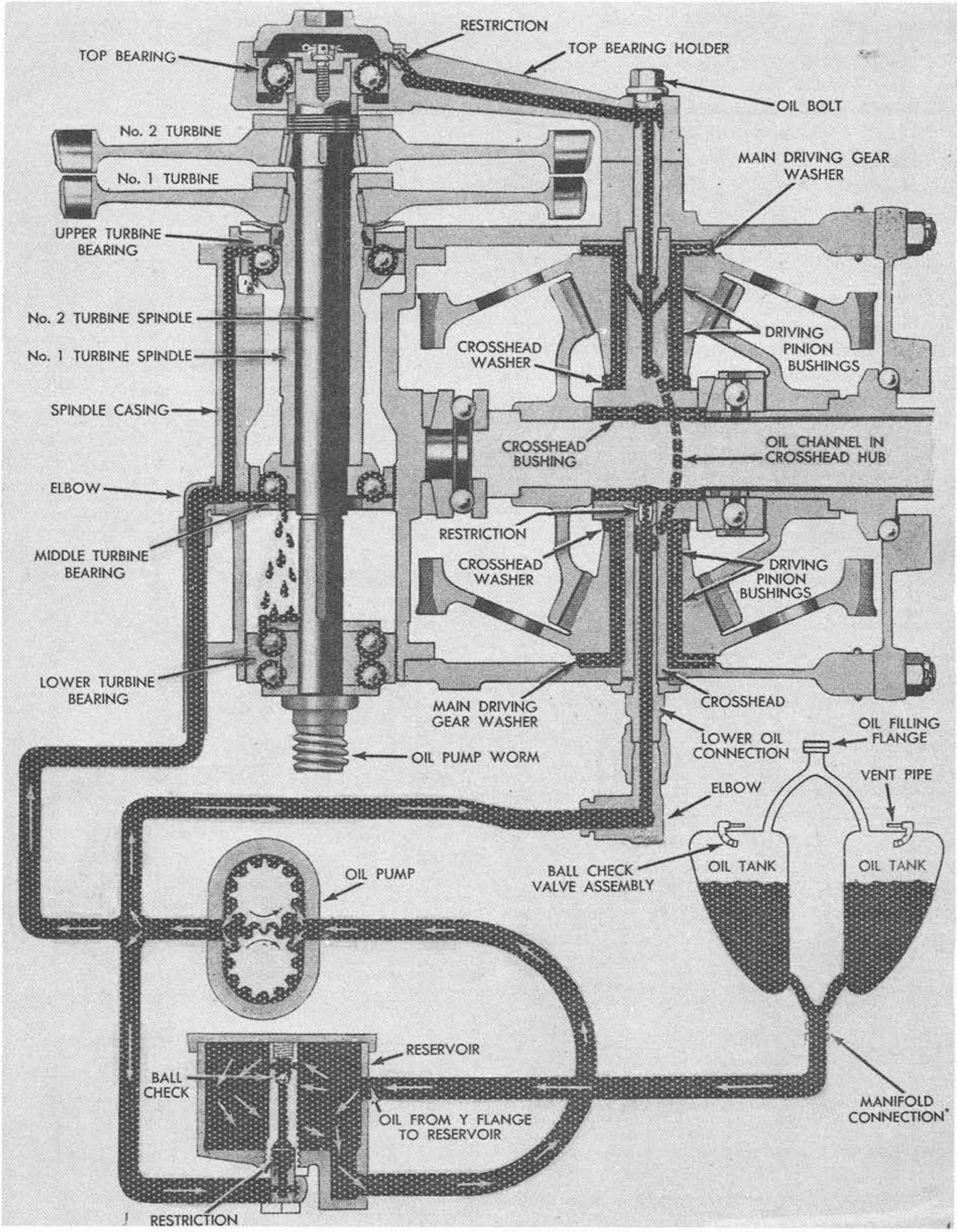

FIGURE 12E6.—Oiling system.

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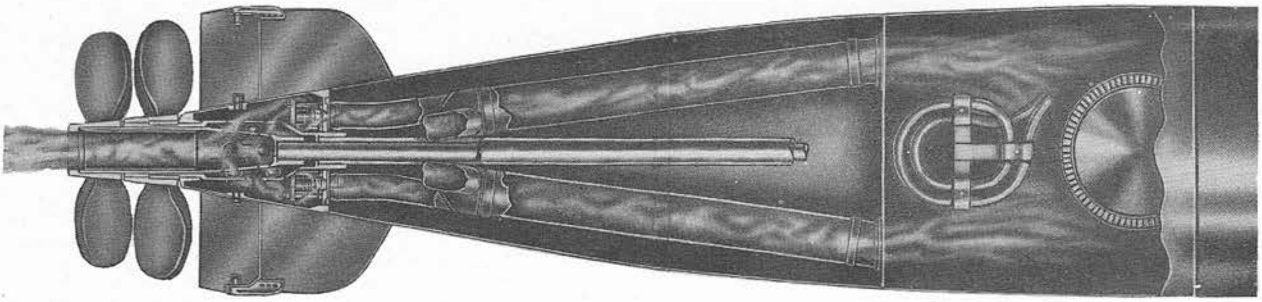


FIGURE 12E7.—Exhaust system.

carry exhaust gases from the space above the turbines to the tail section. Near the after end of the afterbody, each tube separates into two branches. (In figure 12E7, the lower branch of each tube is hidden.) The exhaust gases enter the tail section through four openings in the after bulkhead of the afterbody.

When the torpedo is under way, the main engine space is filled with a fog of oil. If this fog is allowed to mix with the hot exhaust gases it will burn. The torpedo will then leave a heavy wake of smoke. This is prevented in two ways:

1. Under the turbines, attached to the top engine frame, is a sheet steel pan called the turbine oil guard. This pan, together with thin horizontal and vertical bulkheads, keeps oil fog out of the exhaust system.

2. Above the upper turbine spindle bearing is a baffle, called the oil deflector ring. This ring keeps the oil in the spindle bearing from entering the turbine exhaust space.

F. Control Systems of a Mark 15 Torpedo

12F1. General

The torpedo is provided with 2 pairs of rudders—1 horizontal and 1 vertical. The vertical rudders control the steering of the torpedo to left or right, and keep it on its preset course. The horizontal rudders steer the torpedo up or down, to keep it at its preset depth.

The 2 control systems—1 for steering and 1 for depth—are located in the afterbody. The steering system consists of a gyro, a pallet mechanism, and a steering engine. The depth system consists of a diaphragm, pendulum, and depth engine. Each of the two engines operates a rod that extends aft through a packing in the after bulkhead of the afterbody. Each of the two rods is connected to its pair of rudders through a semicircular yoke.

12F2. Functional description

The control mechanisms have been called the "brains" of the torpedo. The steering mechanism turns the torpedo to its preset course, and keeps it there. If the torpedo wanders off course to left or right, the steering mechanism throws the vertical steering rudders to correct the error. And the depth mechanism brings the torpedo to its preset depth and keeps it there. If it starts to rise too high in the water, or sink too low, the depth mechanism throws the horizontal rudders to bring the torpedo back to its proper depth.

Each of the 2 control mechanisms consists of 3 parts: a sensing part, a detecting part, and an engine.

Sensing part. In the steering mechanism, the sensing part is the gyroscope. There is no way to keep the torpedo on course unless some part of the mechanism always points in the same direction—regardless of which way the torpedo may turn. Throughout the torpedo run, the axis of the gyro always points in the same direction.

The depth mechanism has two sensing parts—a diaphragm and a pendulum. To keep the torpedo at the proper depth the mechanism must include a part that can measure how deep the torpedo is in the water. The diaphragm does that job. The pendulum is sensitive to the "running attitude" of the torpedo. Since the pendulum tends to hang straight down, it can tell if the torpedo is tilted up or down, or if it is running level.

Detecting part. In the steering mechanism, the detecting part is the pallet mechanism. Assume that a torpedo has been fired with zero gyro angle. Then the axis of the gyro lies along the desired course of the torpedo, and it will point out the proper course throughout the run. If the torpedo turns to the left or right from its course, the pallet mechanism will detect the difference and send correcting orders to the steering engine.

In the depth mechanism, the diaphragm and pendulum are linked together. Through this linkage they work together to send corrective signals to the depth engine.

Engines. The steering engine, when it gets an order from the pallet mechanism, throws the vertical steering rudders in the direction required to bring the torpedo back on course. When the depth engine gets an order from the diaphragm and pendulum linkage, it moves the horizontal depth rudders in the direction required to bring the torpedo back to its preset depth.

Both engines are powered by working-pressure air. The two control mechanisms provide only enough energy to actuate the controls of the engines. Compressed air, rather than the gyro or diaphragm and pendulum, does the work of turning the rudders.

12F3. Control mechanism assembly

Figure 12F1 shows the control mechanism assembly of a Mark 15 torpedo, looking from the starboard side. The entire assembly is mounted on an oval base plate, which fits a flanged opening in the lower side of the afterbody shell, and is secured in place by screws. The vertical cylinder in the center of the assembly is the *gyro pot,* which serves as a housing for the gyro and its gimbal mounting. The *pallet mechanism,* which detects the relative position of the gyro axis, is mounted on the top plate at the top of the gyro pot. For an angle shot, the top plate and pallet mechanism are rotated, through a shaft and gear train, by a setting socket on the outside of the afterbody shell.

The pallet mechanism is linked to the valve of the

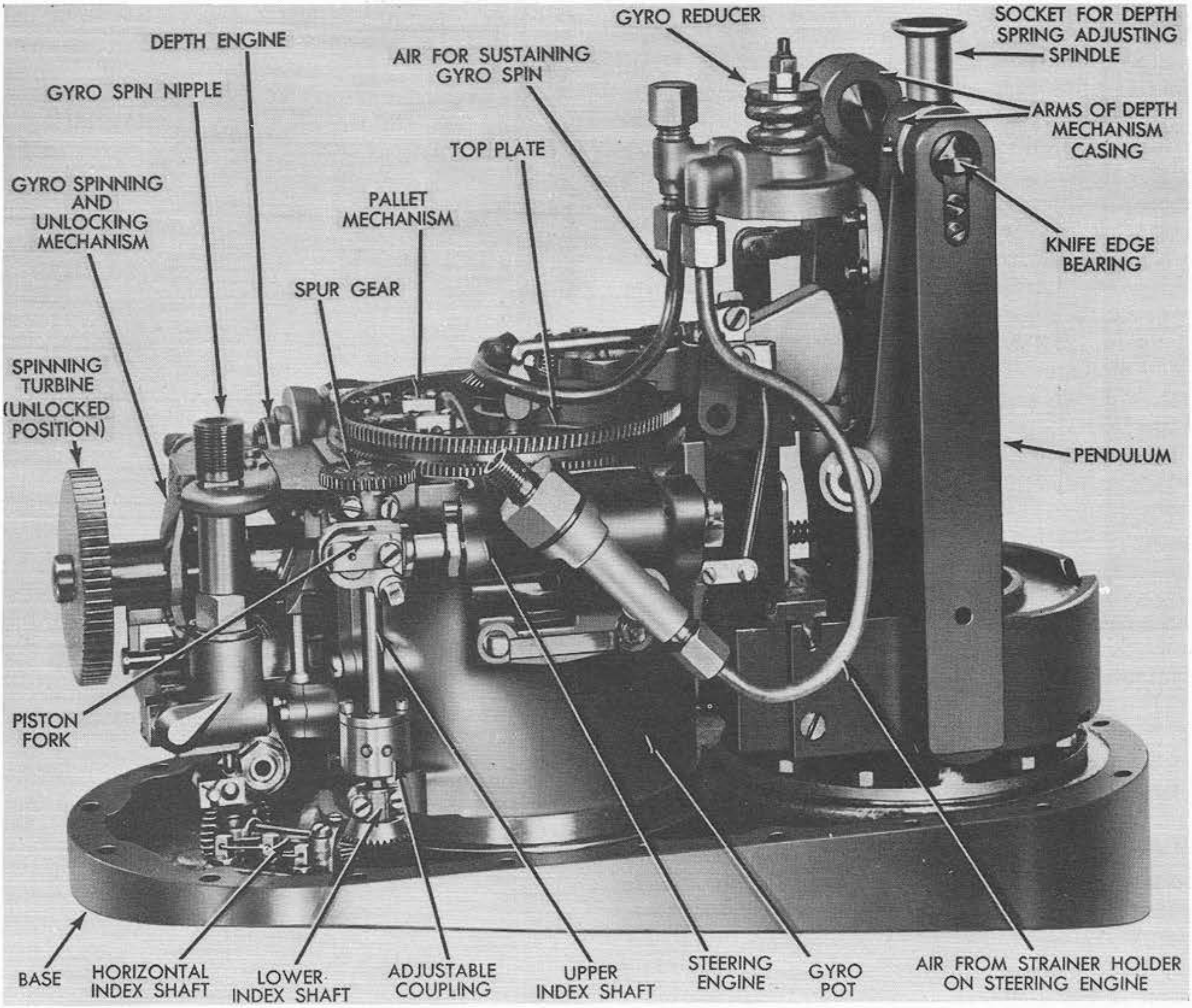


FIGURE 12F1.—Gyro and depth mechanism.

steering engine, which is visible in figure 12F1 on the starboard side of the gyro pot. The depth engine is mounted in a similar position on the opposite side of the pot. The air strainer body is mounted on the outboard side of the steering engine. Air passes from the strainer to the steering and depth engines, and to the gyro reducer (near the upper right in figure 12F1). Low-pressure air for sustaining the gyro spin enters the gyro pot through a fitting in the center of the top plate.

The gyro spinning and unlocking mechanism gives the gyro its initial speed at the moment of firing. It is visible at the extreme left in figure 12F1. The pendulum of the depth mechanism is at the extreme right. The diaphragm assembly is mounted on the base plate under the pendulum.

12F4. Gyro

The action of a gyroscope is explained elsewhere in this text. The gyro has two properties that make it useful in ordnance devices. The property of *precession* is used in the lead-computing sight. The property of *rigidity in space* is used in the torpedo. Throughout the torpedo run, the axis of the spinning gyro remains rigid in space; that is, it points constantly in the same direction. If the torpedo turns off its proper course, it must turn with respect to the gyro axis, which remains fixed. The pallet mechanism detects this relative turning, and sends the necessary corrective orders to the steering engine.

Figure 12F2 shows how a torpedo gyro is assembled in its gimbals. The gyro wheel alone is shown at the top of the illustration. Most of its weight is concentrated in its outer rim, to increase its gyroscopic action. Throughout the torpedo run, low-pressure air from the gyro reducer strikes the spinning buckets on the outer rim of the wheel, to maintain the original rate of spin. A spur gear is mounted on each end of the gyro wheel axis. One of these is engaged by a gear of the gyro spinning and unlocking mechanism, to give the wheel its initial spin. The other is present to balance the first, and to provide equal air resistance so that no unbalanced forces will be applied to the gyro.

The middle picture shows the gyro wheel mounted in its inner gimbal. The wheel is free to rotate on its bearings within the inner gimbal. Note that parts of the inner gimbal are cut away to expose the two spur gears.

The lower picture shows the gyro and gimbals completely assembled. (Note that in each of the three pictures the gyro wheel is shown in a different position.) In the torpedo, the gyro spins on a fore-and-aft horizontal axis within the inner gimbal. The inner gimbal itself is free to rotate on a horizontal axis at right angles to that of the gyro wheel, on bearings in the outer gimbal. The outer gimbal is free to rotate on a vertical axis, in bearings mounted in the top and bottom plates of the gyro pot. Thus the gyro wheel, with three degrees of freedom, is free to turn in any direction with respect to the torpedo. Or, more precisely, the torpedo is free to turn in any direction without disturbing the gyro axis.

The cam plate is rigidly attached to the top of the outer gimbal. If the torpedo turns with respect to the gyro, it therefore turns with respect to the cam plate. The pallet mechanism, by detecting the relative position of the cam on the cam plate, is able to determine when the torpedo has turned off course, and in which direction.

The gyro sustaining air enters through a fitting in the center of the top plate. It flows through passages in the upper arms of the outer gimbal, through the inner gimbal bearings, and through passages in the inner gimbal arms to the spinning buckets.

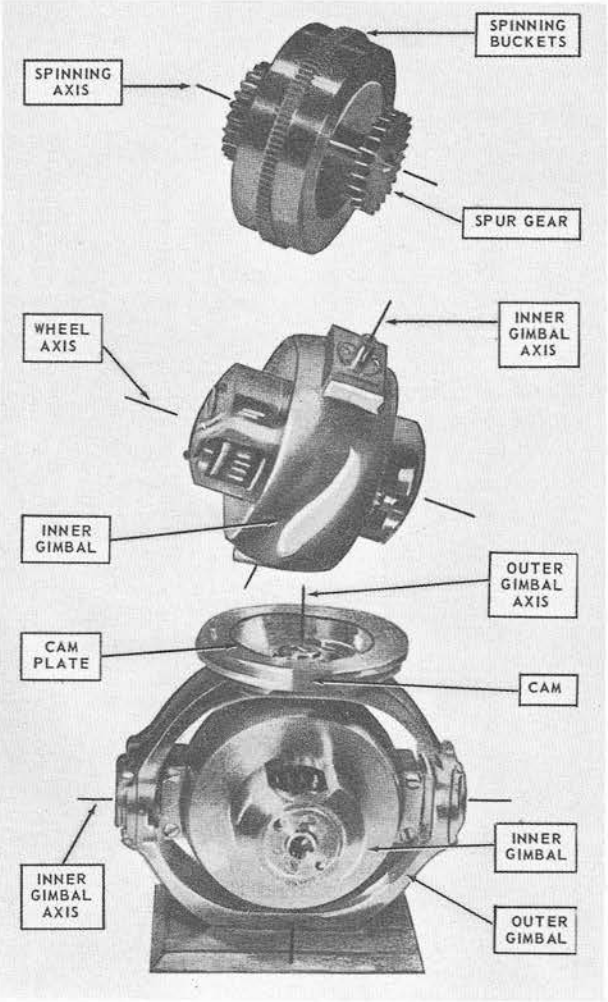


FIGURE 12F2.—How a torpedo gyro is assembled.

12F5. Spinning and unlocking mechanism

At the instant of firing, the gyro is rigidly locked with its axis of spin parallel to the axis of the torpedo. This is accomplished by the centering pin of the spinning and unlocking mechanism. The centering pin is engaged in a cavity in the center of the after side of the inner gimbal. This cavity may be seen in the lower illustration in figure 12F2; it is located just below the opening for the spur gear. The spur gear is engaged by a gear on the spinning mechanism.

When the starting valve opens, flask-pressure air enters the spinning mechanism and spins its turbine. This spin is transmitted to the gyro wheel through its spur gear. The gyro wheel reaches full speed in a little more than half a second. The spinning gear then snaps out of engagement with the gyro spur gear. When this action is completed, the centering pin snaps out of the cavity, unlocking the gyro and leaving it free to control the steering of the torpedo. A valve in the spinning and unlocking mechanism closes automatically, to shut off the supply of high-pressure air.

12F6. Pallet mechanism

Figure 12F3 shows the pallet mechanism of a Mark 15 torpedo, mounted on the gyro top plate. The pallet driving gear is turned by a spur gear on the forward (outer) propeller shaft. Its rotation is transmitted to the bevel gear in the center of the gyro top plate.

Figure 12F4 is a diagram of the whole steering mechanism. (The mechanism shown is actually that of a Mark 13 torpedo. It differs from the Mark 15 in a few details of the linkage between the pallet mechanism and the steering engine. This difference may be seen by comparing figure 12F4 with 12F3. The pallet mechanisms, and the principles of operation, are the same.)

On the shaft of the eccentric gear (figure 12F4) is a cam that passes through an opening in the eccentric plate. Rotation of the cam gives a fore-and-aft motion to the plate, and to the pallet shaft holder attached to it. The pallet shaft is free to turn within its holder, but must move fore-and-aft with it. Thus the pallet shaft and its pallet (at the top) and its two cam pawls (at the bottom) have a continual fore-and-aft motion throughout the torpedo run.

If the pallet (figure 12F4) is on dead center during its motion aft, it will pass between the two pallet pawls. But if the pallet shaft has been rotated in either direction, the pallet will strike one of the pallet pawls and throw it aft. The two pawls are so linked

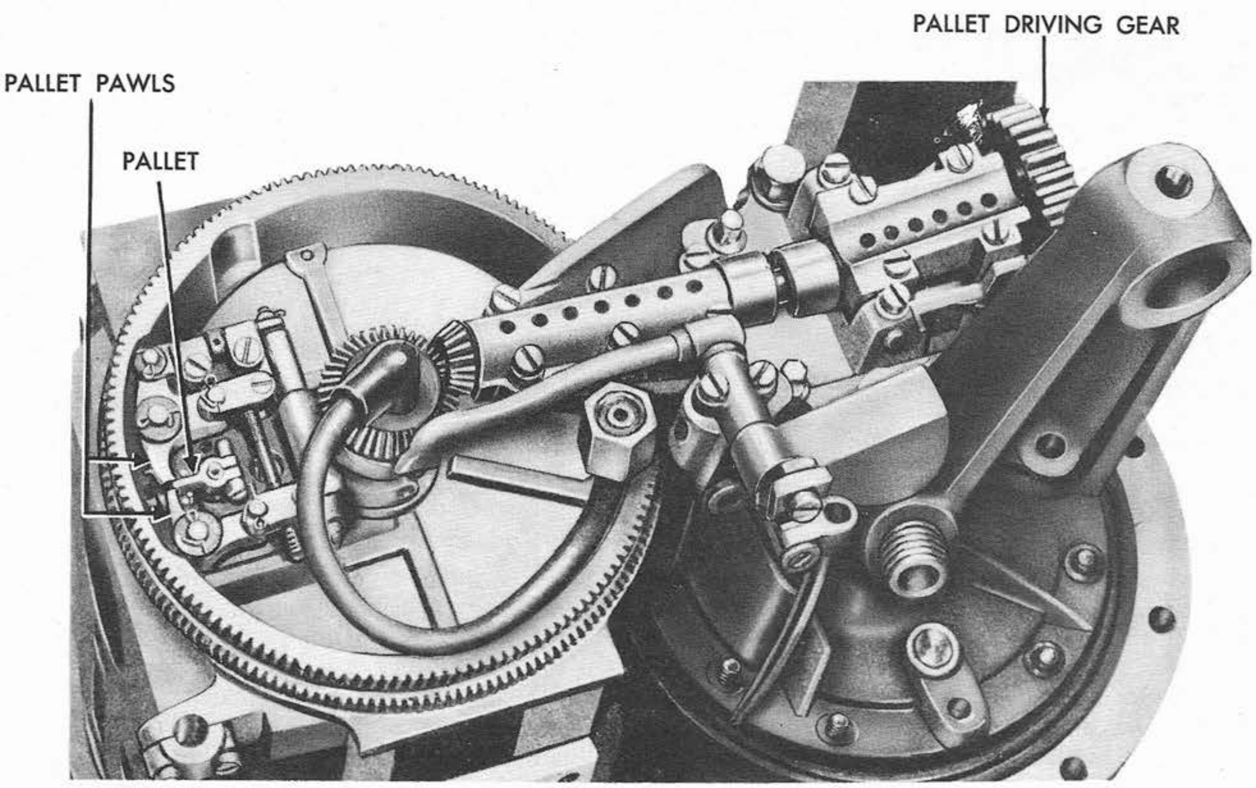


FIGURE 12F3.—Pallet mechanism.

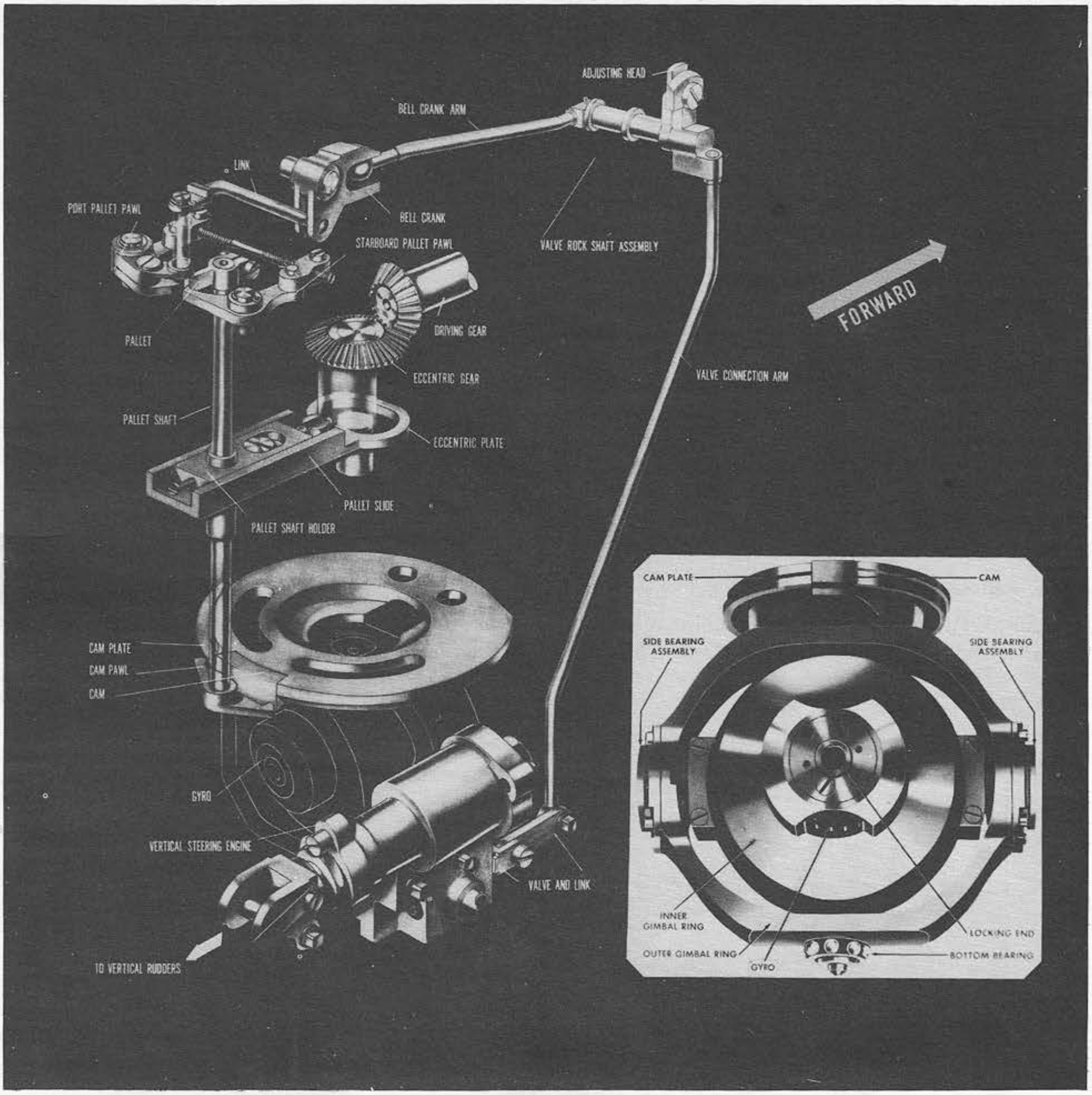
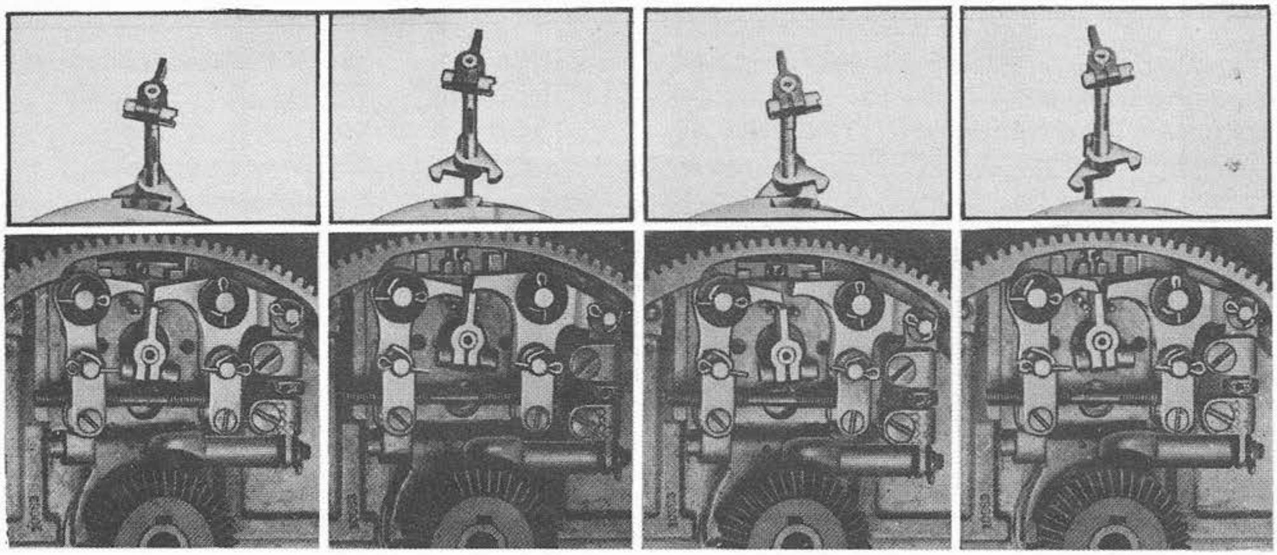


FIGURE 12F4.—Steering mechanism.

that when one of them is thrown aft, the other is automatically thrown forward. At the same time, the linkage will move the valve of the steering engine in or out.

Note the cam on the after edge of the cam plate. Because the cam plate is rigidly attached to the outer gimbal, the position of the cam indicates the desired course of the torpedo. On the starboard side of the cam, a groove is cut in the lower edge of the cam plate; on the port side, a similar groove is cut in the upper edge. If the torpedo is exactly on course during the forward stroke of the pallet shaft, the two cam pawls will straddle the cam and enter the grooves. The pallet shaft will not be rotated. If the torpedo is off course, one of the cam pawls will strike the cam, rotating the pallet shaft. Then, on the next backward stroke, the pallet will strike one of the pallet pawls and throw it aft. The pallet pawl, through its linkage, will



Top view above shows cam pawls forward with port pawl engaging port groove, causing pallet blade to swing to position opposite port pallet pawl. Lower view shows pallet blade in position for thrust against pawl.

Pallet assembly has been thrust aft by motion of pallet slide; pallet blade pivots port pallet pawl aft. To avoid disturbance of gyro, pallet slide is kept in constant motion fore and aft, so contacts with cam are momentary.

Pallet assembly has been brought back by motion of pallet slide; torpedo is now assumed to have swung off course to starboard. Starboard cam pawl engages starboard groove in cam plate, and pallet blade swings to starboard.

The pallet blade having received its "steering orders" through momentary contact of the cam pawls with the cam plate, the pallet moves aft, pushing the toe of the starboard pallet pawl aft.

FIGURE 12F5.—Operation of the pallet mechanism.

move the valve of the steering engine. The action of the pallet mechanism is shown in detail in figure 12F5.

Assume that the torpedo has turned off course to port. The gyro axis and cam are still pointing in the original direction; the torpedo has turned to port with respect to the gyro axis and cam. Because the pallet shaft is abaft the cam plate, it has moved to the starboard side of the cam. When the pallet shaft moves forward, the port cam pawl will strike the cam. The pallet shaft will turn counterclockwise (looking down from the top). The pallet blade will swing to starboard. When the pallet shaft moves aft, the pallet will strike the starboard pallet pawl and throw it aft. The linkage will move the port pallet pawl forward, and it will move the steering engine valve aft.

The steering engine is so designed that when its valve is moved in one direction, its piston moves full-throw in the opposite direction. The piston will therefore move forward, carrying the piston fork and rudder rod with it. The rudder rod, through its yoke, will apply right rudder. The rudder will turn the torpedo back onto its course.

Actually, the torpedo will not stop turning when it comes back on course. It will swing off course on the other side. The rudder will stay where it is until the steering engine gets the opposite order. And there will be no new order to the engine until the torpedo has crossed its course, so that the other cam pawl can strike the cam.

Therefore, the track of the torpedo is not a straight line. The rudder oscillates constantly, and the torpedo weaves back and forth across its course. But because the pallet mechanism is sensitive, the weaving is small; the actual track is very close to a straight line.

Summary. The pallet mechanism is driven by power taken from the forward propeller shaft. A part of the pallet mechanism makes a light, intermittent contact with the cam plate of the gyro. If the torpedo has turned off course, the mechanism will detect a change in the relative position of the cam plate. Then, through a mechanical linkage, it will send an appropriate order to the steering engine valve. The steering engine will respond by throwing the rudders in the direction necessary to bring the torpedo back on course.

12F7. Angle fire

In the foregoing discussion, it has been assumed that the pallet shaft is always in line with the gyro axis, and that the pallet slide moves forward and aft.

But those conditions exist only when the torpedo is fired with zero gyro angle.

It is often inconvenient or impossible to launch a torpedo in the direction required by the solution to the torpedo fire control problem. This is especially true with fixed tubes. In such situations *angle fire* is used. The steering mechanism is set so that the torpedo, after it enters the water, will turn through the angle necessary to bring it onto its proper course.

For an angle shot, the gyro angle is set through one of the gyro setting sockets on the outside of the torpedo. The socket, through a gear train, turns the gyro top plate through the desired gyro angle. (But note carefully that it does not move the gyro.) The top plate carries the whole pallet mechanism around with it. Since an eccentric cam drives the pallet slide, the slide will still have its back-and-forth motion in the new position. That motion will no longer be fore-and-aft, but it will still be toward and away from the center of the gyro top plate.

Figure 12F6 shows the angle of the gyro, the pallet, and the rudder—for both a straight shot and an angle shot. In diagram A, the torpedo is ready to be fired on a straight shot. The gyro angle is set at zero. The cam pawls are in line with the gyro axis and the cam, ready to correct any deviation from the course.

In diagram B, the torpedo is ready to be fired on an angle shot. The desired gyro angle has been set, thus turning the gyro top plate and moving the cam pawls away from the gyro axis. The angle between the cam pawls and the gyro axis is exactly the angle through which the torpedo will turn. Note that for an angle shot, as well as for a straight shot, the gyro axis is fore-and-aft at the moment of firing.

In part C of figure 12F6, the torpedo is under way on an angle shot. The cam pawls have detected that the torpedo is off its set course. They have turned the pallet shaft, and the pallet mechanism has ordered left rudder. In the diagram, the rudder has turned the torpedo part way through the desired angle. And the cam pawls are part way around to the gyro axis. Notice that the gyro axis is still pointed in its original direction.

In diagram D, the torpedo has straightened out on the course it was set for. The cam pawls have moved around into line with the gyro axis and the cam. The rudder is oscillating in the normal way. And the gyro axis is still pointing in the original direction.

12F8. Depth mechanism

While the steering mechanism brings the torpedo onto its proper course and keeps it there, the depth mechanism brings it to its proper depth and keeps it

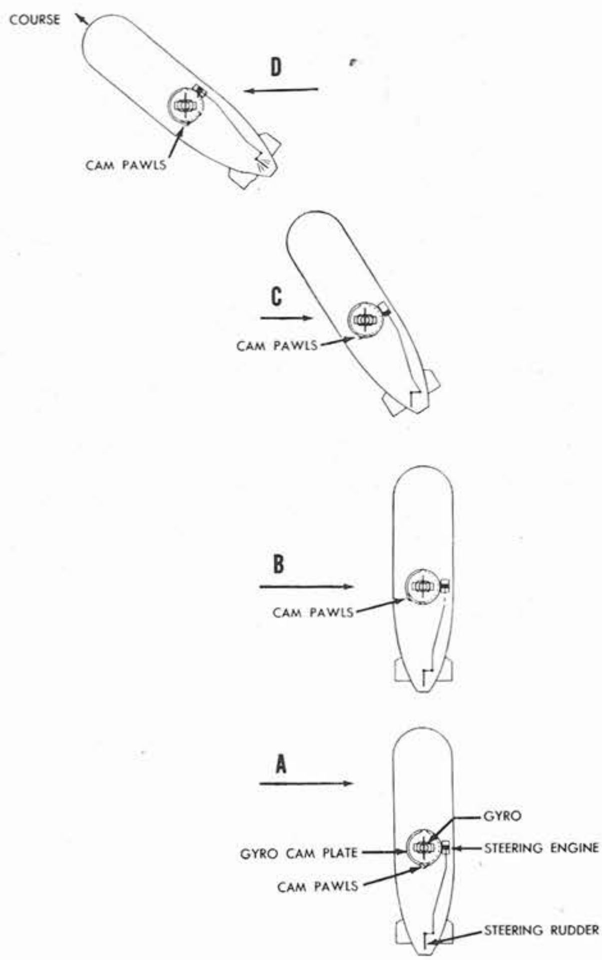


FIGURE 12F6.—Angle shot, showing angle of the gyro pallet, and rudder.

there. The two horizontal depth rudders control the running depth of the torpedo. The depth engine, powered by compressed air from the reducing valve, operates the rudders. And the depth mechanism sends orders to the valve of the depth engine.

This system has two sensing parts—a hydrostatic diaphragm and a pendulum. The flexible diaphragm is open to sea water on one side; a spring resists the pressure of the water. The stronger the water pressure, the farther the diaphragm will move against the force of the spring.

Since the pressure of the water depends on the depth, the position of the diaphragm can be used to indicate the depth at which the torpedo is running. Because the pendulum responds to gravity, and tends to hang straight down, it can determine the angle at which the torpedo is changing depth. The diaphragm and pendulum work together to send orders to the depth engine.

There are two reasons why the depth engine may

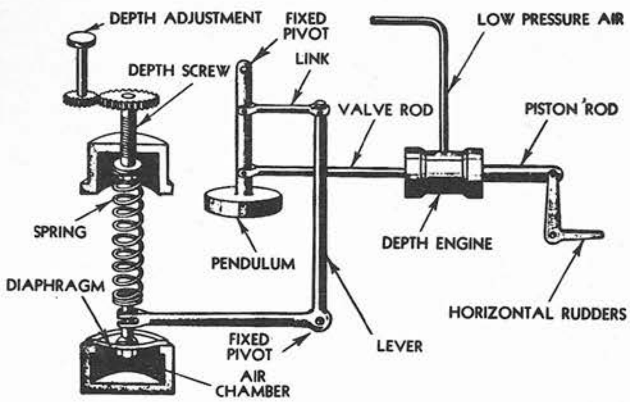


FIGURE 12F7.—Depth control mechanism, schematic.

need new orders. First, the torpedo may be running at the wrong depth. Second, it may be changing its depth at too steep an angle.

Assume the torpedo is running below its preset depth. The diaphragm responds to the extra water pressure, and sends an *up rudder* order to the depth engine. The torpedo begins to climb. If the engine gets no further orders, the torpedo will be climbing fast when it reaches the right depth, and it will overshoot. Then the diaphragm will send a *down rudder* order. The torpedo will go down and overshoot again. So, if the torpedo is going to make a successful run, the depth mechanism must control not only its depth, but also the rate at which it changes depth.

Figure 12F7 shows schematically how the diaphragm and pendulum work together.

Under the diaphragm is a sealed chamber of air. Sea water reaches the upper surface of the diaphragm through suitable passages, and tends to push it down. The spring, being under tension, resists this downward pressure. (The depth at which the torpedo will run is set by adjusting the tension of this spring.)

To see how the mechanism works, assume that the torpedo is below its set depth, with its axis horizontal. Water pressure pushes the diaphragm down, against the force of the spring and the resistance of the air trapped in the chamber. The downward movement of the diaphragm rocks the diaphragm lever counterclockwise. Since the diaphragm has only a limited movement, the lever is pivoted near the diaphragm, so that it multiplies the diaphragm movement by a factor of 18.

The pendulum lever and link transfer the rocking movement to the pendulum, swinging it forward (to the left in figure 12F7). The pendulum pulls the depth engine valve rod forward. The depth engine is built so that its piston follows the movement of the valve. So the piston moves forward, applying up rudder, and the torpedo begins to climb.

But as the torpedo turns upward, gravity tends to pull the pendulum aft (to the right in figure 12F7), against the action of the diaphragm. That reduces the amount of up rudder. When the climbing angle is just steep enough to make the diaphragm action balance the pendulum action, the rudder will be in neutral. But the torpedo will still be climbing.

As it climbs, the water pressure becomes less. So the downward pressure on the diaphragm decreases. That lets the pendulum move farther to the right, and apply down rudder. The torpedo begins to level off, and reaches its set depth at a slow rate of climb. In that way, the pendulum tends to prevent overshooting. And the torpedo runs at a nearly uniform depth—the depth set before firing by adjusting the tension on the diaphragm spring.

Figure 12F8 is a cutaway view of the depth mechanism. It shows the actual appearance and location of the parts shown schematically in figure 12F7. These two figures should be carefully compared.

Like the steering engine, the depth engine works on compressed air from the reducing valve. But the two engines differ considerably in operation. When the valve of the steering engine moves in one direction, the piston goes full-throw in the opposite direction. It has no in-between positions. But the piston of the depth engine moves in the same direction as its valve. And it follows the valve exactly. So the depth engine can hold the horizontal depth rudders at any position between full up and full down.

G. Tail Section of a Mark 15 Torpedo

12G1. General

The tail section is a short, truncated cone. Holes are drilled in its forward end so that it may be secured to the afterbody with joint screws. The principal parts that it carries are:

1. The surfaces that drive the torpedo through the water—the two propellers.
2. The surfaces that control the path of the torpedo—the tail blades and rudders.
3. The sleeves and hubs that support the propellers.
4. The rods and yokes that operate the rudders.

12G2. Construction

Figure 12G1 is a cutaway view of the tail section. A bearing in the after bulkhead of the afterbody sup-

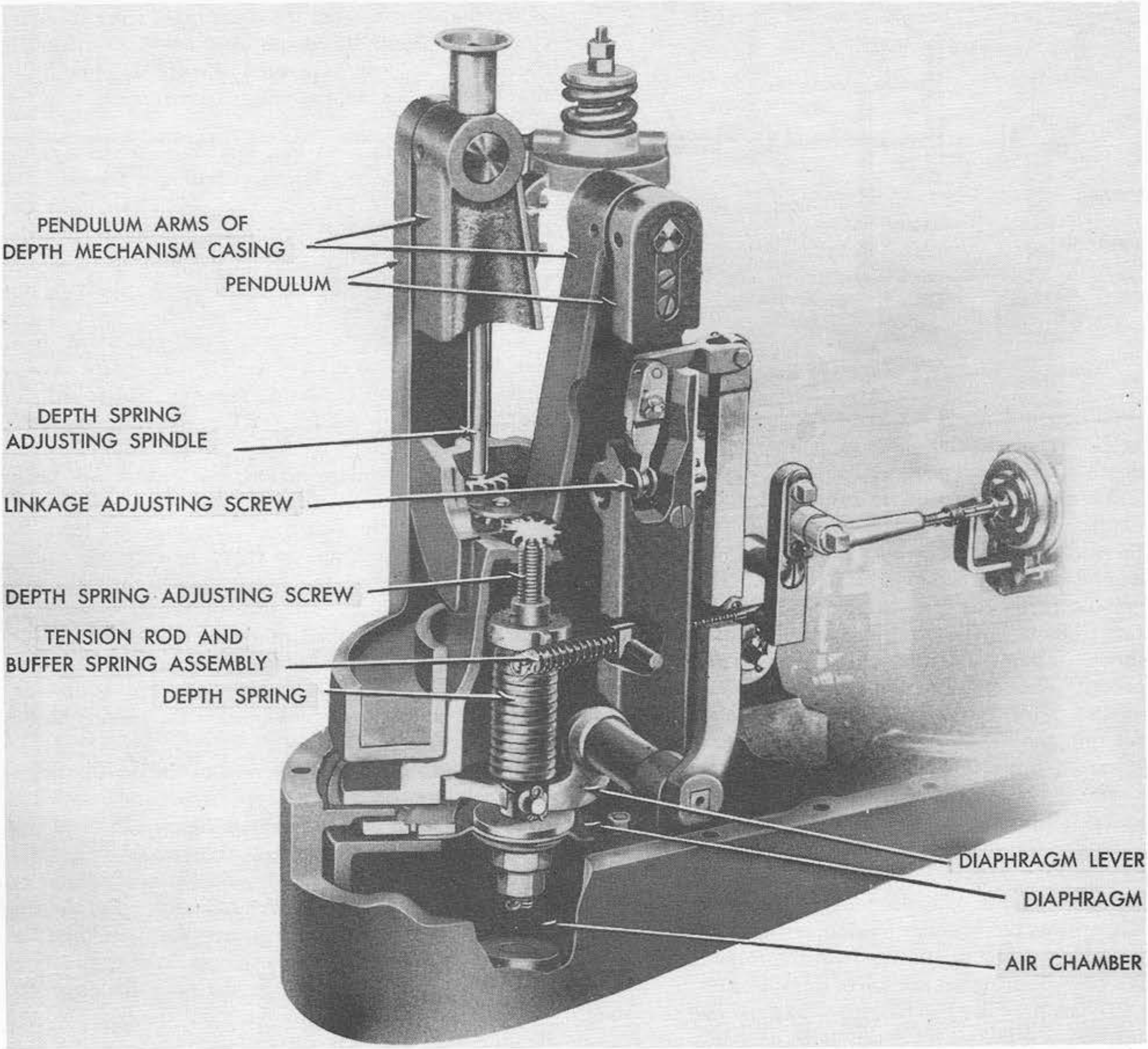


FIGURE 12F8.—Depth mechanism, partially cut away.

ports the after end of the forward propeller shaft. The after propeller shaft turns, in a bronze bushing, inside the forward propeller shaft. The forward propeller sleeve (B in figure 12G1) is keyed to the forward propeller shaft and secured to it by screws. The after propeller sleeve (C) is secured to the after propeller shaft in the same way.

The forward propeller sleeve turns in the tail bearing (F). The after propeller sleeve turns in four bronze bushings (R) inside the forward sleeve. The grease reservoir shell (S) holds a supply of grease inside the after propeller sleeve. When the torpedo is under way, the hot exhaust gases melt the grease in the reservoir. Centrifugal force pushes the melted grease through small passages in the propeller sleeves, to lubricate the bushings (R) and the tail bearing (F).

The forward propeller hub (G) is keyed to the forward propeller sleeve. The forward propeller nut screws onto the sleeve to hold the propeller in place. Locking screws keep the nut from working loose. Half of each locking screw is in the nut, and half in the propeller. The after propeller hub (J) is an integral part of the after propeller sleeve. Except for that, the mounting of the after propeller is the same as that of

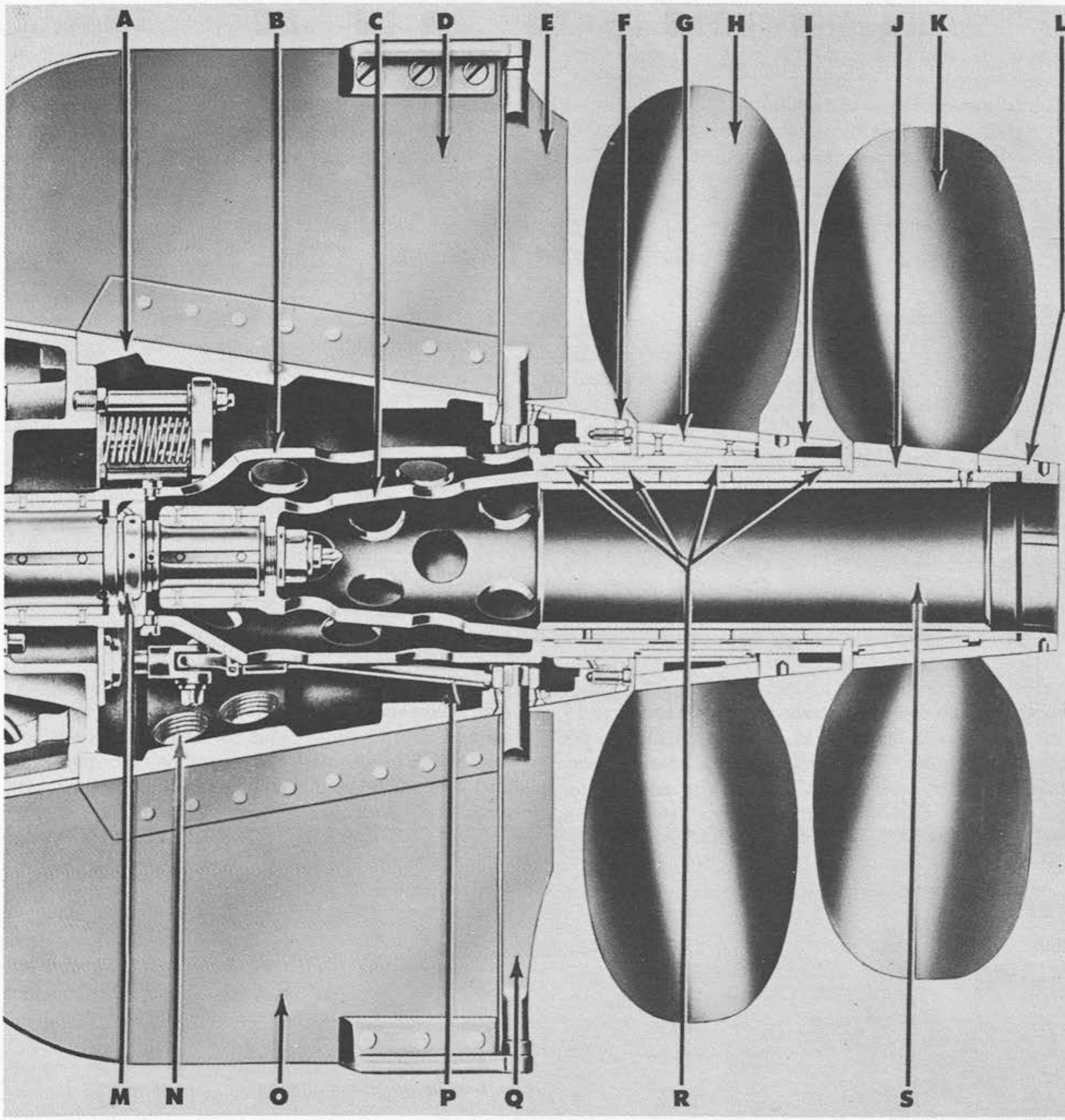


FIGURE 12G1.—Cutaway view of the tail section: (A) tail cone; (B) forward propeller sleeve; (C) after propeller sleeve; (D) vertical blade; (E) steering rudder; (F) tail bearing; (G) forward propeller hub; (H) forward propeller; (I) forward propeller nut; (J) after propeller nut; (M) grease retainer ring for forward propeller sleeve; (N) drain and access hole; (O) vertical blade; (P) steering rudder adjusting rod; (Q) steering rudder; (R) propeller sleeve bushings; (S) grease reservoir shell.

the forward propeller. Each of the 2 propellers has 4 blades.

The exhaust gases pass through openings in the after bulkhead of the afterbody, and enter the tail through exhaust valves. (One of these valves is visible in figure 12G1.) Springs in the exhaust valves hold them shut, except when the pressure of exhaust gases forces them open. The exhaust valves thus keep water out of the afterbody at the end of an exercise run, and when the torpedo is in the flooded tube of a submarine. When the torpedo starts, pressure builds up in the exhaust tubes and pushes the valves open. The exhaust gases then flow into the tail, into the propeller sleeves through the holes in their forward ends, and out to the sea.

The four tail blades are riveted to projections on the outside of the tail cone. They stabilize the torpedo as it travels through the water. The two pairs of rudders are mounted at the after edges of the tail blades. Each rudder turns in an inner bearing on the tail cone, and an outer bearing screwed to the tail blade. These outer bearings have a double purpose. Their outer edges serve as bearing surfaces to guide the tail as the torpedo slides through the torpedo tube.

H. Aircraft Torpedoes

12H1. Construction and use

Aircraft torpedoes came into common tactical use during World War II, as alternate weapons to aircraft bombs for use in attacks on surface ships. Torpedo attacks, however, ordinarily are not made against well-defended units, unless supporting attack is made simultaneously by other types of planes to divide the enemy antiaircraft fire. When properly employed, torpedo attack may force enemy ships to maneuver into an unfavorable position with respect to a main attack delivered by own ships, or accept the penalty of torpedo hits.

Aircraft torpedoes must be able to withstand heavy water impacts. They must also be capable of maintaining stable flight from plane to water, and a stable course through the water to the target. The Mark 13 torpedo, shown in figure 12H1, is one of the older types still in service use. It is similar to the Mark 15 torpedo but differs in certain details of size and design, including the incorporation of special stabilization elements necessary for effective launching from aircraft.

An aircraft torpedo usually is suspended between two racks, which have suspension cables running between them and around the torpedo. A small stop bolt, projecting downward from the plane into a hole in the torpedo casing, serves to prevent fore-and-aft slipping of the torpedo in its cables. When one end of each cable is released, the torpedo falls away.

12H2. Mark 13 torpedo

The Mark 13 torpedo differs from the Mark 15 torpedo in the following ways:

1. The Mark 13 torpedo has better provision for air stabilization, being much shorter and slightly larger in diameter. It is 13 feet 5 inches long, and 22.42 inches in diameter.
2. The Mark 13 torpedo has greater capacity for withstanding water impact.
3. The Mark 13 torpedo contains a smaller explosive charge: 600 pounds of HBX.
4. The Mark 13 torpedo has a shorter designed range: 5,700 yards.
5. The Mark 13 torpedo has a single speed: 33.5 knots.
6. The Mark 13 torpedo has a water trip *delay valve* to prevent ignition until the torpedo enters the water.
7. The Mark 13 torpedo has a *shroud ring* around its tail vanes, which tends to minimize hooking and broaching upon water entry, and makes for greater stability during the water run.
8. The Mark 13 torpedo is rigged for launching with a box-shaped plywood *stabilizer* fitted over the fins and shroud ring. This stabilizer causes the torpedo to fall in a smooth curve, and to enter the water head first. The stabilizer breaks up on impact with the water. A parachute drogue stabilizer has been designed as a substitute for the box stabilizer.
9. The Mark 13 torpedo has a *drag ring*, in the form of a plywood tube open at each end, fitted over its head. The drag ring slows the torpedo's rate of fall, tends to reduce wobbling, and acts as a shock absorber on water impact. The stabilizer and drag ring are shown in figure 12H2. This drag ring is not used when the torpedo is rigged with a parachute stabilizer.

Near the after end of the torpedo is a starting lever. When the torpedo is installed on the plane, a toggle is hooked to this lever and is attached to the aircraft by a lanyard. When the torpedo is released, action of the lanyard and toggle trips the starting lever, but a water trip delay valve serves to prevent the combustion flask from lighting off until water entry. A gyro-locking mechanism is also provided. When the torpedo is installed on the plane, the gyro is locked with its axis parallel to the axis of the plane. The gyro begins to

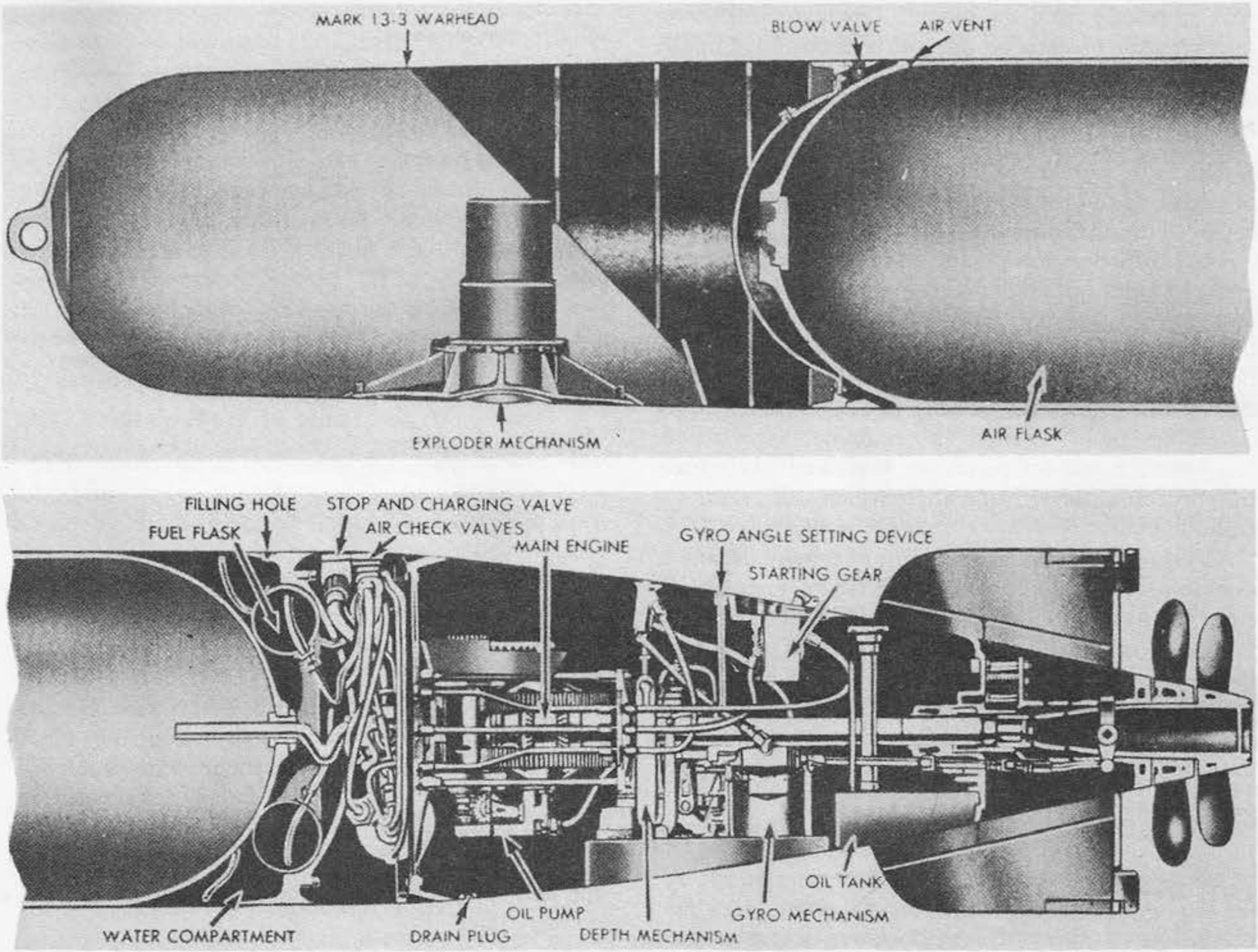


FIGURE 12H1.—The Mark 13 torpedo.

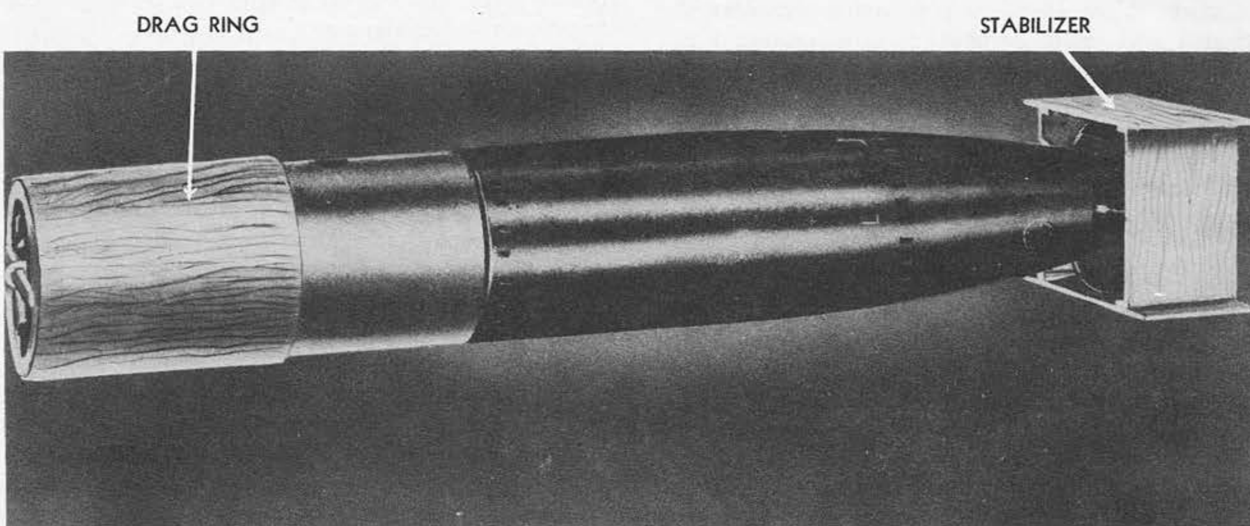


FIGURE 12H2.—Stabilizer and drag ring installed on Torpedo Mark 13.

spin on release from the plane. The gyro will therefore keep the torpedo on the course determined by the direction of aircraft travel at the instant of release.

12H3. The aircraft-torpedo problem

The basic problem in launching a torpedo from an aircraft is to put the torpedo in the water on a collision course with the target. Although improvements in aircraft torpedoes have made launchings possible from greater altitudes and at longer ranges, speed and mobility of attacking planes simplify the problem to the extent that experienced pilots can obtain satisfactory accuracy without the use of special computing gear. The pilot must be able to (1) estimate target angle (see figure 12H3), (2) estimate target speed, (3) estimate and utilize proper lead, and (4) release the torpedo at the sighting angle which will produce a collision course.

Speed of the plane at the point of release usually is established by doctrine, to ensure that the torpedo will enter the water at an angle between 20 and 33 degrees, and not deep-dive or ricochet. When the plane has a speed in excess of 150 knots, and the water is at least 150 feet deep, an entrance angle of 26 to 30 degrees is preferable. The torpedo will assume its preset running depth (up to 50 feet) after water travel of 300 yards; the exploder mechanism is armed after water run of 200 yards.

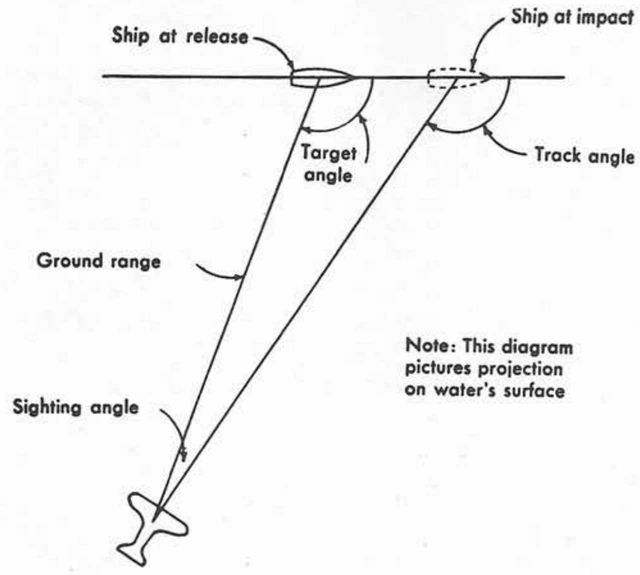


FIGURE 12H3.—The aircraft-torpedo problem.

In recent years lightweight directors have been developed for aircraft installation; their use greatly simplifies practical solution of the torpedo problem.

I. Other Types of Torpedoes

12I1. General

All United States Navy gas-steam torpedoes are similar in principle to the Marks 15 and 13 described above. Electric torpedoes differ from the gas-steam type in respect to their main power plants, as described in article 12I3. In all the nonhoming torpedoes, the steering and depth mechanisms are similar, if not exactly the same. And war heads and exercise heads, although they differ in size, are basically similar.

For these reasons, the discussion of other types of torpedoes will be brief, and will deal primarily with the features that distinguish them from the Mark 15 type.

12I2. Torpedoes Mark 14 type and Mark 23 type

These torpedoes are only 20½ feet long, to fit in submarine tubes. The Mark 14 has two speeds. The low-power setting will give a range of 9,000 yards at approximately 32 knots, and the high-power setting, a range of 4,500 yards at 46 knots. Its war head contains about 700 pounds of high explosive.

There are no side-gear assemblies in the main engine of this torpedo. The two speed settings are obtained by changing the number of nozzle jets in use (two for low speed, five for high) and by altering the size of the restrictions in the air, fuel, and water delivery lines.

The Mark 14 torpedo has a governor whose function is to stop the torpedo, if the starting lever is tripped accidentally, before the engine develops excessive speed, and thereby to safeguard personnel and to prevent serious damage to the torpedo. Centrifugal force actuates the governor, closing a valve in the air line from the starting piston to the low-pressure side of the reducing valve, thus banking the air over the main starting valve and stopping the torpedo's power plant.

The Mark 23 torpedo is a Mark 14 torpedo from which the speed-change mechanism has been removed, leaving all five nozzles open. The restriction valve is locked in high power, and thus the engine can be operated at high speed only.

12I3. Torpedo Mark 18 type

The Mark 18 is an electrically propelled torpedo designed for use in submarines. It is single-speed, designed to run for 4,000 yards at an average speed of about 29 knots. The primary advantage of the Mark 18 is that it is wakeless.

In place of an air-flask section this torpedo has a battery compartment, which contains a lead-acid storage battery, a hydrogen eliminator, and a ventilating system. The battery runs a 90-horsepower series electric motor (located in the afterbody) whose armature is connected by the main drive shaft and gearing to two counterrotating propellers. Compressed air—required to close the starting switch, spin the gyro, and operate the depth and steering engines—is stored at 3,000 psi in three small flasks in the afterbody. The gyro is of "run-down" type. After the initial spin the air is shut off and the gyro is unlocked; the gyro wheel continues to spin of its own momentum. The war head contains about 600 pounds of high explosive.

1214. Torpedo Mark 16 type

The Mark 16 is a single-speed 21-inch by 21½-foot submarine torpedo. It is a gas-steam torpedo in which hydrogen peroxide (NAVOL), instead of compressed air, supplies the oxygen required for combustion of the fuel. This use of NAVOL rather than air allows the Mark 16 torpedo to carry as much explosive as the Mark 15 and to have greater high-speed range, while not exceeding the Mark 14 in size.

The head section of this torpedo is similar to that of the Mark 15. The second or flask section contains a small compressed-air flask, a fuel (alcohol) tank, a water compartment, and a NAVOL tank—the last completely surrounded by the water tank. The main engine, valves, and control devices are located conventionally in the midship section and afterbody.

The source of the oxygen and of part of the water for the combustion cycle of these torpedoes is the NAVOL, which is a solution of hydrogen peroxide (H_2O_2) in water. Hydrogen peroxide, passing through a chamber containing a catalyst, decomposes with evolution of heat, to form water (steam) and oxygen. The oxygen unites with the fuel (alcohol) in the combustion pot, combustion being initiated by an igniter of conventional type. The resulting hot gases mix with steam and drive the main-engine turbines. Part of the steam comes from the breakdown of the H_2O_2 and part from additional water from the water compartment which is sprayed into the combustion pot to control the temperature.

By using NAVOL, the torpedoes require no air except (1) to force fuel, NAVOL, and water from their storage compartments to the combustion flask, (2) to drive the gyro, and (3) to operate the steering controls. As no air is fed to the combustion pot, no nitrogen is present in the exhaust to rise to the surface and leave the customary wake. There is, however, a small amount of nonsoluble gas resulting from the combustion of alcohol, which is forced out of the exhaust, leaving a very small wake that is practically invisible except in flat, calm water.

The main engine is a turbine with reduction gearing, similar in principle to the engine in a Mark 15 torpedo, but differing radically in mechanical detail. The turbine axis is horizontal instead of vertical, for which reason this engine is referred to as a "horizontal" or "H" engine, and spur gears rather than bevel gears are used for speed reduction.

1215. Electrically set torpedoes

In the torpedoes described above, the gyro angle and running depth are ordinarily set mechanically, by inserting a spindle into the setting socket and turning it. Mark 14 and Mark 15 torpedoes have an additional socket for the speed setting. Obviously, all spindles must be withdrawn from their sockets before the torpedo can be fired.

In several modifications of the torpedoes mentioned above, and in practically all homing torpedoes, the settings are made electrically, rather than mechanically. A multi-conductor cable enters the breech of the torpedo tube, and is connected by a plug and socket to a similar cable that enters the afterbody of the torpedo. When the proper electrical inputs are supplied through the cable, servomechanisms in the torpedo automatically set the proper depth and gyro angle (and make the proper speed setting if the torpedo has a speed-change mechanism). At the instant of firing, the cable is automatically cut off close to the torpedo.

The electric setting system has several advantages. Its settings are relatively exact, and it eliminates several sources of error inherent in the mechanical setting system. Electric settings can be made right up to the instant of launching, since the cable is not cut until *after* the torpedo begins to move forward in the tube. And the electric setting system can easily be integrated with the advanced fire control systems, so that the setting signals are supplied automatically.

Except for the short length of cable that protrudes from the afterbody, an electrically set torpedo is identical in external appearance with mechanically set torpedoes of the same mark number.

1216. Homing torpedoes

The torpedoes described above are designed to take up the course set on their gyro mechanisms, and then run in a straight line. Homing torpedoes can also follow a gyro course. In addition, a homing torpedo can search for a target, and, when it finds one, chase it until it secures a hit. Some types can switch back and forth between gyro control, search pattern, and homing control, as appropriate. Several types of homing torpedoes are now in the Fleet, and others are in various stages of development. For security reasons, only a short and very general discussion can be given here.

At present, homing torpedoes are *acoustic* (operated by sound). In general, they are of two types—*active* and *passive*. The active type sends out short pulses of sound, and "listens" for echoes from the target. When an echo is detected, the torpedo steers itself toward the source of the echo. The passive type merely listens for target sounds (such as propeller and machinery noises), then steers itself toward the source of the sounds.

The homing torpedo has the same safety devices as the air-steam type described above. Its exploder is armed both mechanically and electrically, and remains safe until the torpedo has traveled a safe distance from the firing ship. The homing mechanism also has an arming feature, so that it remains inoperable (with the torpedo on a gyro course) until the torpedo has traveled through a preset distance. One or more additional safety features not found in nonhoming torpedoes are present in all homing torpedoes.

Homing torpedoes, almost without exception, are powered by electric motors and batteries. In shape and external appearance they are quite similar to the nonhoming torpedoes already described. Several types are somewhat smaller than air-steam torpedoes, in length, diameter, or both. And several types have a single propeller, rather than two.

J. Above-Water Torpedo Tubes

12J1. Function

Torpedo tubes serve the following purposes:

1. House and protect the torpedo (including heating in cold weather) until the instant of firing.
2. Provide means for setting torpedo gyro angle, running depth, and, where required, torpedo speed as necessary, up to the instant of firing.
3. Expel the torpedo with sufficient force to clear the firing ship and with such velocity and direction that it will remain on its firing course until its engine develops enough power for self-propulsion.
4. As expulsion starts, trigger the torpedo so as to start its engine and gyro.

These functions apply to submarine tubes as well as above-water tubes. Since, however, the former must also serve as pressure members of the ship's hull, they incorporate additional features which are not suitable for discussion in this textbook.

12J2. Type and location

Above-water tubes may be classed as *trainable* or *fixed*. Until afterWorld War II, United States Navy destroyers and destroyer escorts armed with torpedoes all carried trainable tubes. Destroyers mount either the Mark 14 or the Mark 15 quintuple tubes. The two types are substantially identical, except that the latter was designed to accommodate a blast shield for the protection of personnel from the blast of adjacent guns. Trainable tubes require large clear deck areas, and in all ships retaining torpedoes they are mounted topside on the ship's centerline as shown in figure 1B2. From this location torpedoes can be fired through limited arcs of train on either side of the ship.

In the latter phases of World War II the necessity for increasing antiaircraft armament put a high premium on topside deck space. New destroyer and escort designs have therefore featured above-water torpedo tubes in locations other than weather deck. Such tubes are housed and fixed (*i. e.*, nontrainable). With fixed tubes greater gyro angles must be used in firing than from trainable tubes; and, since torpedoes tend to depart more widely from their predicted courses when fired with large than with small gyro angles, this is a disadvantage. Also, tubes must be carried on both sides of the ship. However, the weight gained by eliminating the training gear, pivots, *etc.*, provides a partial compensation. The interior location permits all tubes to be located in the same compartment of the ship, in which reload torpedoes and quick-reloading gear may also be carried. Fixed tube designs include the Marks 23 and 24.

12J3. 21-inch Above-Water Torpedo Tube Mark 14

Each Mark 14 torpedo tube consists of five *barrels*, supported in a single *saddle* which functions like the carriage of a gun except that no provision is made for elevating the barrels. The saddle rests on a roller bearing assembly supported by a stand. The stand, like that of a gun, contains a training circle. The tube is normally trained by an electric-hydraulic drive, similar to a gun mount train drive and controlled by the operation of the training handwheels on top of the mount. Provision is made for manual train in case of power-drive failure. See figure 12J1.

Each barrel is an assembly of a *main barrel*, a *spoon*, and a *spoon extension*. The main barrel is cylindrical in shape, but the spoon and spoon extension are open on the under side. The spoon extension is hinged at the top, so that it can be folded back along the spoon to save deck space. Within the barrel,

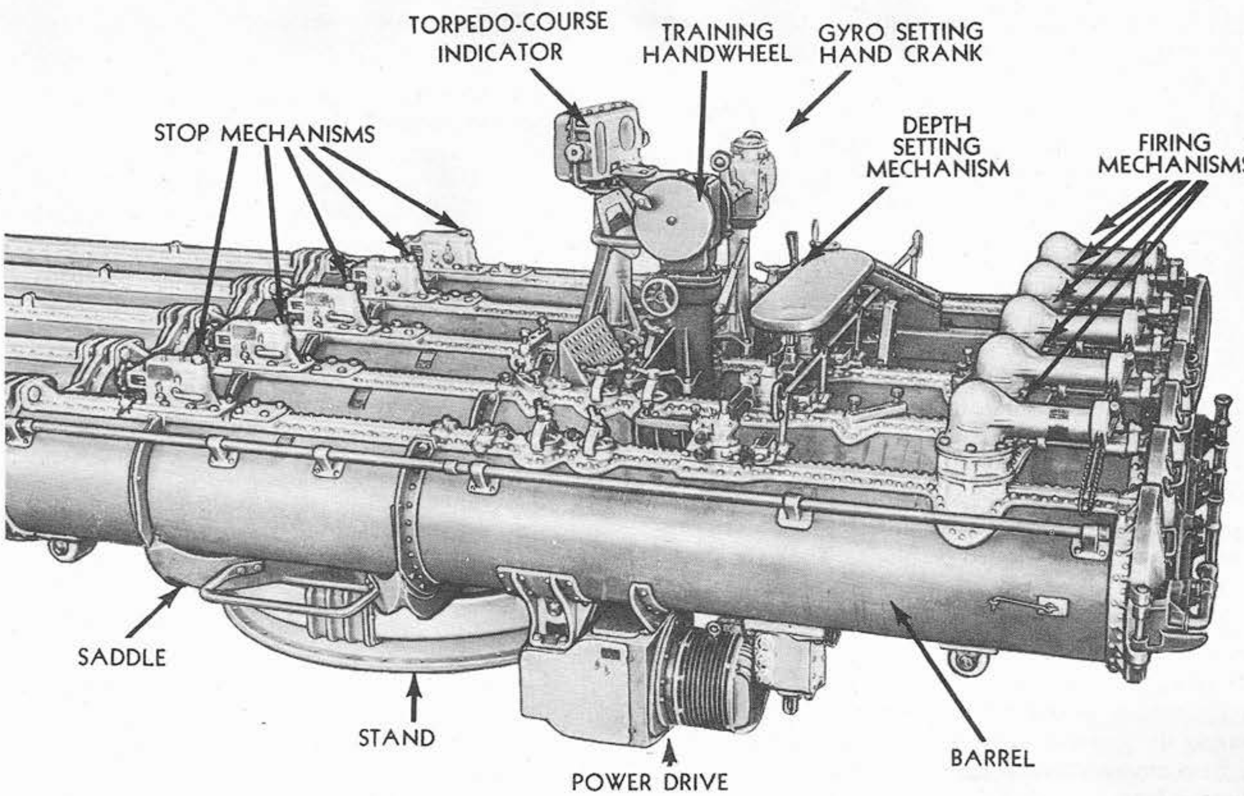


FIGURE 12J1.—21-inch Above-Water Torpedo Tube Mark 14.

at the bottom, are rollers which facilitate loading the torpedo. Running the length of the top of the barrel to the end of the spoon extension is a T-shaped guide slot. The *guide stud* on the torpedo rides in this slot as the torpedo is fired. The stud prevents the torpedo from dropping downward before the tail has cleared the main barrel, thereby preventing damage to the tail assembly and helping to keep the torpedo horizontal as it is launched.

The breech end of the barrel is closed by a *door,* so flanged and sealed that it will hold the pressure developed by the impulse charge in launching the torpedo.

Torpedoes are expelled from each barrel individually by an impulse charge fired in the *firing mechanism* on top of the barrel. A passage from the firing mechanism leads to the space between the door and the torpedo. Normally, charges are fired electrically from the bridge, but they can be fired by percussion at the tube if necessary. Each black-powder impulse charge is contained in a special 3-inch case about 13 inches long.

A torpedo stop is employed to keep the torpedo from sliding in the barrel. The stop is bolted to the T-guide of each barrel. It incorporates a back and a front stop, between which the torpedo's guide stud is gripped. After the torpedo is loaded, a *tension link* is placed in the housing to hold the front stop in position. When the torpedo is fired, the tension link parts and the front stop swings out of the way of the guide stud.

Also mounted on the T-guide of each barrel is the *tripping latch.* It projects into the barrel and engages and trips the starting lever of the torpedo as it begins to move forward in the barrel. As stated in article 12C10 this is essential in order to start the torpedo power plant.

Atop the barrels are a seat for the trainer and gyro setter, the train controls, and the sight and fire control apparatus. Also on top of the barrels, and thus within easy reach of the crew, are the gyro-setting, depth-setting and speed-setting mechanisms. The barrels also have covered openings which permit access to the torpedoes for fueling, air charging, and other maintenance routine.

12J4. Torpedo-setting mechanism

The depth-setting mechanisms, located on top of the barrels, are arranged to set the five torpedoes simultaneously with the same depth setting. A depth-setting hand crank operates through gears and shafts to turn depth-setting sockets in each barrel, at the same time turning a dial index which shows the depth set. A socket-engaging lever moves the socket of each barrel into engagement with the depth-setting spindle of the torpedo; sockets are usually engaged well in advance, so that there may be assurance that the sockets and spindles align properly. They must be disengaged before firing.

The speed-setting mechanisms of the barrels are separate. Each consists of a permanently mounted wrench protruding upward from a cylindrical housing within which is a spring that holds the spindle up out of engagement with the torpedo's speed-setting socket except when the wrench handle is pushed down by hand, and a cam that allows the wrench to spring up only when properly positioned at the HIGH, INTERMEDIATE, or LOW speed position. The wrench and spindle must never be left in the down position.

The gyro-setting mechanism provides a means for:

1. Setting the gyros of the torpedoes in all five barrels to any desired basic gyro angle.

2. Setting any desired spread up to 10 degrees; *i. e.,* setting the gyros of torpedoes in the wing barrels and right-center and left-center barrels so that they will diverge from the course of the torpedo in the center barrel by the desired amount.

3. Engaging the gyro-setting spindles in the sockets of the torpedoes, and withdrawing them, at will.

Two separate handcranks are used, one for setting the basic gyro angle and the other for making spread-angle setting. They work together through a differential at each tube to set the proper resultant angle on each torpedo. The angles set are shown on the dials of the gyro-setting mechanism; basic gyro angle shows also on the dials of the torpedo course indicator, which is described in volume II. Spindles must be disengaged before the torpedoes are fired.

12J5. Torpedo tube sight and torpedo course indicator

The trainer and the gyro setter are guided in determining the proper firing course for the torpedoes, either by the torpedo tube sight (in local control) or by the dials of the torpedo course indicator (in remote control). Since an understanding of either of these instruments presupposes a comprehension of the torpedo fire control problem, they are discussed in volume II.

12J6. 21-inch above-water torpedo tubes Marks 23 and 24

Figure 12J2 represents a single-barrel fixed-type nontrainable torpedo tube designed to mount singly or in groups of two or more on each side of a vessel. The tubes are mounted athwartship within the superstructure, with muzzles extending through the sides of the deck house. The tubes are constructed of a light-weight aluminum alloy. They are air-fired and are suitable for launching only torpedoes having electrically set torpedo controls. The breech and muzzle doors are so interlocked that firing can occur only when the breech door is closed and locked and the muzzle door opened. The torpedo control cable enters the tube through a special electrical terminal plug mounted in the breech door. The door connector is in two parts. One part is permanently installed in the center of the door, while the inner half is affixed to the torpedo cable. The two halves are coupled together after the torpedo is loaded into the tube. The cable is cut by the forward motion of the torpedo at launching. Torpedo Tube Mark 23 is designed to launch 21-inch torpedoes with a length not exceeding 161 inches. Torpedo Tube Mark 24 is designed to launch 21-inch torpedoes with a length not exceeding 246 inches. Both tubes are supplied with adapter rings which can be installed so as to permit launching a 19-inch diameter torpedo.

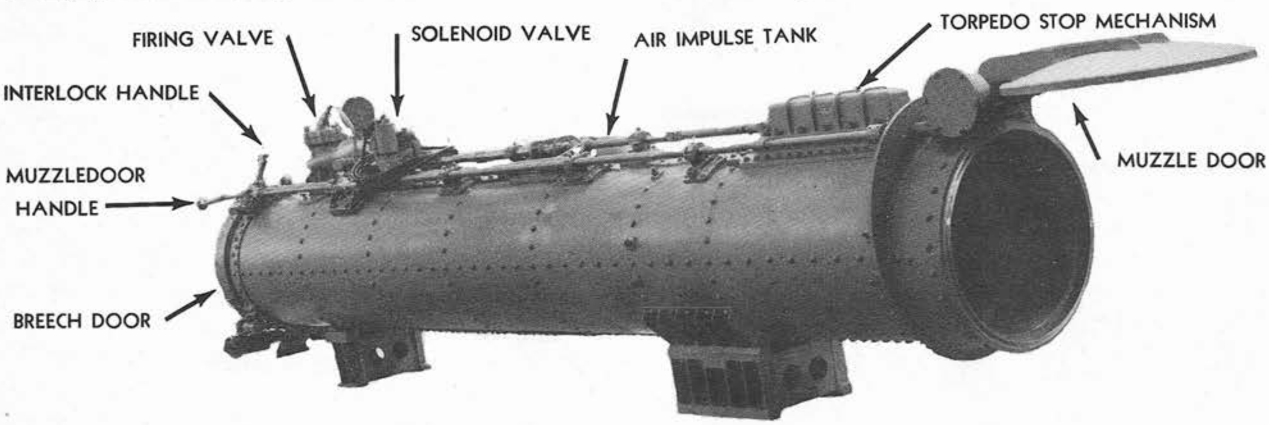


FIGURE 12J2.—Fixed above-water torpedo tube.

Chapter 13

MINES

A. General

13A1. Naval mines defined

There are two general classes of military mines: land mines, under Army cognizance, and sea mines, under Navy cognizance. This chapter is concerned with sea (or naval) mines only.

Navy mines are thin-cased underwater weapons with a heavy load of high explosives—usually either HBX, HBX–1, or TNT. Mines are actuated when touched or closely approached by a ship. An actuation can have 1 of 4 results, as follows:

1. The mine, especially if it is one of the older types, may explode almost immediately.

2. The mine may explode after a short delay that gives the target ship time to reach a more vulnerable position.

3. The actuation may be registered by a ship-counting component that prevents explosion until a predetermined number of actuations have been counted.

4. In a controlled mine field, the actuation of a mine energizes indicating devices at a shore station, but does not result in an explosion unless a return signal is sent to the mine from shore.

13A2. Classes of naval mines

Broad classification. All naval mines fall within 1 or the other of 2 broad classes—independent and controlled.

All old mines and many new ones are the *independent* (sometimes called the *automatic*) type. Once planted and armed, the independent mines can be actuated by the presence of a ship, without any human intervention. They are incapable of discriminating between hostile and friendly vessels. Until they have been made harmless—either by incorporated self-destructive features or by sweeping—independent mines are a threat to all vessels approaching the area.

In contrast to independent mines, *controlled* mines have an electrical system connecting them to a shore station. Signals from approaching or passing ships are transmitted to shore over this electrical system. Depending on the military situation, the personnel at the shore station may merely observe the signals, may detonate a given mine by answering its warning with a return signal, or may set the equipment to return the firing signal automatically.

Other classification methods. The broad classification system described above is cut across by three other methods of classifying mines; namely by method of planting, by position after planting, and by type of firing mechanism. The paragraphs following will explain these three classification systems.

1. *By method of planting.* Mines may be laid from surface craft, from submarines, or from aircraft.

When secrecy is not a prime consideration, mines may be planted from specially designed minelayers or from certain other *surface craft*. By working as a team, surface vessels can lay a large field in a short time. Controlled fields are planted by surface craft, as are many of the defensive fields containing independent mines.

When secrecy is supremely important, *submarines* can carry mines great distances from home ports. Submarines may also launch mobile mines—usually called torpedo mines—into the fringes of established fields or into enemy-held waters.

When extensive mining operations are to be conducted in enemy-held waters, when large defensive fields are to be replenished, or when shallow inland waterways are to be mined, *aircraft* planting is usually most efficient. The airplane has the advantages of speed and maneuverability, but it sometimes has the disadvantage of being easily seen and fired upon by the enemy.

2. *By position after planting.* When classified according to the position they assume in the water, mines fall again into three groups. These are bottom mines

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(formerly known as ground mines), moored mines, and drifting mines.

Its large amount of negative bouyancy brings the *bottom* mine to rest on the ocean floor and keeps it there. Bottom mines are most effective in comparatively shallow waters. If a bottom mine is planted in very deep water, surface vessels may pass over it without actuating its firing mechanism, or, in event of an actuation, without suffering much damage. Of course a bottom mine planted in deep water may still be effective against submarines. Bottom mines are used in controlled fields, but are by no means limited to that use.

The explosive charge and firing mechanism of a *moored* mine are housed in a positively buoyant case. A cable or chain, attached to a negatively buoyant anchor that rests on the sea bottom, holds the case at a predetermined depth beneath the surface.

The *drifting* mine floats freely, at or near the surface. It has no anchoring device, and its buoyancy is approximately neutral. The depth at which this mine travels is determined by one of three methods: by suspending the mine from a small float, by incorporating a mechanical depth-control device, or by attaching a cable or chain that drags on the bottom in shallow water.

3. *By type of firing mechanism.* There are two main classes of mine-firing mechanisms: the contact type and the influence type. The influence type is the newer one. Each type is represented by three distinct classes. The next few paragraphs will explain the terms used in this system of classification.

Actuation of a *contact* mine takes place only when a target ship actually touches the mine or one of its sensitive components. The required contact point may be the mine case, a horn, an antenna, a snag line, or a protruding arm, depending on the particular characteristics of the mine involved. Contact firing mechanisms may be further classified as electrochemical, galvanic, or mechanical.

Electrochemical contact mines have fragile protruding horns, each one of which contains a glass vial of acid. When any horn is struck forcibly, its vial breaks. Then the acid supplies the electrolyte to the plates of a battery cell that generates sufficient current to fire the detonator.

The *galvanic* type of contact firing mechanism employs the current drawn from a *sea battery* formed by the immersion of two dissimilar metals in sea water (a weak electrolyte) to fire the mine. The metals normally used are copper and steel. The copper is in the firing mechanism; the steel is either in the target hull or in a mine component that requires a blow from a target hull to place it in a closed electrical system with the copper.

The earliest galvanic contact devices were horns assembled to the mine case. In the Mark 6 type of moored contact mine, the contact area of this type of firing mechanism has been increased considerably by the addition of an antenna or sometimes a pair of antennas, the second of which doubles as the upper part of the mooring cable. Horns on the float that streams the upper antenna also act as contact devices.

The *mechanical* type of contact firing mechanism is usually triggered by the inertia of impact, or by the mechanical movement of a protruding horn, arm, or bridle. The contact area of this type of mechanism is sometimes increased by the use of snag lines. Mechanical-type firing mechanisms are not extensively used by the United States Navy.

The nearby presence of a ship, rather than actual contact, is all that is necessary, under certain conditions, to actuate an *influence mine*. The three classes of influence firing mechanisms are the magnetic, acoustic, and pressure types.

The actuating influence in a *magnetic* firing mechanism is the magnetic effect of a cruising steel ship.

The *acoustic* mechanism responds to the underwater sound waves set in motion by the normal noises of a cruising ship.

A ship in motion creates an area of reduced or negative underwater pressure, to which the *pressure* mechanism responds.

In actual practice, a number of mines contain 2 of the 3 types of influence devices. Others may contain an influence feature and a contact one.

If contact or influence features are combined with a control feature, the two may be independent of each other, or control may be exercised to render a given mine *safe* or *dangerous* at the will of the control station.

13A3. Major components

The major components of a mine are the case, the explosive filler, the anchor (if one is used), and the firing mechanism with its accessories.

The mine case provides a watertight compartment for the main charge and the firing mechanisms. The main charge is cast into the main compartment, and for bottom mines will fill most of it. For moored or drifting mines, the case must be large enough to provide the proper amount of air space for buoyancy. Smaller compartments within the case house and secure the batteries, firing mechanism, and various accessories.

Mine cases are usually made of steel, but a nonferrous metal is required when certain influence firing mechanisms are to be used.

Anchors for the various moored mines naturally differ in size, shape, and method of operation. All must be capable of mooring the mine at a preset depth below the surface. For ease in handling, the anchor is assembled integrally with the case. Aircraft- and submarine-laid moored mines have the anchor secured firmly enough to the case to allow the mine to be lifted by either end or by a strap in the middle.

The operation of the anchor assemblies during planting of a typical moored mine is illustrated in figure 13A1. Note that this surface-laid assembly has a net positive buoyancy until the mine and case are separated, flooding the anchor. Conversely, aircraft-laid or submarine-laid assemblies, which are employed in offensive mining operations in enemy waters, have a net negative buoyancy and never reach the surface after planting. The submarine-laid assemblies sink to a minimum depth of 65 feet, and further incorporate a few seconds of delay before separation of case and anchor.

Most of the standard naval mine cases will accommodate a choice of explosive fillers and a choice of the various firing *mechanisms* and *accessories*. Because of this, the mark designation of the mine usually applies only to the assembled case and anchor. On the other hand, a specific modification of a production mine usually designates its explosive filler, firing mechanism, accessories, and the special features which adapt this mine to surface, submarine, or aircraft planting.

13A4. Accessories

The accessories of a mine include a number of units which assist or modify the action of the actual firing mechanism. For example, there are the batteries which furnish the power for the operation of the mine. Some of the accessories are safety devices, while others serve to increase the efficiency of the planted mine.

1. An *extender* is a hydrostatically operated device used to move the mine's detonator into a booster charge. Until the mine has been planted, the extender holds the detonator sufficiently clear of the booster to prevent a premature firing of the detonator from exploding the booster or the mine. After the mine is planted and reaches a certain depth of water, the extender moves the detonator into an envelope

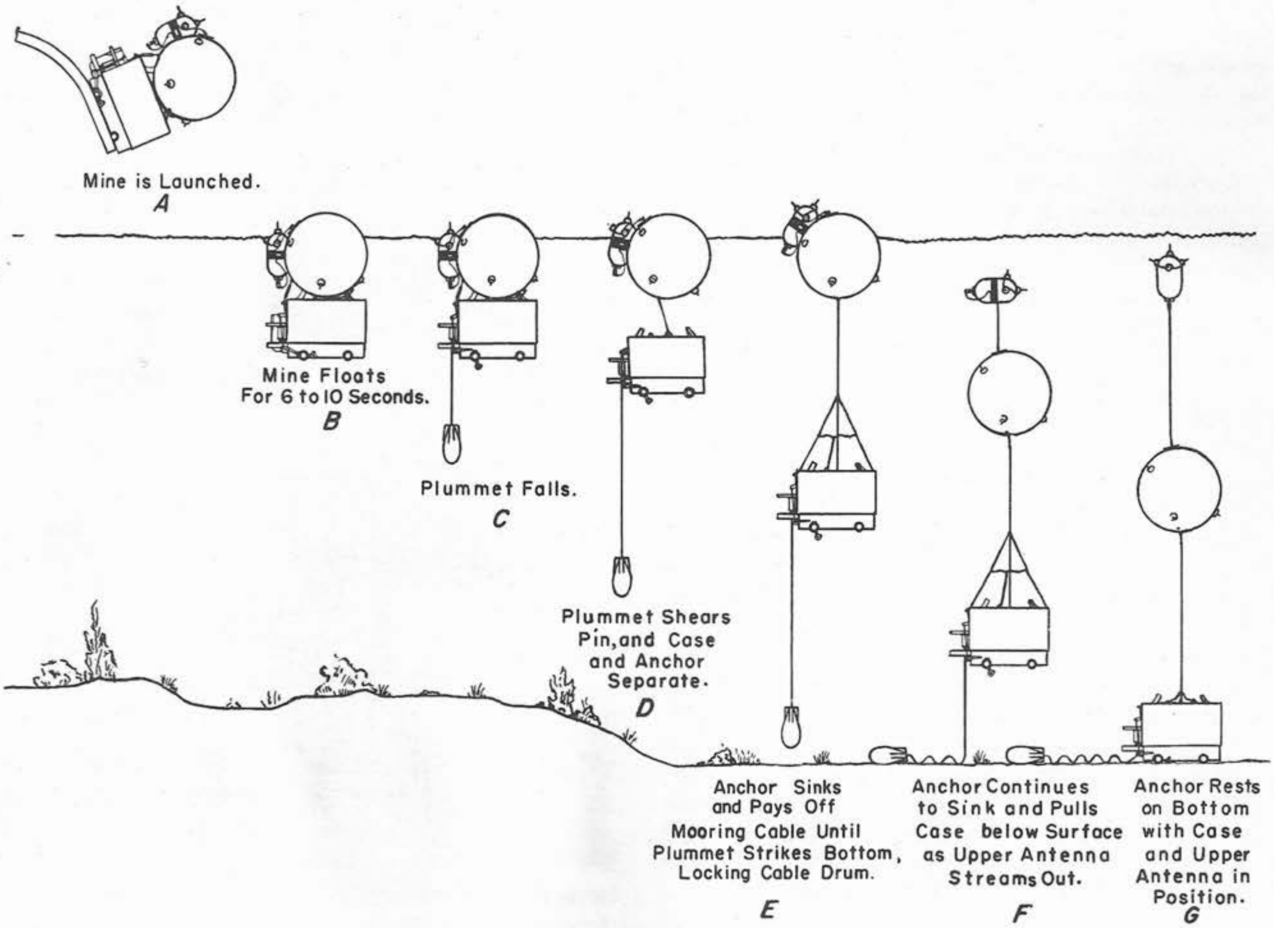

FIGURE 13A1.—Mine Mark 6, planting sequence.

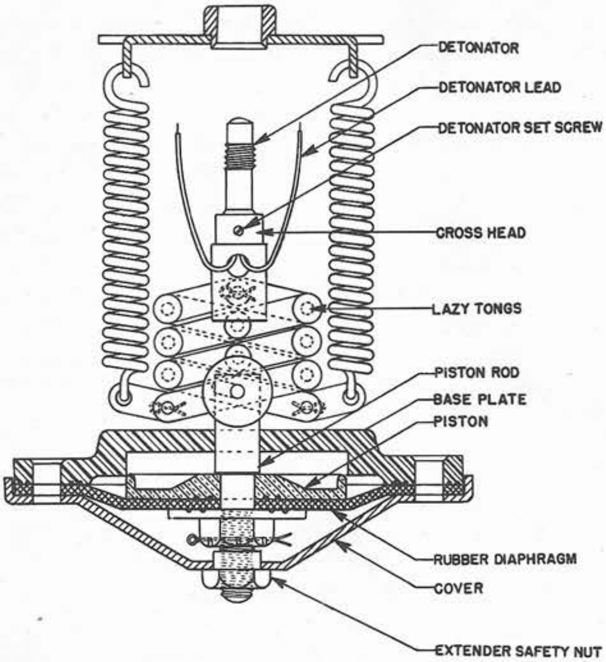

FIGURE 13A2.—Extender mechanism Mark 6 Mod. 2.

in the booster. See figure 13A2. In the extender shown in this figure, the piston rod transmits linear movement of the piston to the lazy-tongs linkage that moves the detonator.

2. A *clock delay mechanism* (CD mechanism) is a device which delays arming of the mine for a preset time after planting. It is basically a spring driven cam that operates electrical contacts or switches. There are two distinct types. One is a hand-wound clock which can be started by the mechanical action of a hydrostatic *clock starter;* the other is a motor-wound clock which can be started by closure of one of the switches of the hand-wound clock which must always be used with it. Figure 13A3 shows where the extender and clock mechanisms are located.

Hand-wound clocks may be set to provide a delay in arming of ½ to 10 days, and motor-wound clocks can provide a delay of 3 to 100 days. In addition, motor-wound clocks have a sterilizing switch, which, if utilized, ends the armed life of the mine 3 to 210 days from the time of planting.

The clock delay employs at least two switches in the process of arming a mine. Closing of the first switch connects the battery to the *firing mechanism.* The second switch closes 3 or more hours after the first one, to complete the circuit from the firing mechanism to the detonator.

3. A *clock starter* (CS mechanism) is a hydrostatically operated device capable of starting or stopping the operation of a clock delay mechanism. See figure 13A4.

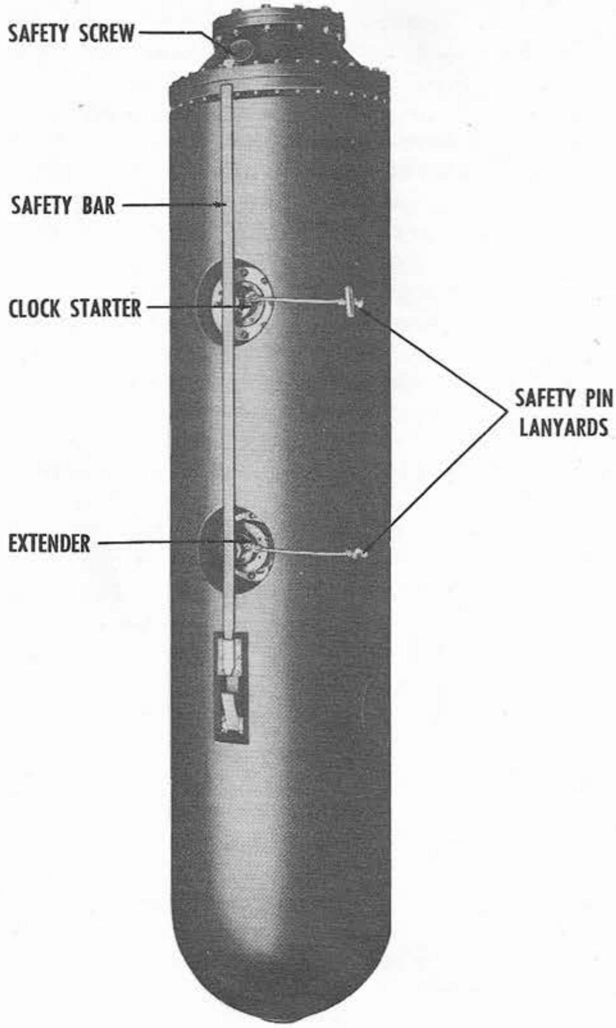

FIGURE 13A3.—Mine Mark 12 Mod 0, showing locations of accessories.

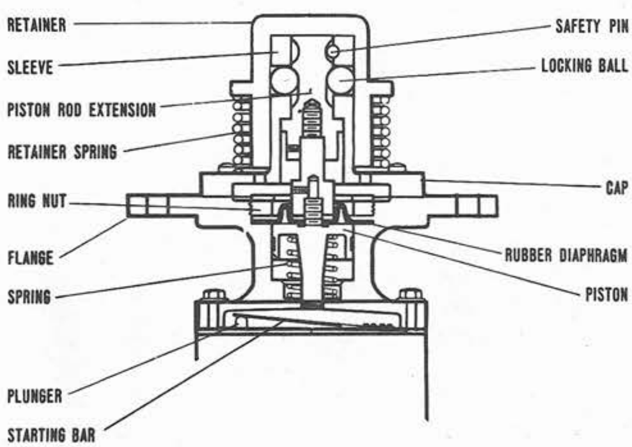

FIGURE 13A4.—Clock starter Mark 1 Mod 0.

Both clock starters and the extender mechanism mentioned earlier employ some positive type of safety device to prevent their operating prematurely. For surface-laid mines, this usually consists of a soluble washer which prevents a spindle attached to the hydrostatic piston from moving inward until the washer has been dissolved by the sea water. Aircraft-laid mines employ an arming wire which must be pulled free of the mechanism. Submarine mines have a positive-locking safety bar which falls free when the mine is ejected from a torpedo tube. They also have a lock-ball safety device which prevents movement of the hydrostatic piston until sufficient depth is reached.

For further safety in handling and stowage, safety nuts are always provided to keep extenders and clock starters in the unarmed condition. These safety nuts must be removed before planting, or the mine will not arm.

4. An *anticountermining device* (AC) is sometimes used to deaden the mine's electrical circuits for a short time following a nearby shock or explosion.

5. *Batteries* used in a mine must provide the voltages and power to operate the firing mechanism and set off the detonator. All naval mine batteries are of the dry-cell type, each composed of several cells arranged in a housing. The life of the batteries in a planted mine is what largely determines the life of the mine itself.

6. A *sterilizer* (SD, for self-destructive, mechanism) is used to limit the armed life of a mine to a predetermined period. At the end of this time it operates, usually to short out the battery. In some instances it may open the detonator circuit. In the case of a moored mine, it may function to fire a sinking detonator which blows out a plug and permits water to enter the case.

Sterilizing switches are sometimes incorporated in a clock delay mechanism. However, the most positive type of sterilizer consists of an electrolytic cell, a resistor, a spring-loaded plunger, and switches associated with the plunger. As current flows through the cell, the anode is electrolyzed away until it is sufficiently weakened for the plunger to rupture the cell. Movement of the plunger closes two normally open switches, shorting out the battery.

When thorough sterilization of a mine field must be sure to be completed by a certain date—for example, to allow passage of our own vessels—two or more sterilizers may be connected in parallel in each mine.

7. A *ship counter* (SE device, formerly called a ship eliminator) is used to delay firing of the detonator until a pre-set number of complete actuations of the firing mechanism have occurred. Thus a number of ships may pass over the mine before it becomes armed. This device reduces the effectiveness of the enemy's countermeasures, and it vastly increases the effectiveness of an offensive mine field.

8. *Microphones* (MI), usually of the crystal type, are used with acoustic firing mechanisms. These microphones must be watertight and extremely rugged in construction. Microphones must be particularly sensitive to sounds in the frequency range for which the associated firing mechanisms are designed.

9. A *search coil* (SC) is used in a magnetic influence mine to detect changes caused in the earth's magnetic field around the mine by the magnetic field of a moving ship. A coil consists of 15,000 to 30,000 turns of fine copper wire wound over a cylindrical core of high-permeability magnetic alloy, such as permalloy. A search coil is always used with a steel mine case, because the steel adds to the effective size of the permeable core.

10. One minor accessory which adds greatly to the ease of assembling a mine and testing its various circuits is the *terminal block* (TB). The circuits, batteries, firing mechanisms, and various other electrical accessories are connected at this block. The block (or the main block, if the mine has more than one) is located just under the main cover leading to the firing mechanism. Thus it is readily available for final electrical tests and for connecting of the detonator leads just before the mine is sealed.

11. Many aircraft-laid mines (see section B) use some sort of *flight gear* to decrease the impact velocity of the mine as it strikes the water. This usually consists of a parachute, parachute pack, and release gear. As the mine strikes the water, the release gear operates, freeing the parachute from the mine case. Parachute and mine will sink free of one another.

13A5. Representative firing mechanisms

Firing mechanisms are the units which are set off by contact with a target ship or which, alternatively, receive a small impulse from the search coil, microphone, or pressure device and send a magnified firing impulse to the detonator. Newer and better firing mechanisms are constantly being designed. The mechanism must, of course, fire the mine when a *bona fide* target goes by. That in itself is simply a problem of amplifying the original signal to an impulse strong enough to trigger the firing circuit. The reason firing mechanisms are so complicated in construction is that they are designed in such a way as to avoid actuation by countermeasures such as minesweeping by the enemy.

Section A of this chapter described contact firing mechanisms in enough detail for the purposes of this course. Influence mechanisms, being more complex, need a somewhat more detailed discussion. The next few paragraphs will take up the three classes of influence mechanisms—namely, the magnetic, acoustic, and pressure types.

1. *Magnetic mechanisms.* Every steel ship has definite magnetic characteristics produced by the permanent magnetism of the ship's hull and the induced magnetism resulting from passage through the earth's magnetic field. A ship's magnetic field may be reduced substantially by using degaussing coils, often in conjunction with the process of *deperming* (neutralizing the permanent magnetism of a ship); but for practical and theoretical reasons it is impossible to eliminate such fields entirely from ships of even moderate size.

Magnetic mine-firing devices are of two general types: *magnetic dip-needle* and *induction.* The actuating unit of the *needle-type* mechanism is a magnetized needle assembly which responds to changes produced in the vertical component of the earth's magnetic field by the proximity of a ship. Once the mine is planted, a very slight movement of the needle may trigger the firing circuit.

The *induction-type* mechanisms employ a search coil and a means of amplifying the signal from the search coil. Some induction mechanisms use a sensitive relay for this purpose. Others have a highly complicated electronic or electronic-mechanical system.

From the above, it will be noted that the needle-type mechanism operates simply upon the magnitude of change in the magnetic field, whereas mechanisms of the induction type may require both magnitude of change and rate of change, two or more actuating pulses (called *looks*) of opposite polarity, or other special conditions. This feature gives the induction mechanism a distinct practical advantage by allowing a wider diversity of selective firing. Induction firing mechanisms can be used in mines with ferromagnetic cases, while needle mechanisms require mine cases of nonmagnetic material (usually aluminum). Induction mines can be made much more sensitive than needle mines.

2. *Acoustic mechanisms.* Acoustic disturbances such as propeller noises, machinery noises, and hull vibration invariably accompany the passage of a ship through the water. The output depends upon several factors such as size, type, and number of propellers, type and speed of engines, condition of loading, character of the bottom, and depth of water. A ship's acoustic signal is therefore variable, and acoustic mines must be designed in such a way as to prevent an intense signal from actuating the firing mechanism at distances well beyond the effective explosive radius of the charge.

Acoustic mines must also be unresponsive to types of underwater sounds that are likely to represent non-target objects—such, for example, as a school of porpoises. Another design requirement is that these mines must not be easily actuated by countermining noises.

Therefore acoustic mines are usually fired by actuating the mechanism when the sound intensity reaches a predetermined value, after building up at a prescribed rate of change. If the incoming sound builds up too quickly, as in the case of an underwater explosion, the mine will inhibit itself from firing by the action of an anticountermining device, and will become passive for a short time. If the sound builds up too slowly, the mine will not respond at all.

The United States Navy has no distinctive acoustic mine, but employs acoustic firing mechanisms as accessories which are designed to be interchangeable with other firing devices in several different mine cases.

3. *Pressure mechanisms.* There is a continuous flow of water from the bow to the stern of a moving ship. As the forward part of the moving ship displaces water, an equal amount must flow to the after part of the ship to restore the displaced water after the ship has passed. This continuous water flow is measurable at considerable distances from the ship, and creates variations in the pressures which normally exist at various depths in the water. The pressure differential becomes more pronounced when the ship is moving in confined waters, such as rivers, but is still appreciable in the open sea, even at considerable depth. The pressure signature of a ship is a function of its speed and displacement and the water depth.

Ocean swells and surface waves also produce pressure variations of considerable magnitude; but in a much faster cycle than those of ships. Therefore, to avoid premature firing because of wave action, pressure firing mechanisms are designed to ignore rapid pressure fluctuations. Pressure firing mechanisms are seldom used alone, but are generally combined with other influence firing devices.

13A6. Special-purpose mines

Special-purpose mines are those designed for special missions.

A *self-propelled* torpedo mine—also called a *mobile* mine—permits a submarine to lay mines in water too shallow for safe navigation of the submarine. This mine becomes a bottom influence mine at the end of its run.

The delayed-rising mine is used in offensive moored fields. This mine lies on the bottom, married to its anchor, until the mine case is released either by the functioning of a time delay or by a ship-counting mechanism. The case then rises to set depth.

Moored *antisweep mines* are interspersed in moored-mine fields. Antisweep mines are designed to explode and destroy sweep wires when such wires strike the mooring cable or float.

Examples of other special-purpose mines are *limpet mines* and *beach-defense mines.* The latter are bottom mines laid in shallow water and designed to explode on contact with landing craft.

B. Aircraft Mines

13B1. Aircraft minelaying

Almost any aircraft capable of carrying bombs can also carry and lay mines. Aircraft, as a matter of fact, were used extensively for such purposes during World War II, carrying and releasing some mines from ordinary bomb racks or shackles, and other mines from cables suspended between a pair of racks or shackles. An aircraft mine may either be free-falling with fin stabilization, or may employ a parachute to control the rate of fall.

As a minelayer, the aircraft has several advantages. For one thing, planes can lay mines in shallow bodies of water, including rivers, which cannot be penetrated by submarines or the larger surface minelayers. Also, planes can drop additional mines to replenish a mine field without encountering the hazard of detonating mines previously planted. Mines dropped by parachute can be released from relatively high altitudes, although with some loss of accuracy. On the other hand, minelaying operations involving parachutes are subject to detection by the enemy.

13B2. Typical aircraft-laid mine

Figure 13B1 shows a current aircraft mine. This is Mod 9 of the Mark 10 type of magnetic dip-needle mine.

Unlike many aircraft-laid mines, the Mark 10 Mod 9 is a *moored* rather than a bottom type. This fact explains the presence of an anchor.

There are two other current modifications of the Mark 10 magnetic mine. Mod 3 is laid from submarines and Mod 7 from surface craft. As regards the anchor and the interior arrangement of the case assembly, the Mod 9 resembles both of these modifications. Its differences from them lie in the parachute assembly and in the other external provision for aircraft planting.

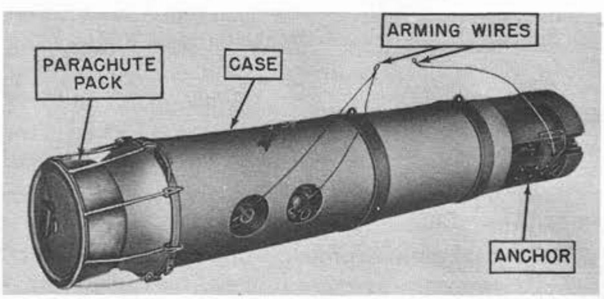

Figure 13B1.—Mine Mark 10 Mod 9.

Parachute assembly. Two parachute assemblies are authorized for use with Mine Mark 10 Mod 9. One of these, *Parachute Pack Mark 14 Mod 1,* is shown in figure 13B1. The other, *Parachute Pack Mark 3 Mod 0,* is shown in figure 13B2.

The Mark 3 Mod 0 pack has a plastic *dish* that fits the contour of the end of the mine case, to which it is bolted. The folded parachute lies inside the dish.

The cover is made of canvas, with eight sectors or flaps. The *risers* shown in figure 13B2 attach the parachute and the pack to the release mechanism.

The *static line* keeps the parachute from opening dangerously close to the planting aircraft. One end of this line is attached securely to the planting craft. The other end is attached by break cord to the parachute. When the mine has fallen the length of the static line, this line acts to pull the parachute from the dish. Almost at the same instant, the break cord snaps and frees the 'chute from the static line.

Parachute packs of more recent design have been improved in various details; but they are similar to the Mark 3 Mod 0, both in components and in principles of operation.

Release mechanism. The device shown in figure 13B3 serves a double purpose. Until the mine enters the water, the release mechanism secures the parachute to the mine. Upon striking the surface of the water with great force, the 2 *impact plates* pull out the *release pins* that have been holding the 2 halves of the release mechanism together. Now flat springs, assembled between the release mechanism and the mine case, force the 2 halves of the mechanism apart and let the mine sink free of the parachute.

If the parachute remained with the mine after water entry, it could foul the mine mechanisms. It might even roll or drag the mine in such a way as to cause a premature explosion. (N. B. In order to clarify the details, the figure shows the mechanism upside down.)

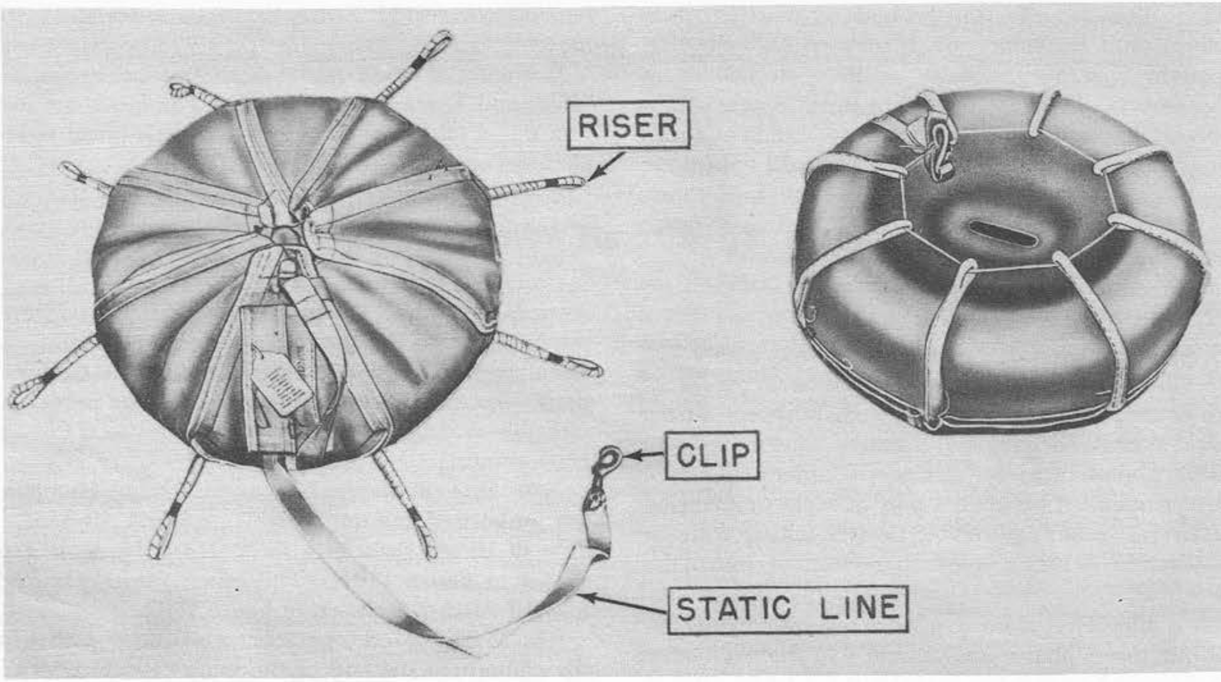

FIGURE 13B2.—Parachute Pack Mark 3 Mod 0 with Parachute Mark 3 Mod 2.

Arming wires. Like bombs, aircraft mines are assembled with arming wires as shown in figure 13B1. These wires, threaded through the delay devices, keep these devices in their unarmed condition. The bitter ends of the wires are attached to the planting aircraft.

Fairings. Some mines are assembled with fairings. These are attachments designed to improve the streamlining of the case and thus make the trajectory easier to predict.

To release the mine ready for arming, the bombardier operates his controls to pull the wires from the mine at the instant of planting. To jettison the mine in a comparatively safe condition, he lets the wires fall with the mine.

A jettisoned mine, however, is not absolutely safe. Therefore the area where it was dropped must be noted with care. As soon as practicable, after a mine has been jettisoned over a friendly area, trained personnel are sent to dispose of it.

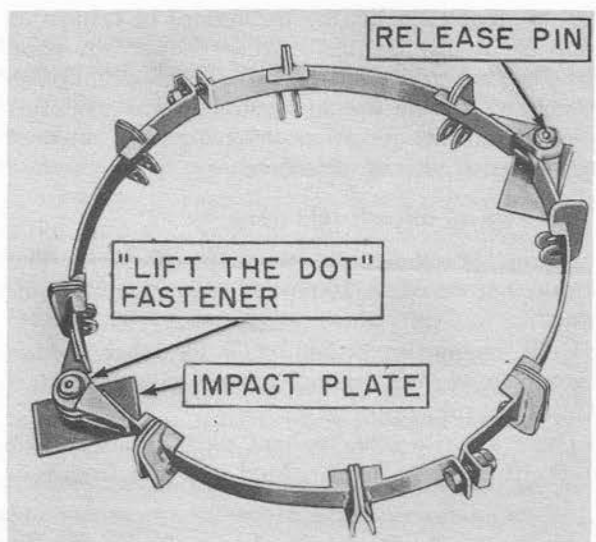

FIGURE 13B3.—Release Mechanism Mark 8 Mod 2.

C. Mine Warfare

13C1. Definitions

Mine warfare is the strategic and tactical employment of naval mines and mine countermeasures in the conduct of war.

Types of operations. Minelaying operations are classified as follows:

1. Physical position of field—defensive or offensive.
2. Relationship to other military operations—strategic or tactical.

3. Purpose of field—closure or attrition.

4. Method of laying—aircraft, submarine, or surface.

Types of fields. Mine fields are defined as follows:

1. *Defensive* fields are those in waters under friendly control, where enemy sweeping would be improbable. These fields are laid by minelayers whose only escort is an antisubmarine screen or combat air patrol. The area to be mined is carefully surveyed. Beach markers may be used as additional aids to navigation. Buoys are sometimes anchored in advance to mark the beginning and end of the field, and every effort is made to lay the mines in the exact location designated.

Controlled mines, to which reference has been made repeatedly in this chapter, are used in some types of defensive fields.

2. *Offensive fields* are those laid in disputed or enemy-controlled waters, and may be subdivided into two classes: (1) those designed to prevent passage of enemy vessels (closure mining) and (2) those in which passing of enemy ships is welcomed because they will be destroyed (attrition mining).

a. *Closure fields* are frequently laid around an area or harbor to prevent passage of enemy vessels.

b. *Attrition mine fields* are laid primarily to destroy enemy vessels, not to deny their passage. They are laid in ship lanes where enemy traffic has been observed. The utmost secrecy is essential. For this mission, aircraft or submarines are employed.

Strategic versus tactical. Strategic and tactical mining are defined as follows:

1. *Strategic mining* is a mining program, independent of other military operations, conducted over an extended period of time for the purpose of blockading enemy ports and strangling enemy supply systems. The term implies that the program does not have as its objective an immediate attack on any specific enemy force. Strategic mining is a very powerful offensive weapon when carried out by aircraft or submarines against waterways vulnerable to mine attack. Against an island empire, it may be the decisive factor in a military campaign.

2. *Tactical mining* in an engagement is now conceived as a function of aircraft or light, high-speed minelayers. The use of drifting mines, for turning the enemy battle line, has been outmoded by the increased speed of the modern battleship. However, tactical use of drifting mines to cover the retirement of a surface raiding or bombardment force is highly practicable.

Such mines, as well as other types, may be used to prevent the escape of enemy vessels from a base or lagoon where such ships are under attack by aircraft or forced to sortie for any other reason. Moored or ground mines may be used in tactical mining operations such as preventing pursuit of own forces to a base, and denying a channel to enemy forces operating tactically against own forces.

13C2. Command problems

The importance of offensive mine warfare is rapidly increasing. A sudden, massive attack by minelaying aircraft is considered to be one of the greatest threats to any maritime power that exists today. So great, in fact, that the possibility of such an attack requires major expenditures of manpower and equipment in conducting countermeasure operations, whether a single mine has been laid or not.

Offensive minelaying by surface craft, including PT boats, has comparatively limited application in enemy-held waters. The utmost secrecy can, of course, be obtained by laying mines from submarines. However, a submarine cannot replenish the interior of an existing mine field without itself being exposed to an unacceptable amount of danger. That brings us to the use of aircraft. The aircraft naturally leads in its ability to lay mines suddenly and in great quantity. It is, further, the only craft capable of replenishing a large existing field without danger from the field itself. Offshore shipping lanes can be mined by bombers and patrol planes whenever the depth of water is not too great. Mining of enemy-held rivers and harbors would generally be effected by tactical aircraft under conditions of low visibility or under cover of diversionary raids.

13C3. Mine countermeasures

Mine countermeasures include all actions taken primarily to protect own or friendly shipping against mines. Protection is accomplished in two general ways: (1) by reducing the effectiveness of enemy mines and (2) by clearing areas mined by friendly forces, after these areas have served their purpose. The three major types of mine countermeasures are ship treatment, mine hunting, and minesweeping. We'll consider each of these very briefly.

Ship treatment. Ships are capable of being treated to reduce their magnetic and acoustic fields of influence. Such treatment gives them a measure of immunity to mines designed to be actuated by those fields. It is possible that eventually hull design will be improved to reduce pressure signals as well.

When protection against *magnetic* mines is mentioned, *degaussing* is the word most likely to come to the mind of the Navy man. The degaussing process is the most effective means of reducing the magnetic influence of a steel ship. This process makes use of electric cable installed either (1) in a single large coil surrounding the hull or (2) in a large coil plus a system of lesser coils. Direct current is sent through each coil in such a direction as to create a magnetic field opposite in polarity to the corresponding component of the ship's magnetic signature.

The installation of the degaussing system is often preceded by an electromagnetic process called *deperming*. This preliminary process reduces the ship's inherent magnetism to a value regarded as standard for vessels of the given class. After a ship has been depermed, mass-production techniques, rather than custom methods, may be used in installing the degaussing equipment.

An older process called *flashing* or *wiping* is similar to deperming, but is normally applied only to small vessels that are not intended to be fitted with degaussing coils.

To reduce the danger from *acoustic* mines, ships are being designed and treated to eliminate unnecessary cruising noises.

Mine hunting. The methodic detection, location, and neutralization of mines is appropriately called mine hunting. Some craft and their highly trained personnel specialize in this work.

The shipboard devices used in mine detection are called *ordnance locators*. The sensing component of an ordnance locator is called an *ordnance detector*. The term ordnance detector can also refer, however, to a small, man-carried ordnance locator in its entirety.

Minesweeping. The process of clearing a given region of mines is called minesweeping. Mechanical devices, explosive charges, and apparatus for producing influence fields may all be needed in the sweeping of a single field.

Moored contact mines are swept by means of a paravane rig, which is an underwater kite towed by the minesweeper. The sweep cable contacts the mine-anchor cable, guiding it into the cutter jaws of the paravane. These jaws cut the mine adrift, allowing it to rise and be destroyed harmlessly on the surface.

Some magnetic mines are capable of being swept by towing a buoyed electric cable over them. The strong magnetic field set up by this cable causes the mine to detonate. Since these mines are designed to function as the peak of the magnetic field passes, they are not set off by the relatively weak field of the minesweeper. Through use of advanced degaussing systems, and nonmagnetic construction materials, new designs of minesweepers reduce their magnetic fields to a minimum.

Some acoustic mines are swept by creating underwater sounds of proper intensity and quality to actuate the mine-firing mechanism. Noise makers are of various types, some being towed astern by a sweep wire and others being located in the bow of the minesweeper to direct the noises ahead of the vessel. New types of engine mountings and other noise-reducing devices are at present being applied to minesweepers to reduce acoustic disturbances produced by their own propulsion equipment, and thus improve their ability to sweep acoustic mines with safety.

As yet the sweeping of pressure mines and subsonic acoustic mines has presented great difficulties.

Other countermeasures. In addition to the three major types of countermeasures, various other protective measures may be taken. These include mine watching, prevention of enemy minelaying action, and the use of long-range detecting and actuating devices.

Gene Slover's US Navy Pages

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Chapter 14

ANTISUBMARINE WEAPONS

A. Antisubmarine Warfare

14A1. Introduction

Antisubmarine warfare (ASW) comprises the employment of available weapons, resources, and necessary tactics against enemy submarines, their operating bases, and their supporting activities. The purpose of ASW is to deprive the enemy of effective use of his submarines.

Operations contributing to accomplishment of this purpose are various in nature and may be either offensive or defensive in character. In general, the principal categories of antisubmarine operations are as follows:

1. *Bombing and mining.* Destructive bombing (or bombardment) of enemy submarine pens, bases, building yards, and repair facilities will reduce enemy capabilities to wage submarine warfare. Mining serves the purpose of preventing movement of enemy submarines to and from their bases. Such operations may be carried out by aircraft or submarines.

2. *Hunter-killer operations.* A hunter-killer group consists characteristically of an aircraft carrier with radar-equipped antisubmarine planes, sonar-equipped antisubmarine helicopters, and a screen of destroyers. Aircraft conduct both surface and undersea searches, and are capable of rocket, depth bomb, depth charge, and antisubmarine torpedo attacks. When aircraft cannot complete the destruction of the submarine, they guide surface units to the scene for concentrated attack and reattack.

3. *Escort of convoy.* Escort of convoy, or screening, is usually conducted by antisubmarine surface vessels. Air support may be available at times, and may include surface search by fixed-wing A/S planes, or sonar search by helicopters and airships.

4. *Harbor defense.* Harbor defense comprises measures for protecting fixed geographical areas by preventing penetration of submarines, small surface craft, or manned torpedoes into these areas. Harbor defense measures include using defensive minefields, nets and booms, and underwater listening and echo ranging equipment. Fixed installations are usually supplemented by surface A/S units capable of attacking any submarine detected. Air patrols, including planes equipped with magnetic airborne detection (MAD) equipment, are also available to harbor defense forces.

5. *Submarine antisubmarine operations.* Submarine-versus-submarine operations are showing increasing effectiveness, and development in this field is being actively prosecuted.

14A2. General

The importance of antisubmarine warfare cannot be too highly stressed. Recent advances have been made in submarine design and operation, such as greater speed and the ability to stay submerged almost indefinitely. These facts, plus the submarine potential of any prospective enemy, make it obvious that maximum effort must be devoted to attain proficiency in antisubmarine warfare. Current emphasis in research and development—in both equipment and tactics—and an intensive fleet A/S training program are directed toward this end.

It was demonstrated during World War II, and has been further confirmed by operational evaluation since that time, that the air-surface hunter-killer team is one of the most effective forces in combating submarines. Aircraft have the advantage of searching large areas quickly, an important consideration because of increased submerged speeds of modern submarines. Formerly, aircraft contact with underseas craft was limited to surfaced or snorkeling submarines. If the submarine submerged before the attack, surface units were guided to the scene for further operations. It is now possible for airborne units to maintain contact on submerged targets and to deliver lethal attacks while the submarine is below the surface.

Airships and helicopters track submarines with

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sonar. The airship tows a sonar transducer which gives azimuth, or scanning, presentation comparable to surface ship sonar. As a matter of fact, airship sonar applications are quite similar to those of surface vessels, and the airship has the additional advantage of greater search speeds. Antisubmarine helicopters are equipped with dipping sonar. The helicopter hovers in the target area, lowering a searchlight-type sonar transducer for careful step-by-step underwater search.

Another means of tracking submerged targets from the air is by magnetic airborne detection equipment. MAD operates on the same principles as fixed magnetic loops that are standard equipment in harbor defense detection systems. MAD measures distortion of the earth's magnetic field caused by the presence of ferrous metal such as a submarine.

Attack capabilities of both airships and helicopters have been increased by recent developments. The helicopter is capable of carrying an antisubmarine torpedo, while the airship may attack by torpedo, depth charge, depth bomb, or conventional hedgehogs.

14A3. Weapons

Since antisubmarine warfare has a high priority, the near future will see in use against submarines weapons which cannot be described in this volume because of security classification. In addition to those weapons described in preceding chapters, there is a special group of weapons designed especially for use against *submerged* submarines. They have common characteristics of sinking or diving from the surface of the water and producing an underwater explosion either (1) on contact with the submarine, (2) in proximity to the submarine, or (3) at a preset depth. Depending upon the launching method, such weapons are grouped as follows:

1. Throwing weapons, including the hedgehog and an antisubmarine rocket called weapon A;
2. Torpedoes;
3. Depth charges;
4. Depth bombs.

In addition to the three classes of active weapons, this chapter includes a discussion of *nets and booms,* described above as one of the passive means for antisubmarine (and antitorpedo) defense.

B. Depth Charges

14B1. General

Depth charges are thin-walled containers filled with a heavy charge of explosive and designed to explode at a predetermined depth or by the action of an influence fuze.

The older depth charges are cylindrical in shape, about 28 inches long and 18 inches in diameter. They contain 300 pounds of TNT. This type of depth charge, the Mark 6, is now used largely for training. An even larger cylindrical depth charge, the obsolete Mark 7, contained 600 pounds of TNT. The later types of depth charges, Mark 9 and Mark 14, have a teardrop shape and a weighted nose, to increase the sinking rate and improve the underwater trajectory. They contain about 200 pounds of TNT or of HBX and have the same over-all dimensions as the 300-pound cylindrical charge. Representative depth charges are shown in figure 14B1.

The depth at which explosion will occur is controlled in the older type by setting a hydrostatic exploder mechanism which is graduated to 600 or 1,000 feet (in different mods). In the newer charges explosion is initiated by an influence-type firing mechanism. Neither type of exploder mechanism depends upon contact with a submarine. It is extremely difficult to obtain a direct hit with depth charges, because the exact position of the submarine usually is not known. Consequently, depth charges depend on the percussive wave of the explosion for their effectiveness.

The effective radius of the percussive wave depends upon the structural strength of the attacked vessel, and no definite values can be stated. Approximate information indicates that a 600-pound charge may cause moderate damage at 80 feet, but to be fatal it

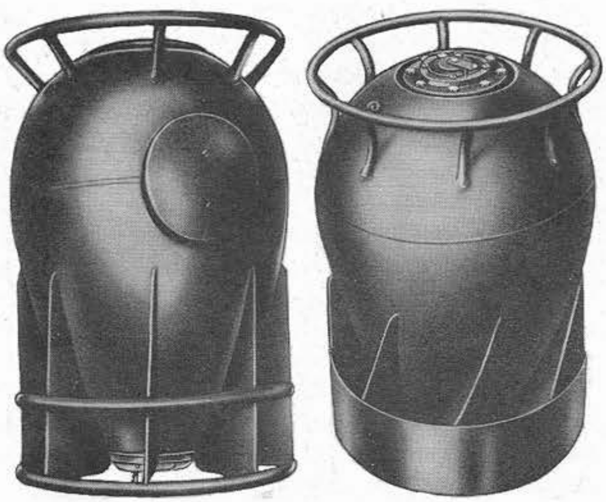

FIGURE 14B1.—Depth charges.

must explode within about 30 feet. The 300-pound charge may prove fatal within 20 feet. It is to be noted that doubling the weight of charge does not double the effective radius.

Destroyers, destroyer escorts, subchasers, PT boats, and other vessels likely to engage submarines, carry depth charges. Generally several charges are released in rapid succession to form a pattern in depth, width, and length, and thus increase the probability of destroying the submarine. The pattern is obtained by dropping some charges from release gear on the stern, and firing others abeam from projectors, with appropriate depth settings made on the depth charges before launching. The charges are never thrown far from the attacking vessel; hence care must be taken that the ship is making sufficient speed to be out of the way of the violent effect produced. The computation of the speed necessary is considered to be part of the antisubmarine fire control problem, which is discussed in volume 2.

14B2. Release gear

One type of track used to drop depth charges from the stern of a vessel is illustrated in figure 14B2. Essentially, it consists of inclined rails on which the charges rest, with suitable mechanical devices arranged to release one charge at a time. The track shown will hold eight Mark 6 charges. Minor modifications make the track suitable for dropping teardrop charges.

The charges roll aft by their own weight and rest against the *after detents.* When the *release lever* is operated, the after detents depress, allowing the first charge to roll off the track into the water. At the same time, *forward detents* (not shown) rise and hold the second and following charges steady on the rails. When the track control lever is returned to its original position, the detents move in reverse directions, and the second charge rolls down to the dropping position against the after detents. The track control unit is

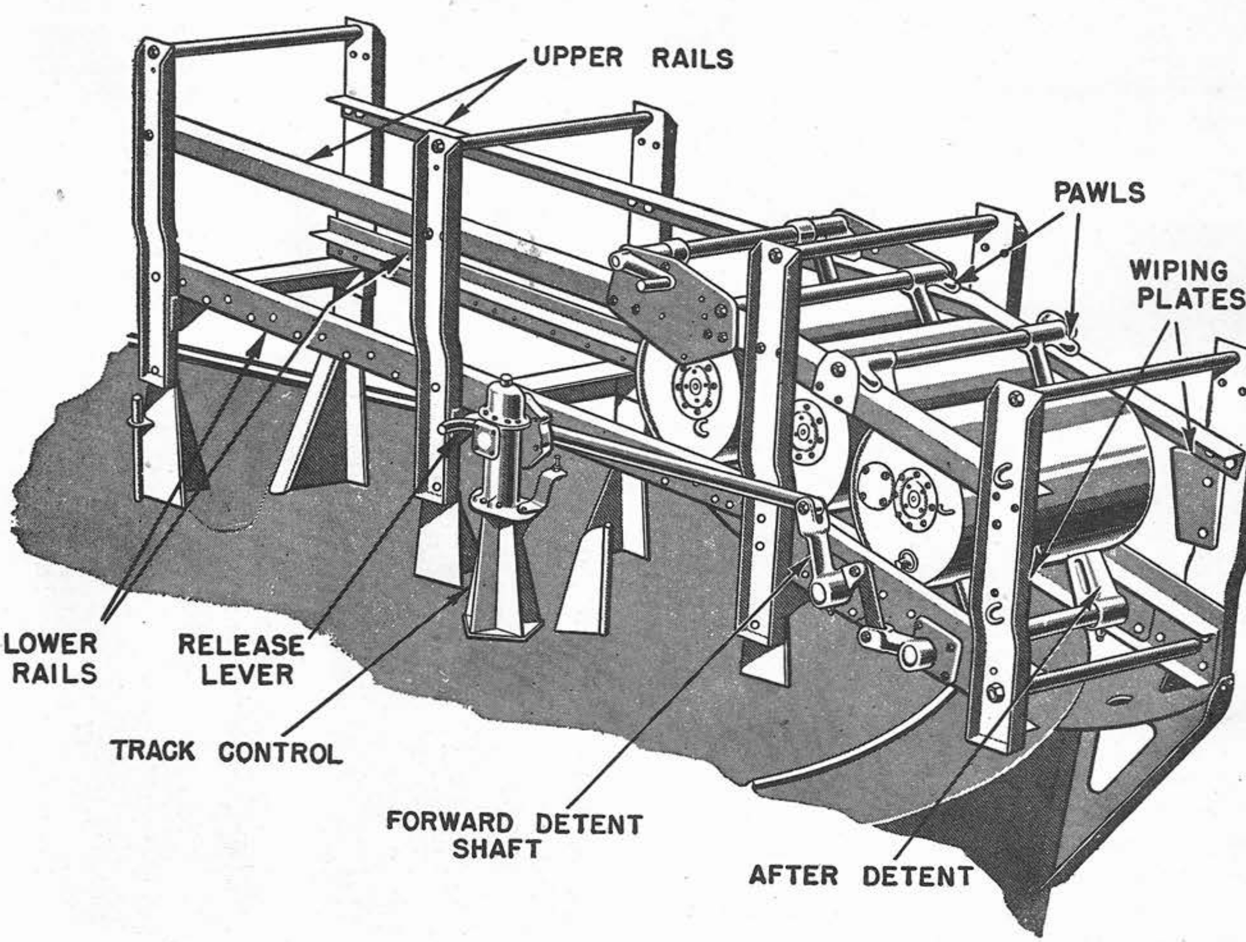

Figure 14B2.—Depth-charge release gear.

connected hydraulically to a control unit on the bridge of the ship by means of which the charges may also be released.

Most depth-charge release tracks bear mark and mod designations. Four tracks, however, have letter designations instead. All four of these tracks are intended primarily for use on small vessels and motor boats, although they have been grouped along the sides of somewhat larger craft on occasion. All have cable pendants for holding the depth charge (or pair of charges) in place. All have built-in local control devices. Types A and C hold a single charge; types B and D are designed to hold two charges. They are dropped by releasing the cables which hold the case in position and letting the charge roll from the track.

14B3. Projectors

The Depth Charge Projector Mark 6 Mod 1, commonly called the K-gun, is illustrated in figure 14B3. It is used to launch the 300-pound cylindrical depth charge or the 200-pound teardrop charge.

The K-gun consists of a smooth-bore barrel attached to an expansion chamber fitted with a breech mechanism. The breech plug is an interrupted-screw type, housing a firing mechanism which provides for local percussion firing by lanyard, or electrical firing controlled from the bridge.

The projector is permanently secured to the ship, and cannot be trained or elevated. Variations in range are obtained by altering the weight of the im-

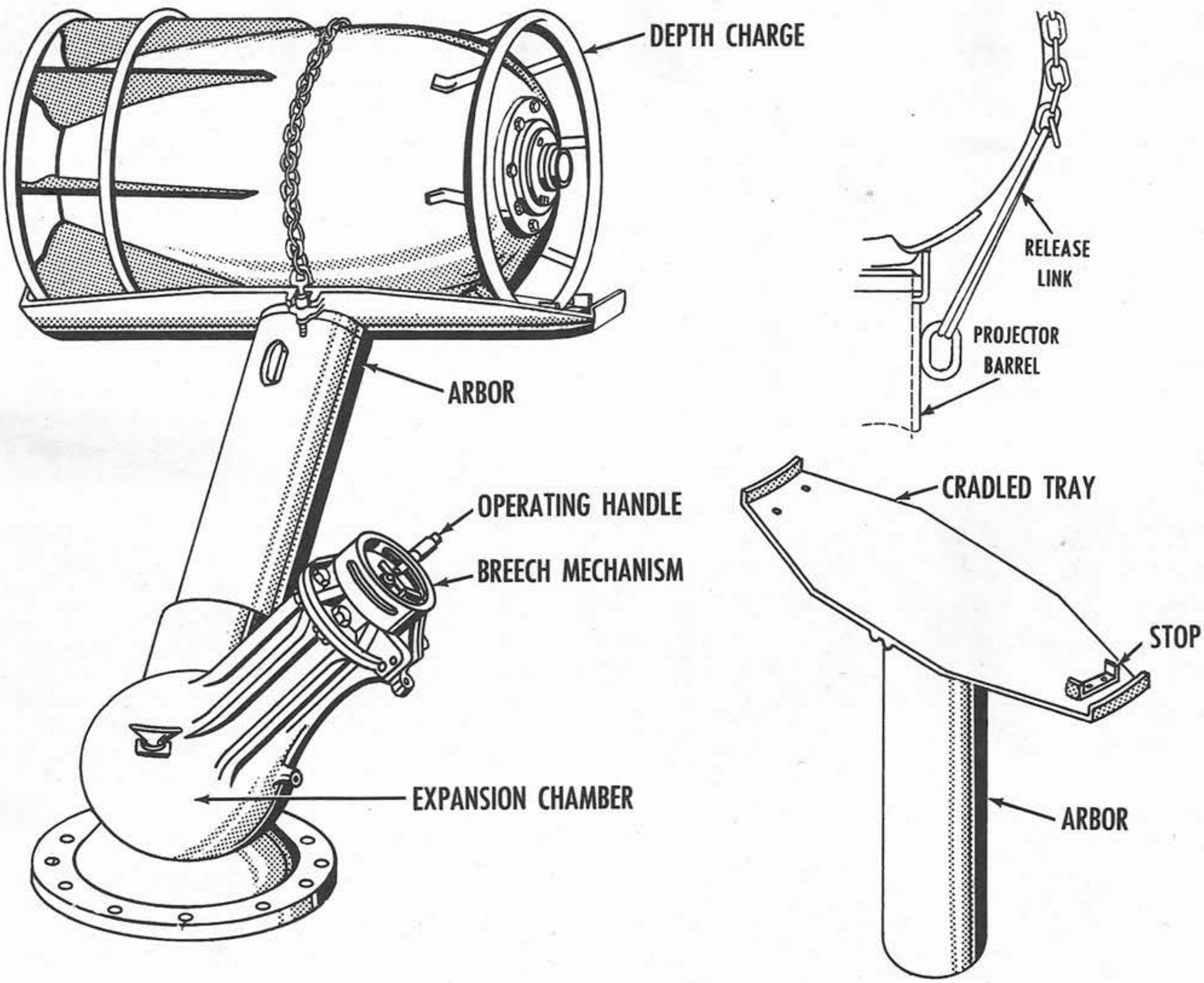

FIGURE 14B3.—Projector, ready to fire.

pulse charges, which are assembled in 3-inch cases similar to those used for torpedo impulse charges. Three standard weights of spherohexagonal black-powder charges are used to obtain ranges of 50, 75, and 120 yards (Mark 6 depth charge), or 60, 90, and 150 yards (Mark 9 and Mark 14 depth charges).

The depth charge is launched with an *arbor* (fig. 14B3) attached to it, the action of the propellent gas being against the base of the arbor. The arbor used with a cylindrical depth charge remains attached to the charge after firing, whereas that used with a tear-drop charge detaches after firing, to permit taking advantage of the streamlined design.

14B4. Depth-charge operation

Mark 6, Mark 7, and Mark 9 charges are similar in functional operation. The general arrangement of a typical charge is shown in figure 14B4. The principal components are:

1. *The main charge and case.* The outer shell is a sheet-metal case, through which passes a *central tube.* The space between the tube and case is completely filled with cast TNT or HBX.

2. *The booster and booster extender.* The booster is attached to the booster extender, and is free to move longitudinally in the tube. A central recess in the inboard end of the booster envelops the detonator when

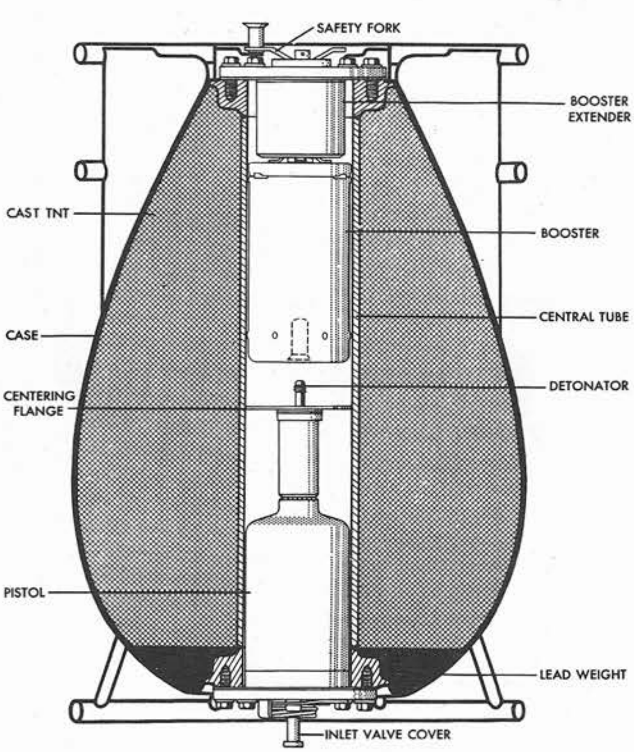

FIGURE 14B4.—Depth charge, sectional view.

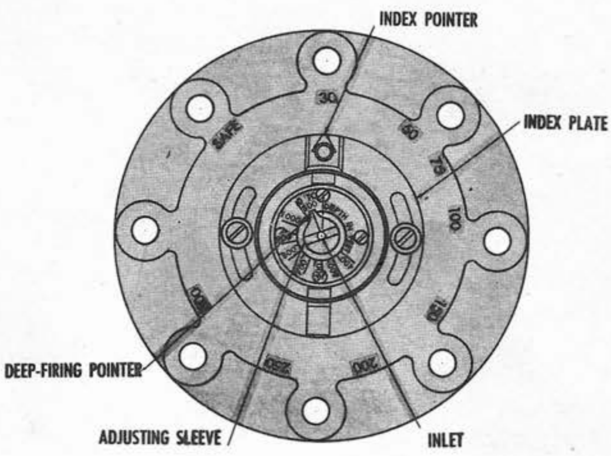

FIGURE 14B5.—Depth-setting index dials.

the booster is moved against the *centering flange.* The booster extender, operated by hydrostatic pressure, pushes the booster against the centering flange when the charge reaches a depth of between 11 feet and 25 feet.

3. *The detonator and pistol.* The detonator is secured to the inner end of the pistol, and is supported in the center of the tube by the centering flange. The pistol mechanism, when operated by hydrostatic pressure, releases a firing pin which strikes the cap of the detonator. Before the charge is launched, the depth at which the pistol is to operate is set as described in the next article. Depth settings from 30 to 1,000 feet may be made.

Accidental detonation of the depth charge is prevented (1) by setting the pistol on SAFE, thereby locking the pistol, and (2) by a *safety fork,* which prevents the booster from moving inward. The booster will not detonate unless it partially surrounds the detonator. An *inlet-valve cover* protects the water inlets to the pistol against dirt. It should always be removed prior to firing, as otherwise it will prevent the entrance of water after a charge is launched.

Depth settings are made with a special wrench. If the charge is dropped from a rack, the safety fork and inlet-valve cover are automatically wiped off by wiping plates on the rack. The cover must be removed by hand and the fork by lanyard if the charge is launched from a projector.

14B5. Pistol operation

The construction of a pistol is illustrated in figure 14B6. The *firing pin* is secured to the *firing plunger.* Around the plunger are three holes, each of which contains a *lock ball.* The *release plunger* is free to slide within the firing plunger, and is held by a spring in the position shown. The lock balls, held outward by the

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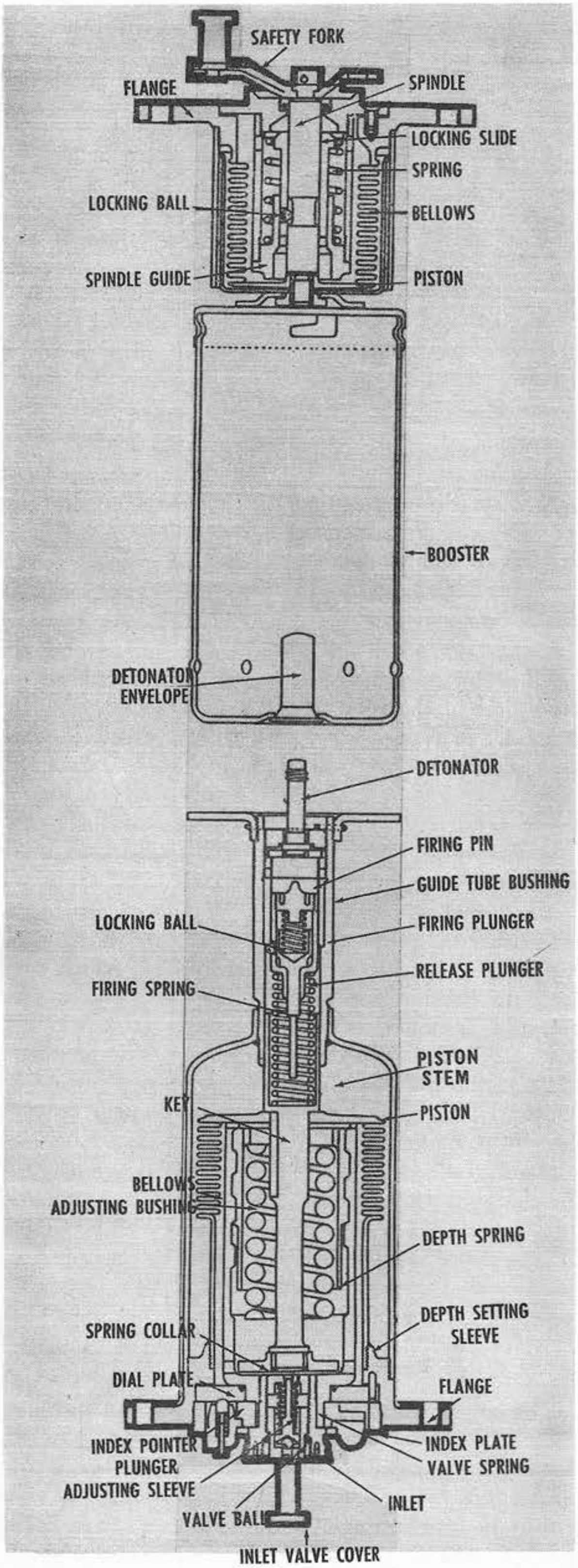

FIGURE 14B6.—Depth-charge pistol and booster extender.

release plunger, rest against the end of the *guide-tube bushing* and prevent the firing plunger from moving toward the detonator.

When water flows through the *inlet,* it fills the *bellows.* Water pressure then expands the bellows, pushing the *piston* and *piston stem* toward the release plunger. This action compresses the *depth spring* and the *firing spring.* As the movement continues, the piston stem contacts the release plunger and moves it toward the firing pin. When the annular recess on the release plunger has moved under the lock balls, the latter move inward, releasing the firing plunger with its attached firing pin, which is driven into the detonator by the firing spring.

The depth spring is seated in the *adjusting bushing,* and is compressed between it and the *spring collar* as the bellows expand. The adjusting bushing, threaded within the *depth-setting sleeve* and keyed to the piston stem, is positioned by rotation of the sleeve when the *index plate* is turned. The position of the bushing controls the resistance offered by the depth spring to the expansion of the bellows, and thus determines the water pressure required to operate the pistol. When the pistol is set on SAFE, the adjusting bushing is so close to the spring collar that the piston stem is prevented from moving far enough to release the locking balls.

The 300-foot setting uses the maximum strength of the depth spring; hence it cannot keep the pistol from firing at greater depths. The inlet valve provides the necessary control for depths between 300 and 1,000 feet. The *valve ball* is held against its seat by the *valve spring.* The compression of this spring is set by rotating the *adjusting sleeve* (with the inlet-valve cover off). When the valve is set for depths between 0 and 300 feet, it admits water freely as soon as the charge is submerged. When set for greater depths, the valve admits no water until the set depth is reached. Then the pressure of the water opens the valve, and the water pressure immediately expands the bellows, firing the detonator. Figure 14B5 shows the two dials.

For depths up to 300 feet, the *deep-firing pointer* on the adjusting sleeve is set at 0 to 300, and the *index* pointer on the index plate is set to the required depth. The *dial plate* has, opposite each depth mark, a small recess to receive the *index-pointer plunger,* which acts as a detent to maintain the setting. For depths greater than 300 feet, the index pointer is set at 100, and the depth-firing pointer is set to the required depth.

14B6. Booster-extender operations

A booster-extender mechanism, ready for launching, is shown in figure 14B6. The operating parts are enclosed within a watertight *bellows,* which fills with

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water and extends the booster to envelop the detonator as the depth charge descends.

The booster and the piston are secured to the *spindle,* which is locked in position by the safety fork. When the safety fork is removed at launching, the bellows, assembled under slight compression, elongates enough to open the inlet around the spindle. The spindle moves inboard until the outboard shoulder of the annular groove contacts the locking balls held in the locking slide. The spring prevents further inboard movement of the locking slide until the water begins to operate the bellows.

As water pressure builds up, the locking slide is gradually drawn inboard by the spindle. When the charge reaches a depth of between 11 and 25 feet, the locking balls move outward into the enlarged recess in the spindle guide and release the spindle. Water pressure then quickly extends the bellows, placing the detonator envelope around the detonator, thus arming the charge.

14B7. The Depth Charge Mark 14

The Depth Charge Mark 14 (see fig. 14B7) is a streamlined missile similar to the Mark 9, but is fitted with an influence-type firing mechanism. This device greatly increases the accuracy with which the explosion may be placed in depth, and eliminates the disturbance caused by explosions of noneffective charges, which otherwise may interfere with the solution of the antisubmarine fire control problem.

The case, like that of the Mark 9, contains a 40-pound nose weight, and has canted fins which provide stable underwater flight characteristics, and a sinking speed of about 23 feet per second. These charges are launched in a conventional manner from tracks or projectors, but because of the influence feature, they do not have to be set for a depth pattern.

The A-4 is an influence firing mechanism, designed to initiate an explosion when the charge is close enough to a submarine to do serious damage. Delay in its operation and in the detonator make the minimum depth at which the charge will fire upon actuation from a normal signal about 65 feet. It is equipped with an anticountermining switch which prevents firing for a short period following any other explosion near by. The mechanism may fire upon reaching the bottom of the ocean or, in very deep water, the charge may fire at about 2,500 feet as a result of leakage or deformation of the case.

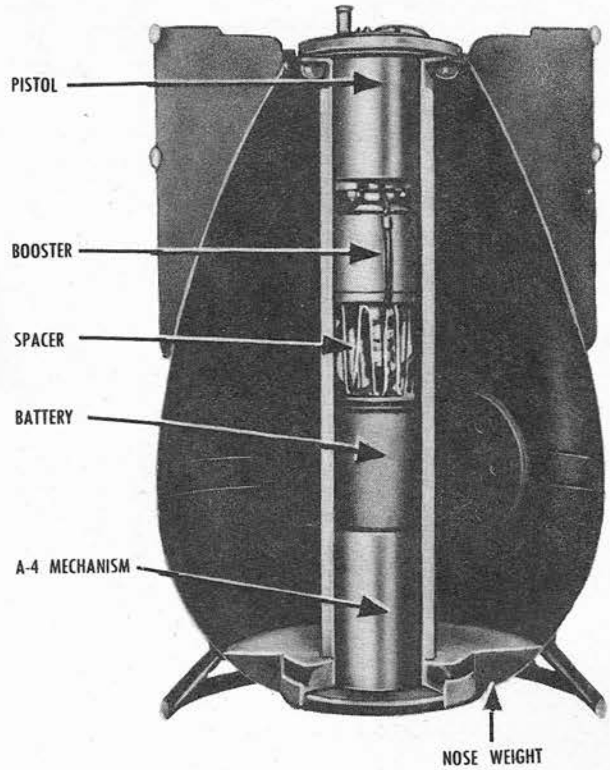

FIGURE 14B7.—Depth Charge Mark 14.

The Pistol Mark 12 acts as a safety device. It is equipped with two hydrostatic arming switches, a detonator, and a detonator positioning device. Prior to use, the pistol safety latch is kept at SAFE and locked with a safety fork. When the charge is to be used, the safety latch is turned to SERVICE or to the deep arming position, and the safety fork is removed by lanyard or by wiping. Water pressure arms the pistol at a depth of about 35 feet when set on SERVICE. When the *deep-arming safety latch* is set to the deep-arming position, it locks the extender mechanism and keeps the pistol from arming until some depth between 200 and 400 feet is reached.

The deep-arming feature is designed for use in "creeping attacks" against deeply submerged submarines. It prevents premature explosion which might result in damage to a slowly moving attacking vessel.

C. Depth Bombs

14C1. Description

Figure 14C1 shows a current depth bomb, the HBX-loaded Mark 54 Mod 1. Depth bombs are sometimes defined as depth charges designed for dropping from aircraft.

Depth bombs were among the major antisubmarine weapons used in World War II. Three methods of

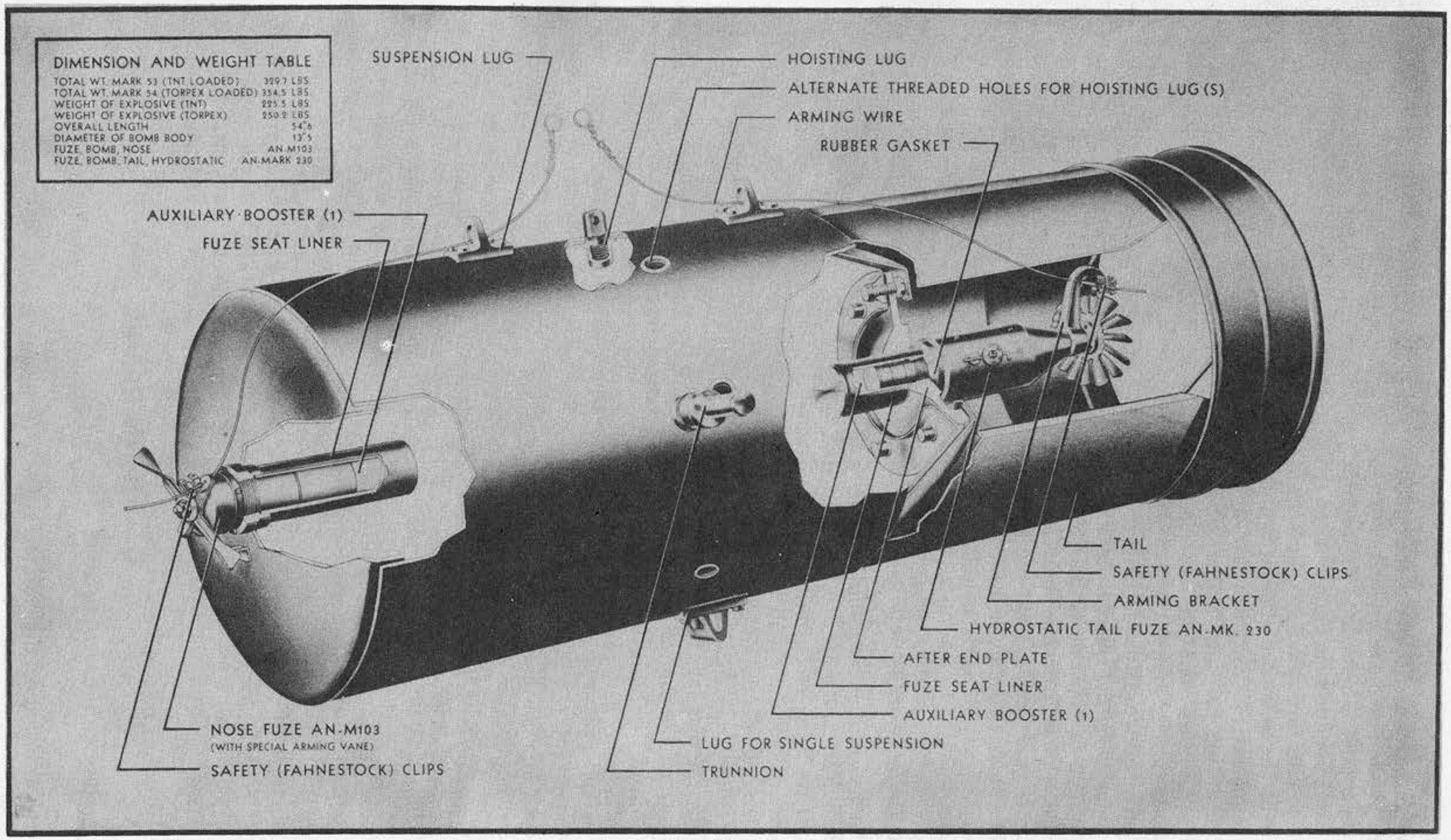

FIGURE 14C1.—Aircraft Depth Bomb Mark 54 Mod 1, HBX-loaded.

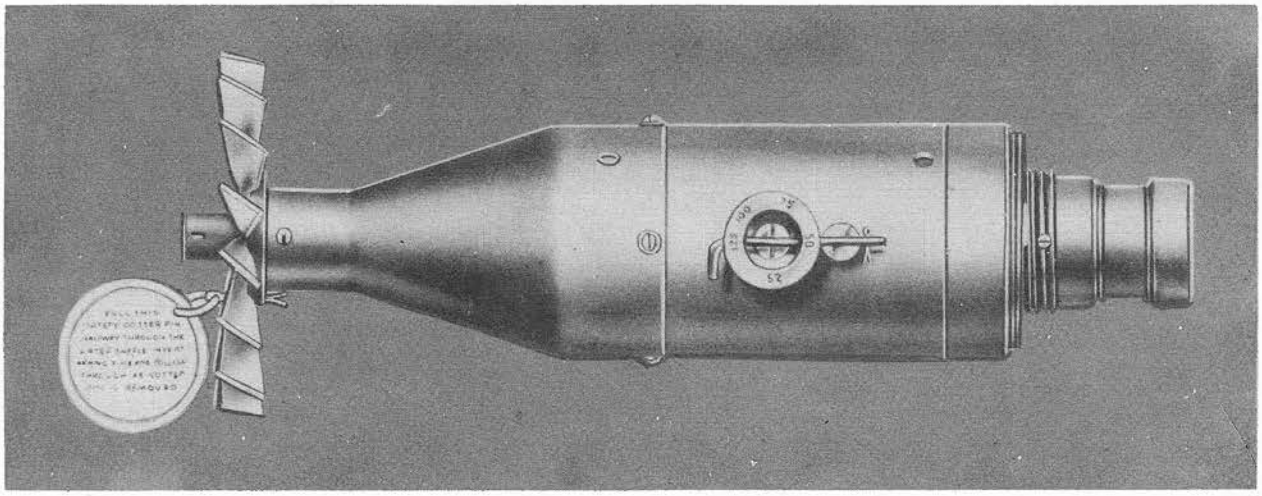

FIGURE 14C2.—Bomb Fuze AN-Mark 230 Mod 4 (Hydrostatic Tail).

dropping—toss bombing, glide bombing, and low-altitude release—were employed.

A depth bomb has a rather light case. The explosive filler comprises about 70 percent of the weight of the assembled bomb. To reduce the danger of ricochets at small entrance angles, the depth bomb has a flat nose. Fuzing arrangements are discussed in the next article.

14C2. Fuzing

When carried in aircraft with selective arming, depth bombs normally take two fuzes. An impact-type nose fuze with a special flat arming vane is installed for use against suitable surface or land targets. A hydrostatic tail fuze, shown in figure 14C2, is intended for use against submerged submarines.

When the tail fuze is dropped armed, the nose fuze must be dropped safe. Otherwise the bomb will detonate on water entry. In planes that lack selective arming, only the tail fuze is used.

During World War II, many depth bombs were fitted with an athwartship hydrostatic fuze. This feature, however, is not present in the Depth Bomb Mark 54 Mod 1 shown in figure 14C1.

The tail fuze shown in figure 14C2 allows five choices of depth setting, varying from 25 to 125 feet. Normally the depth setting is made before take-off, though it can be made aboard the planting aircraft. This gives an approximate control over the depth of the explosion.

14C3. Damage to target

Like its close relative the depth charge, a depth bomb is unlikely to hit a submarine directly. Instead, it gains its effect by creating an underwater pressure wave that may weaken or crush the hull plates of the target.

D. Throwing Weapons

14D1. The 7.2-inch rocket

Chapter 11 described the solid-nose 3.5-inch rocket, which is used as an airborne antisubmarine weapon. Surface craft may also carry antisubmarine rockets and rocket-type missiles.

The first thrown missile put in service by the Navy was the 7.2-inch rocket and its associated Rocket Launcher Mark 20, illustrated in figure 14D1. Two such launchers, mounted on the forecastle of an antisubmarine vessel, can fire a pattern of eight charges. Since the charge is a true rocket, there is negligible thrust against the deck when a pattern is fired; thus this weapon is suitable for use on such small craft as PC's and SC's.

As the rocket head carries a contact fuze, a direct hit on the target submarine is required; but, when a direct hit is obtained, even the small charge carried in the rocket head can well be lethal.

The Mark 20 launcher and its associated rockets have been replaced in service on DE's and larger vessels by the Mark 10 projector and its 7.2-inch missile. Since, however, the Mark 10 projector is much heavier

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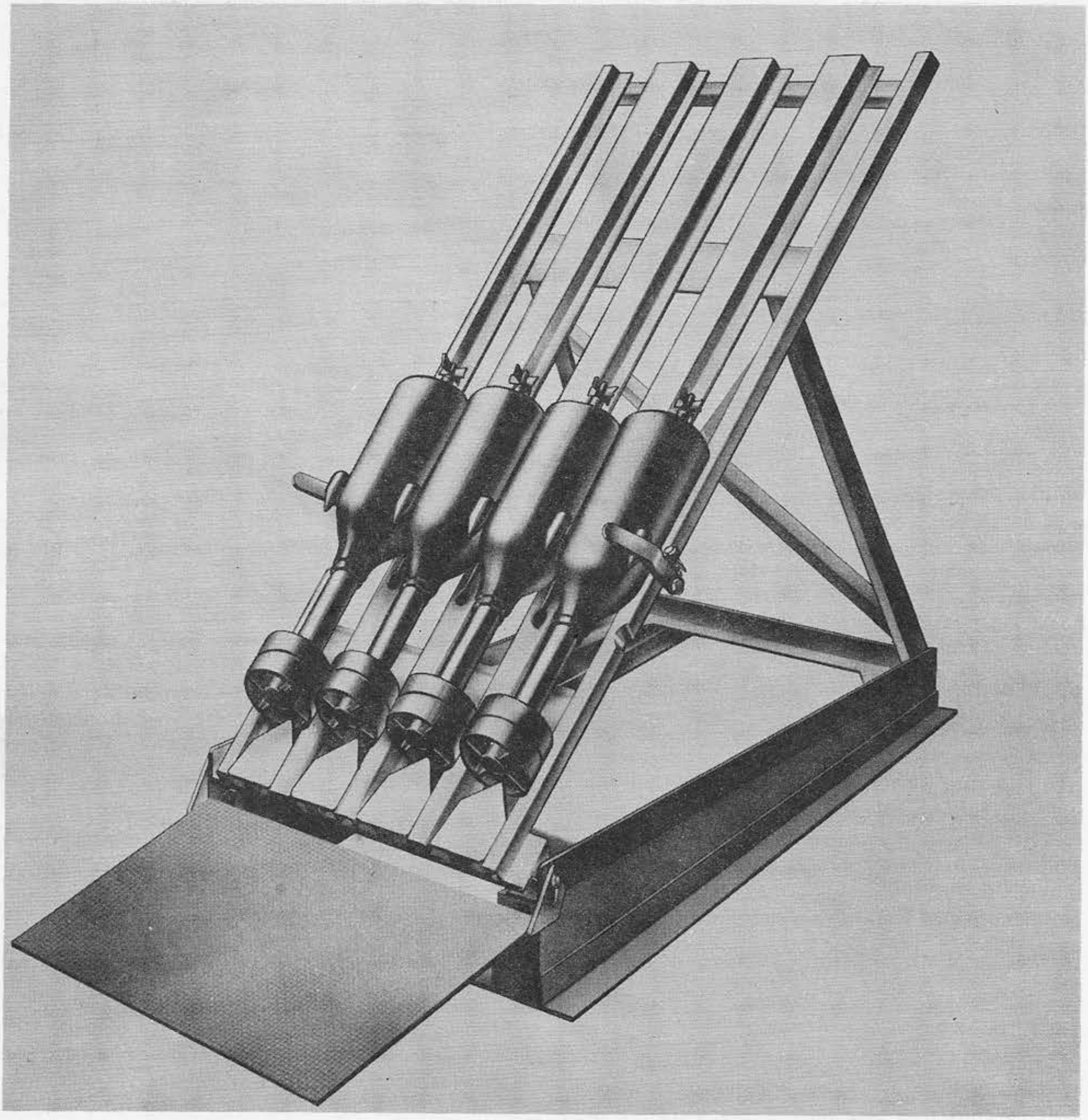

Figure 14D1.—7.2-inch Rocket Launcher Mark 20, loaded and ready for firing.

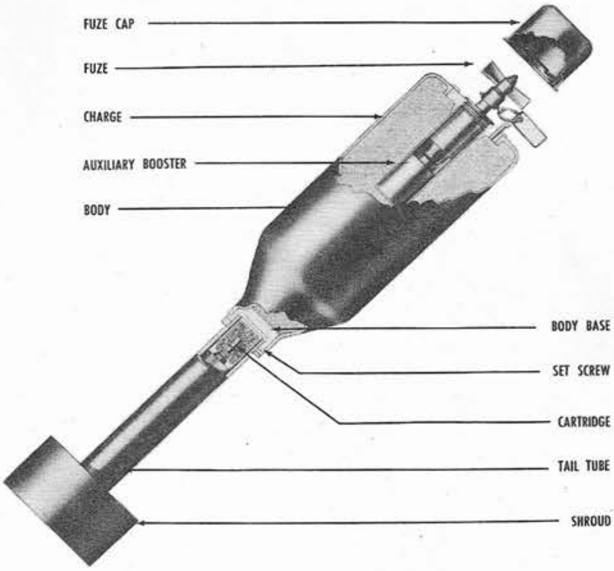

FIGURE 14D2.—7.2-inch projector charge.

than a rocket launcher and the deck thrust incident to its use is considerable, the Mark 20 rocket launcher is not considered obsolete for small craft.

14D2. 7.2-inch projector charge

The projector charge is similar in shape to the 7.2-inch rocket. It has a head 7.2 inches in diameter, with a tail, fins, and a shroud. (See fig. 14D2.) However, this missile is *not* a rocket; the propelling charge is an impulse charge of smokeless powder. The fuze arms during flight and is designed to function upon impact only. The explosive charge consists of 30 pounds of TNT. The tail is a steel tube, the forward end of which contains a cartridge case with the propelling charge of smokeless powder. The propelling charge is fired electrically by means of a primer in the base of the cartridge case. As the missile leaves the projector, the cartridge case base falls to the deck.

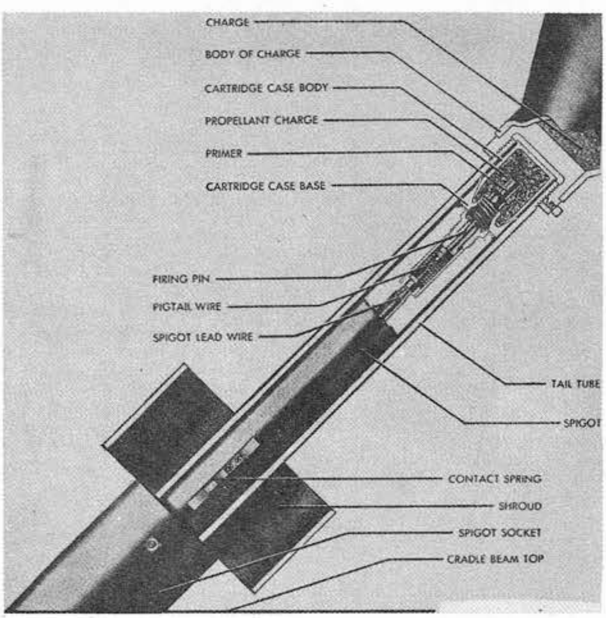

FIGURE 14D3.—Section through spigot and tail tube.

14D3. The 7.2-inch projector Mk10 and Mk 11

Several different projectors are used with the 7.2-inch charge. In principle, all of them resemble the Mark 10 (fig. 14D4), which projects a pattern of 24 charges ahead of the attacking vessel. The missiles are loaded on cylindrical bars called *spigots,* attached to *cradles* which can be swung about a fore-and-aft axis by means of a roll-correction gear assembly mounted on a gun-train indicator pedestal. This movement is limited, but it allows the spigots to train enough to compensate for roll of the ship and to aid in leading the target. The spigots are so positioned that, when fired, the charges describe an elliptical pattern of about 140 by 120 feet.

The base frame of the projector consists of two 18-inch channel beams running fore and aft and two 12-inch I-beams athwartship, forming a box. Each I-beam carries four bearings which support the *cradle assemblies.* The four 10-inch cradle beams (fig. 14D5) ride on trunnion assemblies welded at each end. The trunnions fit into the bearings on the base frame. The cradles can be tilted on their trunnions about an axis parallel to the keel of the ship. A connecting bar tilts all four cradles simultaneously when the roll-correction gear is operated.

Six spigot sockets are welded to each cradle and hold the spigots on which the charges are loaded for firing. The wires of the firing circuit pass through holes in the spigot, as shown in figure 14D3. The ungrounded side of the firing circuit terminates in a firing pin, which is contained in the spigot. The grounded return of the firing circuit is through a spring contact which touches the inside of the projector-charge tail tube.

14D4. Operation

The projector is loaded by placing the tails of the missiles over the spigots and sliding them down gently. After the missile is all the way down on the spigot, it

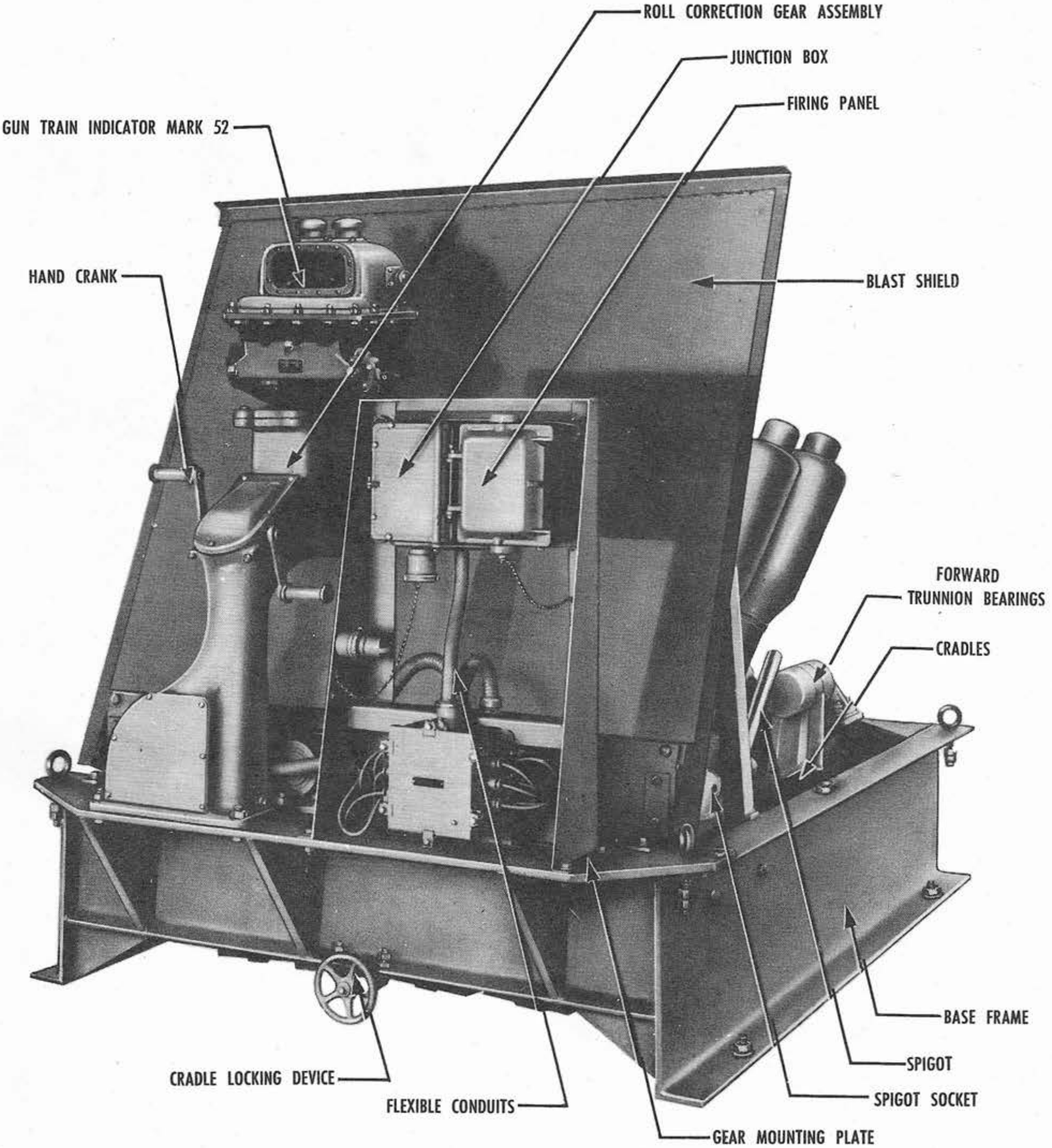

FIGURE 14D4.—Projector Mark 10.

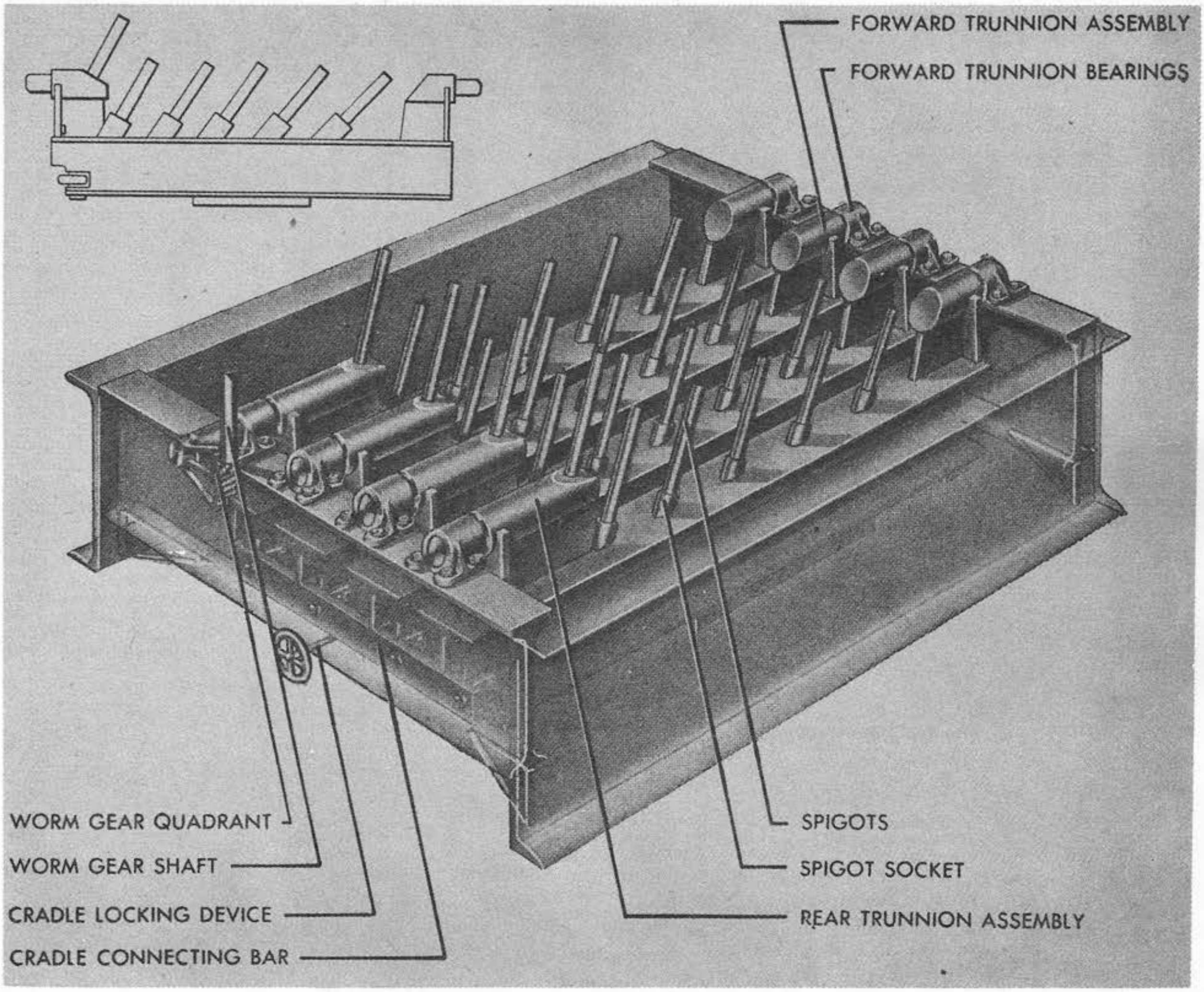

FIGURE 14D5.—Cradles.

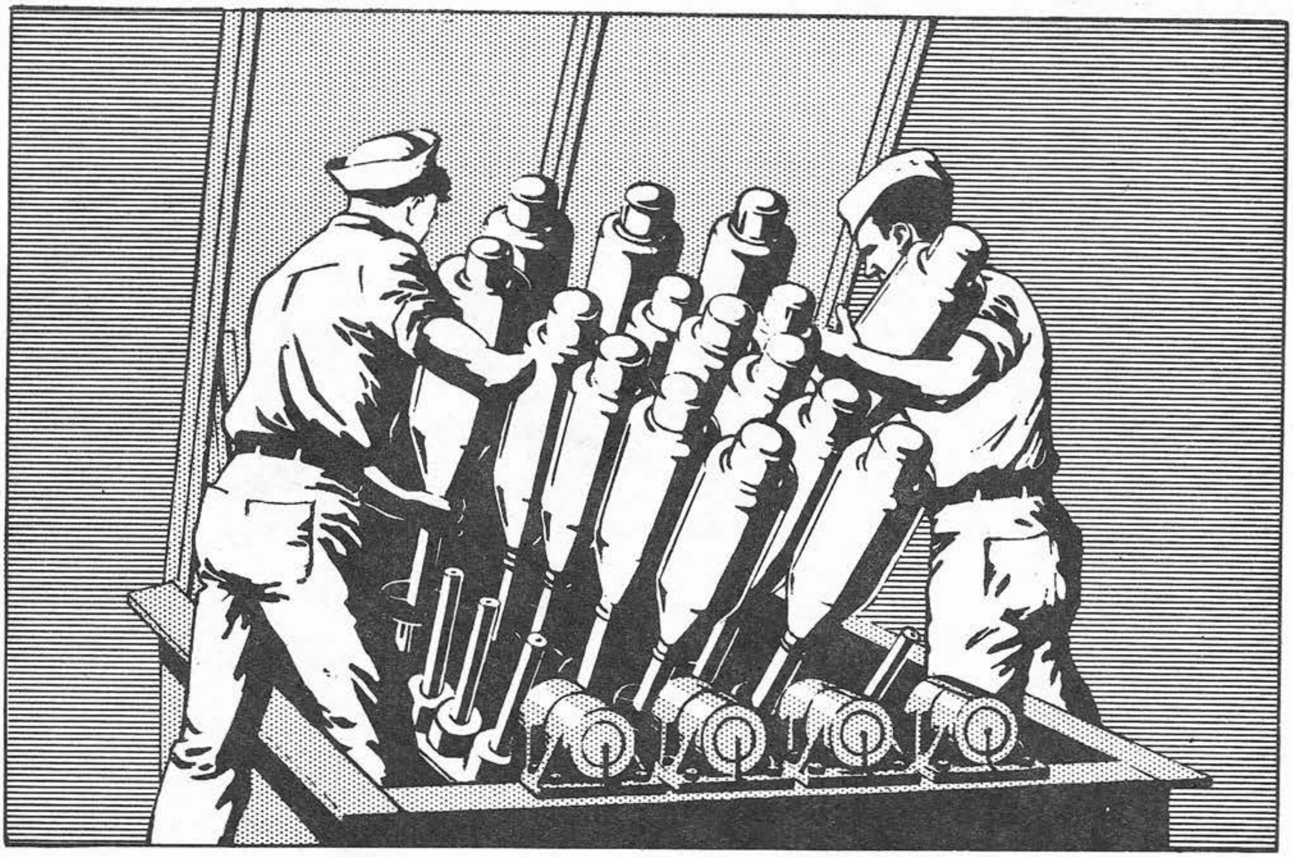

FIGURE 14D6.—Loading outboard spigots.

is rotated 360° to ensure good contact between the firing pin and primer. (See fig. 14D6.)

The charges are fired by means of a *ripple switch*. This switch has 12 contacts and, as the switch rotates, it completes the firing circuit to the missiles by pairs. the interval between contacts is about 0.10 second (0.20 second in some mods). The firing circuits are so wired that the missiles with the highest trajectories are fired first and those with the flattest trajectories last. Thus all the missiles hit the water at approximately the same time. The average range is about 200 yards. Variations in powder temperature have little effect between 30° and 90° Fahrenheit. Figure 14D7 shows the nominal trajectory and sinking time of the 7.2-inch projector charge.

The Mark 11 projector is very similar to the Mark 10 described above.

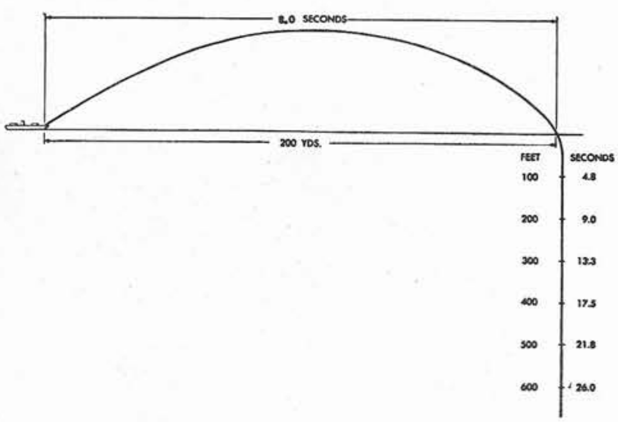

FIGURE 14D7.—Trajectory curve, Mark 10 projector missile.

14D5. The 7.2-inch Projector Mark 15

In principle of operation and in general external appearance, the A/S 7.2-inch Projector Mark 15 (fig. 14D8) resembles the Mark 10 type described in some detail in the preceding articles. It is equipped with 24 spigots which accept 7.2-inch charges like those already described, and ripple-fires them in a circular

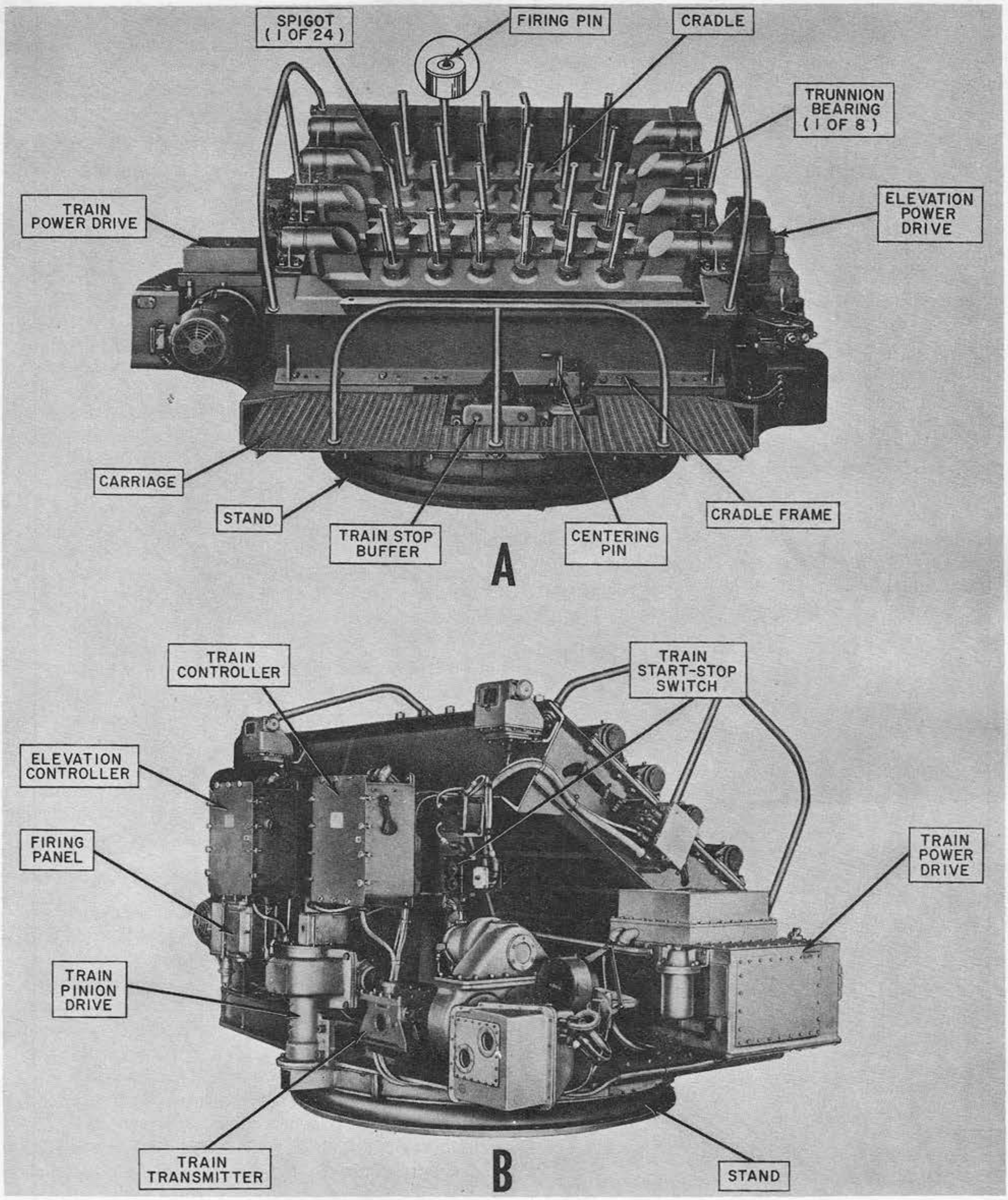

FIGURE 14D8.—Projector Mark 15 Mod 0. A. Front view. B. Left rear view.

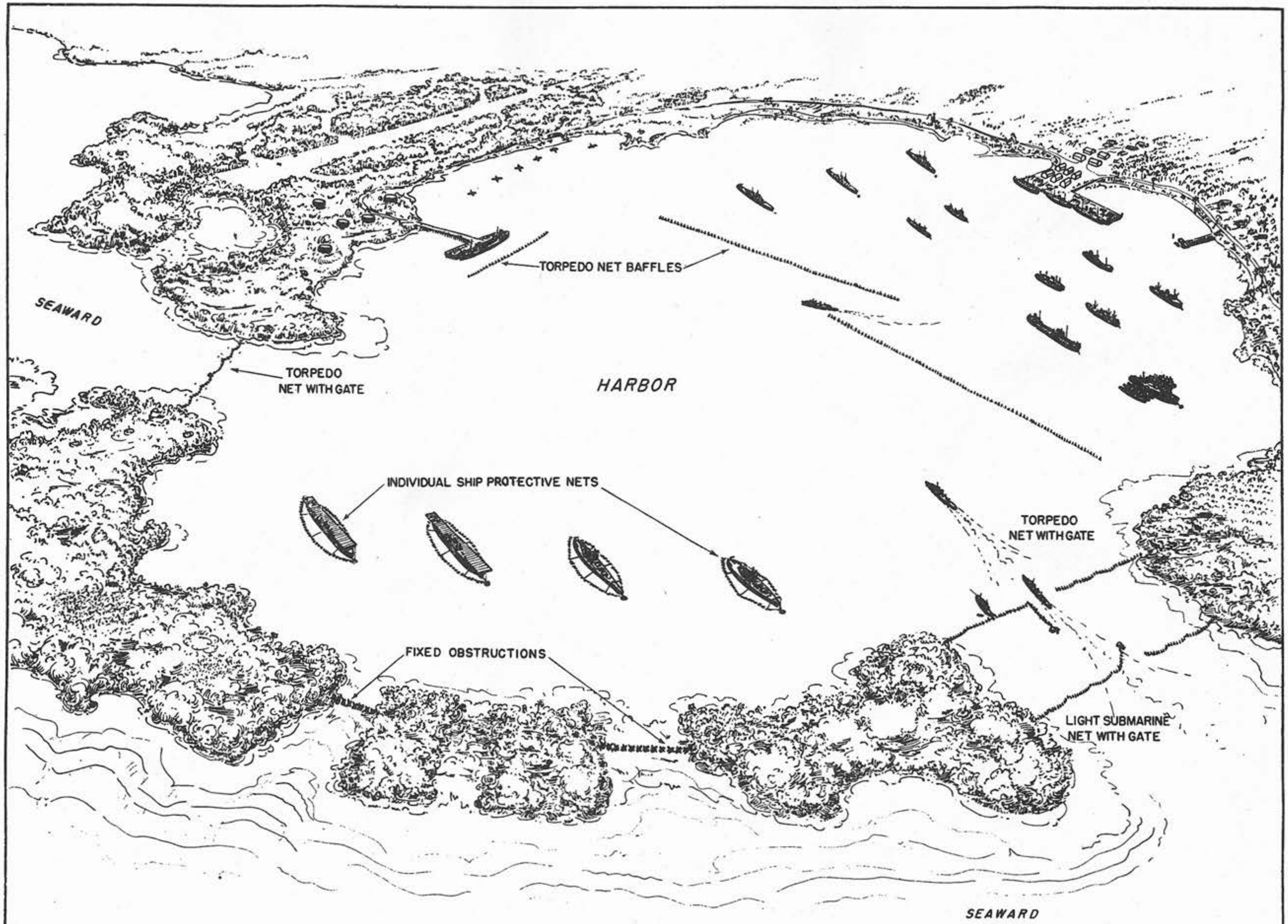

FIGURE 14E1.—Net defenses as employed at a typical advanced base.

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pattern. However, the cradles on which the spigots rest are at right angles to the line of fire (the Mark 10's are parallel to the line of fire), and can rotate in limited arcs of elevation in trunnion bearings. (The Mark 10 projector's spigots cannot move in elevation at all.) The cradles are cross-connected so that they elevate in unison. The cradles are housed in a trainable carriage mounted on a stand on the deck (as contrasted with Mark 10's fixed-base frame). The elevating and training parts are positioned by electro-hydraulic power drives similar to those used on 40-mm quad mounts.

E. Nets and Booms

14E1. General

Efforts to block the entrances to harbors against surface vessels date back to the earliest times. The appearance of the high-powered, steel-hulled surface vessel, the submarine, and the torpedo have made the present-day problem of protecting ships at anchor increasingly difficult. The problem has evolved into one of defense against torpedoes. This defense is accomplished in two ways: by preventing the vessel carrying the torpedo from approaching within firing range, or by stopping the torpedo itself. See figure 14E1.

There are five classes of nets and booms, with individual variations within each type. These are:

1. Type S net (antisubmarine).
2. Type I (Indicator) net (antisubmarine).
3. Type T net (antitorpedo).
4. Type B boom (antimotorboat).
5. Rigid obstructions.

To protect ships at anchor in a harbor either (1) the harbor must be blocked off or (2) each ship must be protected individually. During World War II merely blocking off the harbor did not, in itself, give sufficient protection, because of the torpedo-carrying aircraft. Therefore, valuable ships and floating dry docks may be surrounded by a variation of the Type T net called an ISP (Individual Ship Protection) net.

14E2. Type S net (antisubmarine)

The purpose of the Type S net is to block submarine attacks, or, if a submarine does break through, to reveal its presence to patrol craft. To prevent the passage of a submarine the net must be constructed of very heavy material and must have sufficient elasticity to absorb a sudden heavy strain without breaking. The three basic elements are:

1. The *net,* a fabric woven of heavy wire.
2. The *flotation,* a system of buoys and floats.
3. The *moorings,* the anchors and their connections.

The standard submarine net is constructed of a diagonal mesh measuring 8 feet per side, assembled in lengths, called *panels,* which measure 300 feet. Nets are tailored to fit the depth of the water; they must reach the bottom without fouling on it. Two panels joined together longitudinally form a *section,* the lineal unit used in installing and when referring to large net systems. The net is woven around a top wire rope, called the *jackstay,* and around end and bottom wire ropes, called *perimeter* ropes. The jackstay supports the weight of the net, and it is to this that the flotation gear is secured.

The net is floated by spherical or barrel-shaped buoys shackled to the jackstay. The moorings are designed both to keep the net in position against the force of tide and current, and to furnish the installation with the required elasticity. The typical mooring consists of four 6,000-pound stockless anchors, two on the seaward and two on the harbor side of the net. These anchors are laid in tandem at right angles to the net line. Elasticity is provided by slinging heavy iron cubes, called *stretcher weights,* in the bights of the mooring system. The stretcher weights and ends of the net are floated as illustrated in figure 14E2.

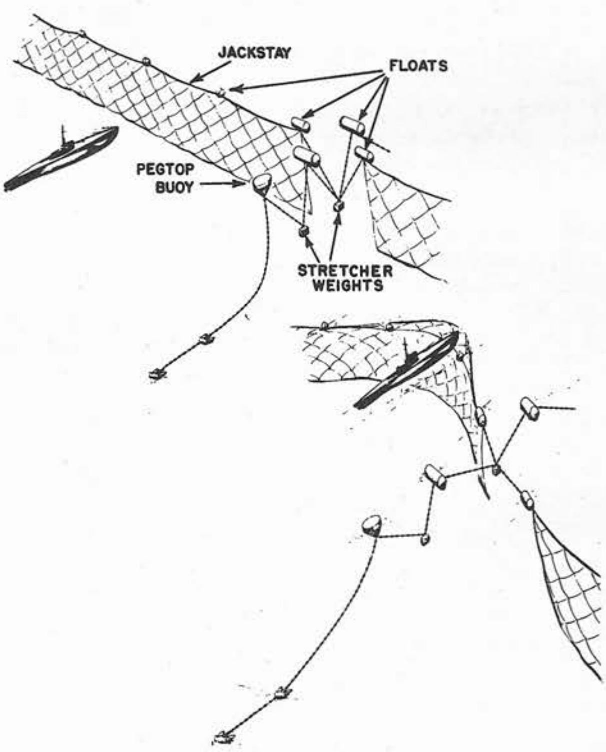

FIGURE 14E2.—Type S net, showing yield in moorings.

A harbor entrance net has one detachable panel, called a *gate,* which may be swung open by a gate vessel to allow passage of friendly ships. In deep entrance channels the gate may be guarded by a submerged *bottom net* under the entrance. Such a net is supported by submerged buoys; it effectively seals the gate against submarines attempting to slip through, deeply submerged, while the gate is open. Of course the top of this net must be deeper than the draft of the largest friendly ship which will use the gate.

14E3. Type I (Indicator) net (antisubmarine)

The purpose of this net is to indicate the position and movements of a submerged submarine. As the Type S net is extremely heavy and bulky, it requires heavy equipment to move it, lay it, and tend it. Therefore a relatively light, compact net, easily shipped to and installed in distant harbors, is required.

The Type I net is not designed to stop a submarine. Its strength requirements are that it must be capable of staying in position in all conditions of wind and weather, and that any section must hold together while being towed by a submerged submarine.

The net is woven with a 4-foot diagonal mesh into panels 210 feet long and 50 feet deep. The net is not tailored to fit the depth of water, but the panels are fastened to each other until the net reaches the bottom. Any excess is secured by brailing and stopping, so that it will not foul on the bottom.

The two distinctive features of the Type I net are *burster clevises* and the *indicator floats.* Burster clevises are U-shaped shackles used to connect the mesh of the net to the jackstay. They are designed to break at a predetermined stress, thus freeing the net from the jackstay. Indicator floats are small steel pontoons, each containing a reel with 300 feet of line, a flotation chamber, and a pot of calcium chloride and calcium phosphide. When a panel of the net is pulled clear of the jackstay, *tear-off strips* are pulled from the indicator floats; water enters the pots containing the calcium compounds, and smoke is generated.

The operation of the net is illustrated in figure 14E3. A submarine, attempting to enter the harbor, comes in contact with a panel of the net; when the stress on the net reaches a certain amount the burster clevises part, freeing the panel from the jackstay; this panel drapes itself around the bow of the submarine; as the net moves away with the submarine, the indicator floats initially remain attached to the jackstay; the tear-off strips are pulled clear and the floats produce smoke; when the 300 feet of line in the indicator float is paid out, the floats are pulled clear of the jackstay and are towed along the surface astern of the submarine.

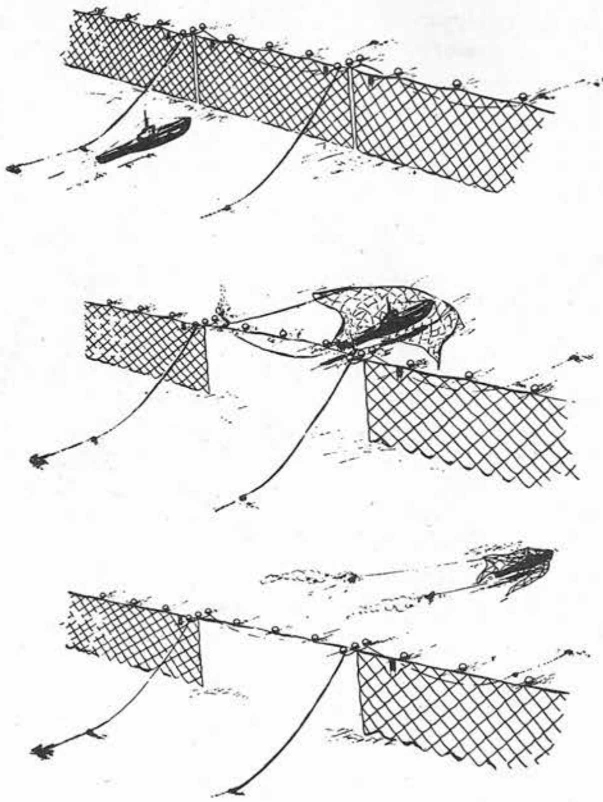

FIGURE 14E3.—Action of indicator net (Type I).

14E4. Type T net (antitorpedo)

The Type T net is used (fig. 14E4) to fence out torpedoes. It may be laid in any of the following ways:

1. As a continuous barrier across a harbor.
2. In a non-continuous baffle arrangement.
3. In individual ship-protection units.

The Type S net must withstand the impact of the slow-moving large body of a submarine, the kinetic energy of which is diffused rapidly throughout a large area of the net. A torpedo, however, poses an entirely different problem to the net designer. A torpedo arrives at the net with a high degree of kinetic energy. At the critical instant of impact, because of the small diameter of the war-head nose and its high velocity, that total energy of the 300-horsepower torpedo is concentrated upon one element of the net. If that element fails, the net is defeated.

The distinctive feature of the torpedo net is the *grommet.* Grommets are rings of steel wire with a breaking strain of 46 tons. As the net is woven, each grommet finally is passed through six other grommets

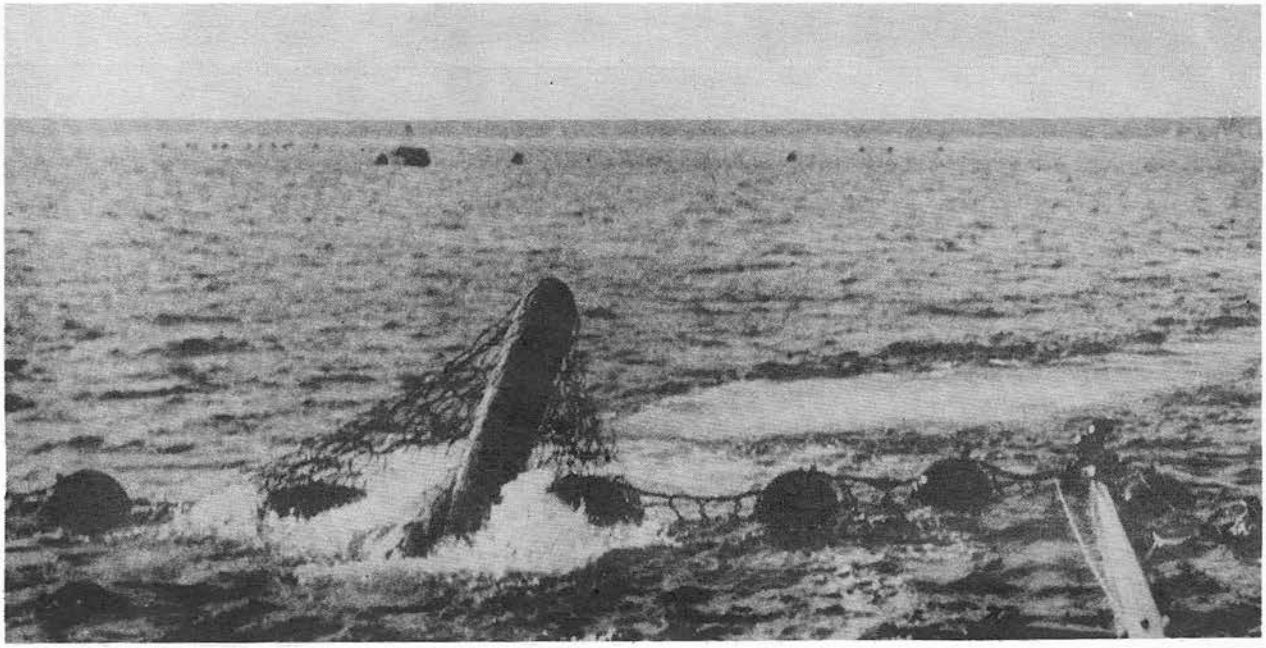

FIGURE 14E4.—Type T net defeating a torpedo.

(as shown in fig. 14E5), producing a fabric much like the chain-mail armor of feudal days. When the torpedo strikes, the force of its impact is expended in stretching, or elongating, the grommets, each one rendering against the adjoining grommets.

Antitorpedo nets are attached both to the top and to the bottom of the flotation buoys, in order to protect agains surface torpedo runs. The bottom of the torpedo net is left free to swing from the jackstay, thereby adding to its elasticity.

The *continuous barrier* and the *baffle* methods of laying the Type T net are self-explanatory. However, neither of these affords protection against torpedo attack by plane.

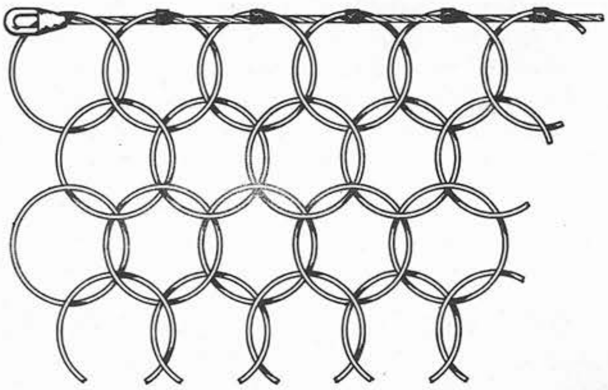

FIGURE 14E5.—Portion of Type T net.

An Individual Ship Protection (ISP) net provides an answer for this problem. It is an antitorpedo net completely surrounding an individual ship. The net is held off about 60 feet from the sides of the ship by special spars and is attached to the anchor chain or mooring buoy. The main disadvantage of this net is tactical; that is, it interferes with the ability of a ship to get under way rapidly.

14E5. Type B boom (antimotorboat)

The purpose of the boom is to block passage of motor torpedo boats. Such a craft is built with an extremely light hull, because speed is its principal and virtually its sole protection. The Type B boom is designed with this weakness in mind.

The distinctive feature of this boom is the *baulk*—a heavy iron-strapped wood-and-metal tank fitted with eyebolts and links for connecting it to the boom jackstays. Two watertight iron tanks occupy the interior of each baulk and provide flotation. Each baulk is fitted with four steel *spike cutters* whose points project outward from the baulk. The baulks are connected by upper and lower jackstays; along the upper jackstays, at intervals of 4 feet, are four-pronged steel *star cutters*.

While this type of defense has been effective under favorable conditions, its limitations should be kept in mind. It is designed only for protection against very light craft and will not stop steel-hulled boats and heavier landing craft equipped with propeller guards.

Moreover, the weight and shape of the baulks creates a definite problem where strong currents are encountered.

14E6. Rigid obstructions

It is sometimes necessary to close entrances to harbors where the water is too shallow for efficient net operation. In such cases it is usually more efficient to employ some kind of rigid obstruction. These may take one of several forms:

1. *Cribs.* These are heavy structures built up from the bottom in the form of boxes of the heaviest timbers available and ballasted with rock or concrete. Heavy wire is rigged between them.

2. *Concrete blocks.* Where time and cost are not controlling factors, heavy tetrahedronal concrete blocks have been cast with their bases jointed to form a semibreakwater across the channel.

3. *Dolphins.* Pile dolphins may be used where the nature of the bottom and availability of pile-driving equipment permit. These may be connected with jackstays and star cutters.

4. *Blockships.* The traditional means of closing a harbor is, of course, to sink a ship in the channel. This is very difficult to do correctly since, to be effective, the ship must be sunk on an even keel directly across the channel. Provisions should be made for very rapid, controlled flooding and for venting of trapped air.

14E7. Multiple installations

Because of the specialized character of nets and booms no single installation can deal with all of the torpedo threats which may develop against an important base or anchorage. Often it is necessary to combine different types of barriers, either using one in support of another, or joining two or more into a single-line obstruction.

A Type S net, for example, constitutes no very effective obstacle to a torpedo fired through its mesh. And to a motorboat designed to ride over low obstacles a torpedo net would not be a much more positive barrier than a motorboat boom would be to a torpedo fired under it.

Sometimes the only solution is a combination of two or more types of defense. In practice any or all of the possible combinations may be used, from simply doubling a line of one kind of net to combinations of three separate types. Standard Type S moorings for a double line will readily carry a Type T net in place of the second Type S net. Such a barrier, while not as formidable to either a submarine or a torpedo as a double line of its specific antidote, will still stop most torpedoes fired into it and, if well patrolled, will leave little chance that a submarine will pass through undetected. This combination is a compromise, but a thoroughly practical compromise. Without unlimited reserves of material it often constitutes all that can be done in a given situation.

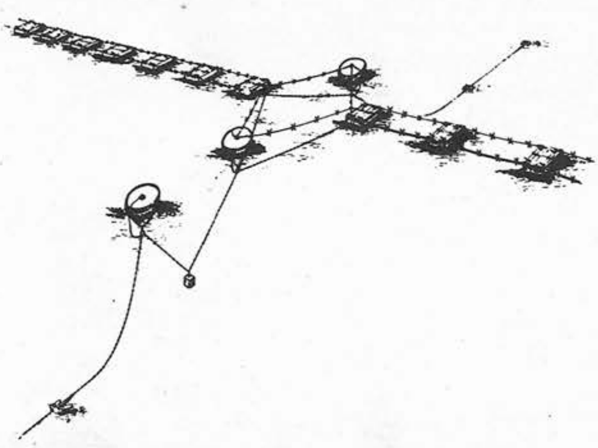

FIGURE 14E6.—Type B boom (motorboat boom).

The double-line Type S net installation provides as nearly complete protection against submarines as can be established at the existing stage of net development. But a review of actual war experience in this field indicates that, when considered on the basis of calculated risk, the expense in materials and transportation capacity is justified only where there is both very great risk of determined attack by submarines and an extremely important prize inviting such attack.

The case against double-line installation applies in a lesser degree to torpedo nets. They too, with their flotation and moorings, impose a heavy load upon war-burdened transportation and maintenance facilities. Torpedo net is used in greater quantities than any other type of heavy installation. A practice which would double the mileage of net required would almost inevitably entail leaving some naval anchorages entirely unprotected.

Type SBT net is a combination of submarine and torpedo net lines with a motorboat boom (fig. 14E6) added, the submarine net being installed at the seaward line, using the motorboat baulks for flotation. It provides protection against three types of attack: submarine, torpedo, and motorboat.

14E8. Gates

Where nets or booms entirely close the entrance to a port, passage must be provided for friendly vessels while still barring the enemy. This is the function of the gate. Net and boom gates are simply movable sections of the barrier so rigged that they may be opened to permit the passage of friendly craft. When closed, such gates will be as strong as or stronger than the other sections of the barrier.

Gates are classified according to use as *main, emergency,* and *side.* All must be so rigged that they may be operated easily and rapidly under all conditions of weather and sea, will be entirely secure when closed, and will be controllable by the officers operating the port's defenses.

They are classified according to design as *horizontal* and *vertical.* The horizontal gate is operated by swinging it open, still floated by its buoys, until the passage is cleared. The vertical gate is lowered at one end or at both ends until sufficiently submerged to permit vessels to pass over it.

14E9. Summary of net defenses

In considering the type of net defenses to employ, one must give thought to transportation facilities, weight of the net and accessories, net-laying and tending vessels available, and tactical requirements. Type S and Type T nets are very heavy and bulky, and require the use of large laying and tending vessels. The Type I nets are made in various weights, varying from fairly heavy to extremely light.

The adage among net personnel states that "a net is no stronger than its patrol." These patrols must keep watch not only for the enemy but also for damage to the net by currents, weather, and corrosion. The most important factor in maintaining effectiveness of any net installation is a continuous and alert patrol.

Appendix A

SAFETY PRECAUTIONS

The following safety precautions were issued, in accordance with article 0406, *Navy Regulations,* by the Chief of the Bureau of Ordnance, 29 October 1948, and approved by the Acting Secretary of the Navy 3 November 1948. In separate publication, they are designated NavOrd Instruction 5100.1; and the contents are the same as the contents of chapter 20, *U. S. Navy Safety Precautions,* OpNav 34P1.

I. General

1. To avoid danger of casualties, the observance of the following safety precautions is mandatory. The Bureau of Ordnance shall be informed of any circumstances which conflict with these safety precautions or which for any other reason require changes in or additions to them.

2. When in doubt as to the exact meaning of a safety precaution, an interpretation shall be requested from the Bureau of Ordnance. Conditions not covered by these safety precautions may arise which, in the opinion of the commanding officer, may render further operation of the equipment unsafe. Under these conditions, nothing in these safety precautions shall be construed as authorizing such further operation.

3. Safety devices provided shall always be used as designated to prevent possibility of accident, and shall be kept in good order and operative at all times. All instructions promulgated by competent authority to insure safe operation or handling of equipment shall be strictly observed.

4. Whenever any motion of power-driven units is capable of inflicting injury on personnel or material not continuously visible to the person controlling such motion, the officer or petty officer who authorizes the unit to be moved by power shall, except at general quarters, insure that a safety watch is maintained in areas where such injury is possible both outside and inside the unit, and shall have telephone or other effective voice communication established and maintained between the station controlling the unit and the safety watch. These precautions are applicable to turrets, gun mounts, guns, directors, range finders, searchlights, torpedo tubes, rocket launchers, and similar units. Under the conditions stated above, the station controlling shall obtain a report "all clear" from each safety watch before starting the unit. Each safety watch shall keep his assigned area clear and if unable to do so shall immediately report his unit fouled, and the controlling station shall promptly stop the unit until it is again reported clear.

5. In turrets and enclosed mounts, a warning signal shall be installed outside the turret or mount; and whenever power train is used, except at general quarters, the officer or petty officer in charge of the turret or mount shall cause warning signals to be sounded before using power and at intervals during its use.

6. Changes, modifications in, or additions to ordnance material, or other material used in connection therewith, shall not be made without explicit authority from the bureaus concerned.

7. No ammunition or explosive assembly shall be used in any gun or appliance for which it is not designated.

8. No other than drill ammunition shall be used for drill.

9. On guns equipped with hydropneumatic counterrecoil systems, the safety link, locking the gun to the slide, shall be connected up at all times except when firing or when testing and overhauling the counterrecoil systems or when a battery is in a condition of readiness for action.

10. Except in action or when specifically authorized, antiaircraft guns shall not be fired at elevations greater than, or fuze settings less than, those prescribed in the current orders for Gunnery Exercises. When firing antiaircraft guns as such, all personnel not required to be exposed shall be kept under cover.

II. Ammunition Handling and Stowage

1. As familiarity with any work, no matter how dangerous, is apt to lead to carelessness, all persons who may supervise or perform work in connection

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with the inspection, care, preparation, use, or handling of ammunition or explosives—

(*a*) Shall exercise the utmost care that all regulations and instructions are rigidly observed.

(*b*) Shall carefully supervise those under them and frequently warn them of the necessity of using the utmost precaution in the performance of their work. No relaxation of vigilance shall ever be permitted.

2. Except in case of emergency, ammunition shall not be transferred during fueling operations.

3. All ammunition, explosives, and powder shall be protected from abnormally high temperature. If so exposed, they shall be handled in accordance with current instructions of the Bureau of Ordnance. Permissible maximum storage temperatures shall be prescribed by the Bureau of Ordnance.

4. Smokeless powder which has been wet from any cause whatever must be regarded as dangerous for dry storage. Such powder shall be handled in accordance with current instructions of the Bureau of Ordnance.

5. Smokeless powder which shows unmistakable signs of advanced decomposition shall be disposed of in accordance with current instructions of the Bureau of Ordnance.

6. To minimize the risk of fire, explosion, and damage to ammunition and its containers from accidental causes, ammunition shall be handled as little as practicable. As the action of denting thin-cased high-explosive ammunition is known to have caused detonation of the explosive in some instances, special care shall be exercised to insure that such ammunition is never struck, dropped, or bumped.

7. Defective bomb-type and thin-case ammunition shall be disposed of in accordance with current instructions of the Bureau of Ordnance.

8. A fuzed projectile, whether in a container or not, if dropped from a height exceeding 5 feet shall be dumped overboard in a manner conforming with regulations for dumping ammunition at sea except when practicable to turn the projectile in to a Naval Ammunition Depot. Such ammunition shall be handled with the greatest care.

9. Care must be used to avoid tapping or otherwise striking fuzed projectiles. This precaution is particularly applicable to attempts to loosen such a projectile in the cartridge case by repeated light blows of a mallet, unloading such a projectile wedged in the bore of a gun, and the striking of a projectile by the recoil of a gun or an ejected case.

10. The covers of switches, circuit breakers, etc., shall be kept securely closed while powder is exposed in the vicinity.

11. Magazines shall be kept scrupulously clean and dry at all times. Nothing shall be stored in magazines except explosives, containers, and authorized magazine equipment. Particular attention shall be paid that no oily rags, waste, or other foreign materials susceptible to spontaneous combustion are stored in them.

12. Naked lights, matches, or other flame-producing apparatus shall never be taken into magazines or other spaces used primarily as magazines while these compartments contain explosives.

13. Before performing any work which may cause either an abnormally high temperature or an intense local heat in a magazine or other compartment used primarily as a magazine, all explosives shall be removed to safe storage until normal conditions have been restored.

14. Black powder is one of the most dangerous of explosives and shall always be kept by itself. Only such quantities as will meet immediate needs shall be taken from the magazines. A container of black powder shall never be opened in a magazine nor in the vicinity of a container in which there is any explosive.

15. Ammunition shall not be altered, nor shall fuzes or any other parts be removed or disassembled, without explicit instructions from the Bureau of Ordnance.

III. Service of Guns, including Ammunition Supply

1. Live ammunition shall be loaded into guns for firing purposes only. Test or inspection of ammunition by fitting it into guns is prohibited, except when authorized by specific instructions of the Bureau of Ordnance.

2. During firing no other ammunition than that immediately required shall be permitted to remain outside of the magazine.

3. During gunnery exercises, charges in excess of the amount required to be available for one run shall not be assembled in the vicinity of guns mounted outside of turrets. No charge for a bag gun shall be removed from its tank, nor shall the tops of tanks be removed or so loosened that the bags may be exposed to flame until immediately before the charge is required for loading.

4. When either cartridges or bag charges are outside the magazines, each flame-proof compartment or space which forms a stage of the ammunition train, including the magazines and gun compartments (in or out of turrets), shall, wherever practicable, be kept closed from all other compartments or spaces except when the actual passage of ammunition requires it to be open. Where practicable, no flameproof stage

of the ammunition train shall be open to both the preceding and the following stages at the same time.

5. If flame seals be damaged during firing, except in action, so that they can not fulfill their purpose, the gun or guns concerned shall cease firing until the flame seals are again effective.

6. (*a*) In a magazine or handling room in which powder is removed from tanks to be sent to the guns in bags, not more than one charge per gun, for the guns being served by that magazine or handling room, shall be exposed by removal from tanks, by removal of tank tops, or by so loosening the tank tops that the bags may be exposed to flame.

(*b*) In each subsequent flameproof stage of the ammunition train, not more than one charge per gun, for the guns being supplied through that stage, shall be allowed to accumulate. For this purpose, the spaces or handling rooms at the tops and bottoms of continuous-chain powder hoists will be considered separate stages (whether or not separated from the hoists by flameproof doors, flaps, or shutters).

(*c*) In addition to the above, continuous-chain powder hoists may be kept filled; or if hand passing is used, there may be one bag of powder at the station of each man in the train.

(*d*) It is the intent of this article to permit sufficient powder to be exposed to provide an adequate supply for the guns being served. The maximum amount specified above should be exposed only if a smaller amount will not assure an adequate supply.

7. As there is an inflammable gas present in the chamber of a gun after firing which, under certain conditions, may constitute a danger by igniting the powder charge which is to be used for the next round, and as smoldering remnants of powder bag may also be present, the following precautions shall always be observed:

(*a*) Bag guns shall not be loaded until a member of the crew has assured himself that the bore is clear of powder gases and remnants and has announced "bore clear" either by voice or by approved signal, such as a hand, whistle, gong, or horn, except that, when the gas-ejector system does not readily clear the bore, the combined sponge and rammer (where provided) may be used. The sponge shall be dipped in water for each load.

(*b*) Until the "bore clear" signal above described is given, or the projectile is rammed home with the wet combined sponge and rammer, powder shall not be exposed closer than 4 feet to a gun not mounted in a turret.

(*c*) In turrets fitted with ammunition cars, the car and the center of an open breach shall not be allowed within 6 feet of one another until the "bore clear" signal has been given. In turrets fitted with continuous-chain powder hoists, or for hand passing, the powder shall not be exposed in the turret chamber, nor shall the flame seal, shutter, or flap between the turret chamber and the next stage in the powder train be opened or unlocked until the "bore clear" signal is given.

8. If a powder bag is broken to the extent of allowing powder to fall out, the command "Silence" shall be given and the loose powder shall be gathered up. If it is impracticable to utilize this section of the charge satisfactorily in loading, it shall be secured in a flameproof container or immersed in water.

9. In turrets not fitted with bulkheads between guns, the "bore clear" signal to the turret crew shall not be given until the guns which have been fired and whose breech plugs have been opened are reported clear, at which time one signal to the entire turret crew shall be given.

10. Care shall be exercised to prevent projectiles from slipping back from their seats, as unseated projectiles may cause abnormally high pressure. In bag guns, projectiles shall not be rammed by interposing one or more sections of a powder charge between the head of the rammer and base of the projectile.

11. The mushroom of every bag gun shall be wiped after each shot with a sponge or cloth dampened with fresh water.

12. As soon as a gun is loaded the breech shall be closed without delay.

13. When priming a lock of the sliding-wedge type, care shall be taken to insure the primer being pushed in beyond the primer catch to prevent the primer coming out or being crushed by the operation of the wedge in closing.

14. In loading a bag gun, neither the gun ready light switch nor the gun firing cut-out switch (which are combined in some installations) shall be in the closed position until the breech is fully closed and all personnel are clear of the recoil.

15. To guard against blowing out primers which may fire at the instant of closure, care shall be taken whenever the breech of a bag gun with a live primer in the lock is being closed, that the operating lever is followed through during the last part of its travel, to prevent any opening of the lock due to rebound.

16. The breech plug of a bag gun shall never be unlocked or opened while there is a live primer in the lock.

17. A firing lock into which a live primer has been inserted shall never be opened, either independently or by operation of the breech mechanism, unless the firing circuit is broken externally of the lock or breech mechanism (for example, at local pointer's key or gun captain's ready switch), except when it is known that the loaded gun has fired. This applies to the firing of

primers at drill, to the operation of loaded guns, and the examination of primers.

18. The limiting position of the breech of the gun on recoil shall be indicated and the gun crew shall be instructed to keep clear.

19. While a gun is being unloaded, all personnel not required for the unloading operation shall be kept at a safe distance from the gun.

20. Only approved ramming devices and methods shall be used in loading live cartridges. Any cartridge which does not freely and fully enter the chamber of the gun shall be carefully extracted and put aside, and no further attempt shall be made to fire such a cartridge.

21. In every case gun using primers with a percussion element, except those guns of the sliding-wedge type, the breech plug shall not be closed until the plugman is assured by actually feeling that the front face of the plug is free from any projections, such as a protruding firing pin or fuzed metal, in order to prevent discharge of the gun when the breech plug is swung to but not rotated.

22. In order to avoid danger from inflammable gases, fired cartridge cases shall, before stowing below, remain in freely circulating open air for at least 10 minutes. If practicable they should be stored on their bases.

23. Effective measures shall be taken to guard against prematurely opening the breech of a loaded gun, whether or not the gun is fitted with a salvo latch.

24. If a gun is loaded at the order "cease firing"—

(*a*) The gun shall be kept pointed and trained in a safe direction.

(*b*) The breech mechanism shall be kept fully closed.

(*c*) The gun shall normally be cleared by firing as soon as practicable.

25. A loaded and fuzed projectile, seated in the bore of a gun that is hot from previous firing, presents a hazard, since detonation of the projectile is possible as a result of being heated. Whenever practicable, such projectile should be disposed of promptly by firing the round. Whether a gun is hot or cold, the risks attendant upon removing a loaded and fuzed projectile seated in the bore, by backing out, are considered unwarranted except in the case of guns for which existing instructions specifically prescribe this procedure.

26. (*a*) The possibility of a serious accident due to opening the breech of a gun too soon in the case of a hangfire demands the constant exercise of the utmost prudence and caution. A hangfire must be assumed to exist when:

(1) An unsuccessful attempt has been made to fire the gun.

(2) A charge remains in a bag gun, with the possibility of ignition by an undetected ember from the previous round.

(*b*) The following procedure shall be followed in the cases noted above:

(1) Keep the gun pointed and trained in a safe direction.

(2) Keep the breech mechanism fully closed.

(3) Continue attempts to fire, if desired, repriming bag guns provided such efforts do not involve any movement tending to open the breech.

(*c*) If the gun is not fired under the above conditions:

(1) Open the firing key and break the firing circuit elsewhere.

(2) Unhook the firing lanyard, if detachable.

(3) Remove the primer from the lock of a bag gun, using the primer tools supplied for this purpose, taking care to avoid danger from recoil or blowback. For this purpose, or for shifting primers, do not leave the firing lock open longer than necessary.

(4) Do not open the breech for 30 minutes (10 minutes for field and landing guns on shore) after the last attempt to fire. This, at the discretion of the commanding officer, is not obligatory in time of action; nor is it obligatory or advisable with a hot gun if an instruction of the Bureau of Ordnance to prevent a projectile "cook-off" recommends earlier opening of the breech when the gun cannot otherwise be cleared by firing it.

(*d*) The crew shall never leave a loaded gun until the precautions in (*b*) and (*c*) (1) to (3) above have been carried out.

(*e*) Ammunition removed from a loaded gun shall be disposed of in accordance with current instructions of the Bureau of Ordnance.

27. Ships shall cease the firing of any gun whose line of fire is endangering any object other than the designated target. These objects include friendly ships and aircraft and own ship's structure together with the mounts and launchers and their barrels, fixed or moving. This stipulation applies to objects in the vicinity of the firing point, throughout the trajectory and in the vicinity of the target. Turrets, mounts, guns and launchers which are not firing, shall be trained and elevated if manned, or secured if unmanned, in a manner that will provide the greatest amount of safety from the firing. The position of greatest amount of safety of the unmanned mounts will generally be that position which the firing cut-out mechanism cams of the firing mounts were cut to clear.

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IV. Precautions to be Observed in Handling, Fuzing, or Inserting Detonators in Explosive Ordnance

1. Since it is not always possible to ascertain readily whether mines, depth charges, rockets, projector charges, and aircraft bombs have been inadvertently armed in storage or handling, all of these types, when fuzed or assembled with firing mechanisms, shall at all times be handled and treated as if armed, in strict conformity with the instructions for safeguarding against the inadvertent arming, firing, or launching of such ammunition.

2. Certain types of bombs, mines, depth charges, rockets, and projector charges are normally issued unfuzed. Fuzes shall not be inserted in such ammunition (nor in the case of fuzes having separate detonators, shall the detonators be inserted into the fuzes) until just prior to placing in ready stowage, or just prior to or after loading the ammunition on the racks, launchers, or projectors preparatory to dropping or launching. Such fuzing or inserting of detonators shall not be accomplished in or near a magazine or ready service stowage, but may be accomplished in handling rooms or spaces specially designated for such purposes by competent authority. In general, fuzing or inserting of detonators shall be done on individual rounds isolated from other ammunition insofar as practicable.

3. Fuzes which have been set shall be reset to the safe position before sending them below.

4. Fuzes, firing mechanisms, or primer mechanisms for bombs, depth charges, rockets, projector charges, demolition outfits, or mines shall not, except as covered by special orders or current instructions of the Bureau of Ordnance, be removed, disassembled, repaired, or in any way altered.

5. Bombs, rocket heads, and projector charges, for which fuzes are issued separately, shall not be stowed with those fuzes installed in or near magazines containing explosives.

6. Fuzes issued separately for bombs, rockets, and projector charges, which contain integral detonators or other explosive components, shall be stored only in specially designated fuze magazines which shall not be located adjacent to magazines containing high explosives.

7. Detonators which are not assembled integrally with fuzes shall be stored only in standard type detonator lockers located in approved places.

8. Fuze-arming wires or devices shall not be removed from the unarmed position until just before releasing or firing. Safety pins or other devices requiring removal before flight, or firing, shall not be removed until the ammunition has been loaded in racks, projectors, or launchers and not until after the arming wire or device has been put in place. Bombs, mines, depth charges, rockets, or projector charges not expended shall be made "safe" at the first opportunity in accordance with current instructions for the respective assemblies. When handling or unarming an accidentally armed fuze, the prescribed procedure shall be carefully followed.

9. Electric igniters, primers, or detonators, electrically fired rocket and guided missile motors, electric or electronic ordnance fuzes, including VT fuzes, shall not be stowed in the same compartment with, or be exposed within five feet of, any exposed electronic transmitting apparatus or antenna or antenna lead, except where such electronic apparatus or antenna is a part of authorized test equipment of a weapon or is integral with a weapon containing such components, in which event special instructions pertinent thereto shall apply.

V. Torpedoes, Torpedo Air Flasks, and Accessories

1. Torpedo air flasks shall never be charged to more than 100 pounds above the prescribed working pressure. When the prescribed working pressure is for any reason altered, the new pressure designated shall be stamped on the flask near the charging valve.

2. The artificial cooling of torpedo air flasks during or after charging by spraying with water or by flooding the torpedoes in the tubes is prohibited.

3. Any cutting of torpedo air flasks, accumulators, piping, or other receptacles for compressed air is prohibited.

4. Torpedo air flasks in a fully charged condition shall not be transported, hoisted from one deck to another, struck below, etc., except when it is not possible to perform the operation efficiently and expeditiously with the air flasks partially charged.

5. In recovering a torpedo in the water the propeller lock shall be put on at the first opportunity and kept on until the torpedo is safely landed.

6. Because the filling material used in torpedo torch pots ignites spontaneously or forms poisonous gas when combined with water, or subjected to moisture, extreme care must be taken to follow existing Bureau of Ordnance instructions concerning the handling of torch pots.

7. The use of electric torpedoes involves hazards of mechanical injuries, electrical shock or burn, acid burns, and hydrogen explosion or combustion. Bureau of Ordnance instructions prescribe effective measures to prevent accidents and shall be rigidly adhered to at all times.

VI. Miscellaneous Ordnance Safety Precautions

1. Current instructions prescribe effective measures for the safe employment, operation, and service of catapults and their guns. In addition, all safety precautions pertaining to guns and ammunition, unless manifestly inapplicable, apply to catapult guns and their ammunition.

2. Smoke-making devices which misfire or have been in the water shall not be taken on board ship or inside buildings or structures on shore. Gas masks shall be worn when entering concentrated smoke clouds.

3. All personnel working with chemical ammunition shall be trained in the fundamentals of handling toxic chemicals and shall be familiar with the instructions pertaining thereto. They shall be equipped with adequate and effective equipment, including protective clothing and gas masks.

4. Pyrotechnic material shall always be kept by itself in regular pyrotechnic storage spaces, if such are provided, or in pyrotechnic lockers on upper decks. In using it, only a minimum amount shall be exposed.

5. All personnel shall keep clear of the possible exhaust path of rockets at all times.

6. Launcher-firing circuits shall not be tested when rockets are in the launchers.

7. In case of rocket misfire, personnel shall not approach the rocket for at least 10 minutes, nor until firing circuits are known to be open. This, at the discretion of the commanding officer, is not obligatory in time of action.

8. When a misfire occurs in handling demolition material, an ample margin of time shall be allowed before investigating the reason of misfire. A period of 30 minutes after the longest predictable delay has elapsed is considered ample.

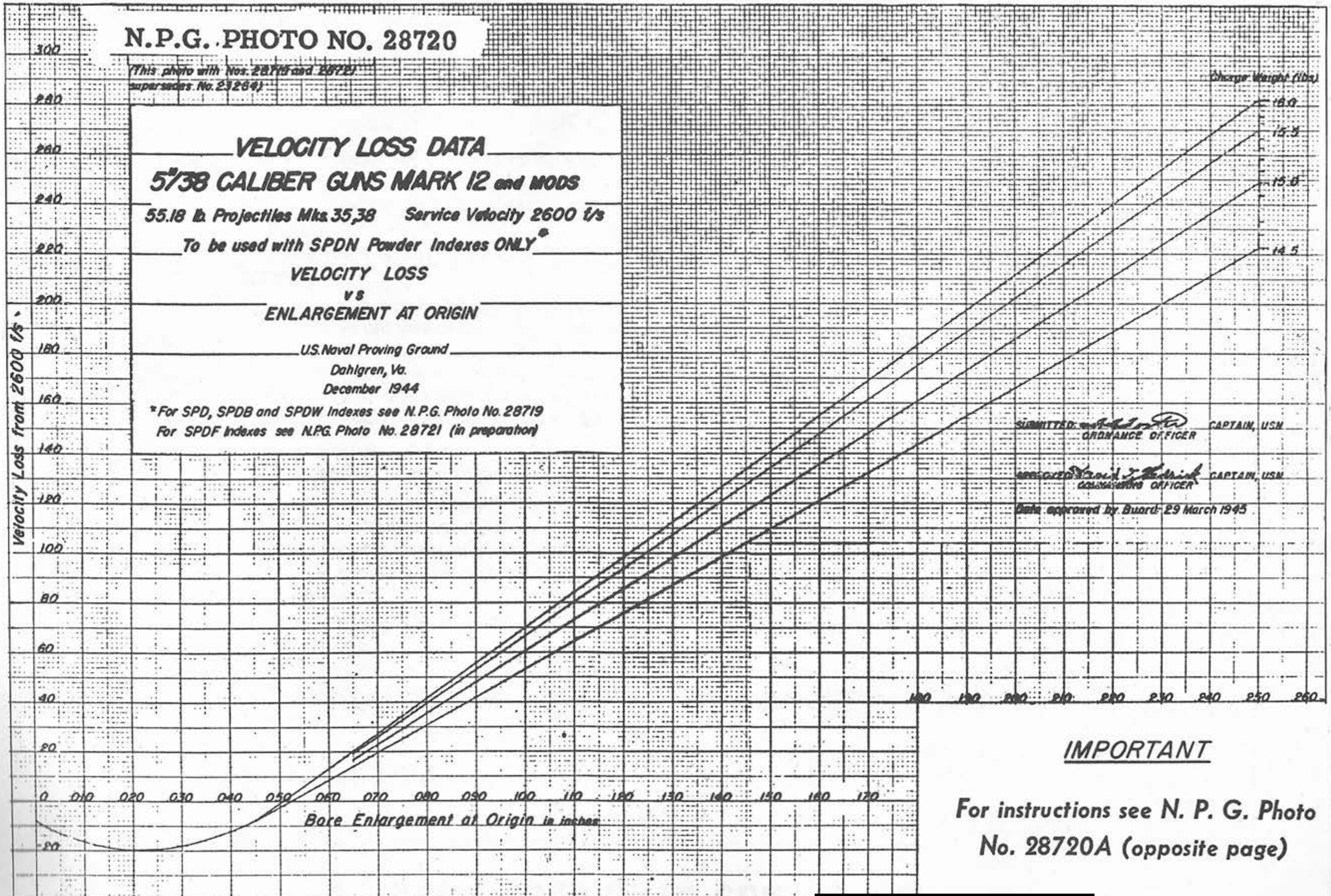
9. In firing small arms, machine guns, and submachine guns, whenever a blow-back occurs, the bore shall be examined for foul bore before firing another round.

Appendix B

VELOCITY-LOSS DATA CURVES (5"/38 GUN)

The curves and data reproduced in the following pages are intended for use in connection with part of the text of chapter 7.

VELOCITY-LOSS DATA CURVES



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VELOCITY-LOSS DATA CURVES (Continued)

N.P.G. Photo No. 28720 A

INSTRUCTIONS for use of N.P.G. Photo No. 28720 (opposite page):

I Powder Index	II Charge Correction	III Velocity Loss
0 to 4103 4105 to 4120 4122, 4123, 4331 4347, 4348	0.15 lbs	+21 f/s
5609 to 5616 5618	0	+6 f/s

A If powder index to be used is NOT listed in Column I:

1. Enter curves with present estimated bore enlargement and charge weight as marked on powder tank (interpolating if necessary) and obtain velocity loss.

B If powder index to be used IS listed in Column I:

1. Add the charge correction given in Column II to the charge weight marked on powder tank and obtain corrected charge weight.
2. Enter the curves with this corrected charge weight (interpolating if necessary) and present estimated bore enlargement and obtain velocity loss due to erosion.
3. To this loss add the loss given in Column III to obtain velocity loss due to both erosion and charge weight as assembled.

EXAMPLE:

Given Index SPDN 4103 (charge weight marked on tank 14.78 lbs) and Bore Enlargement 0".190.

1. Corrected charge weight is 14.78 + .15 = 14.93 lbs.
2. Velocity loss due to erosion is 171 f/s.
3. Total velocity loss is 171 + 21 = 192 f/s.

U.S. Naval Proving Ground
Dahlgren, Va.
December 1944

Date approved by BuOrd:
29 March 1945

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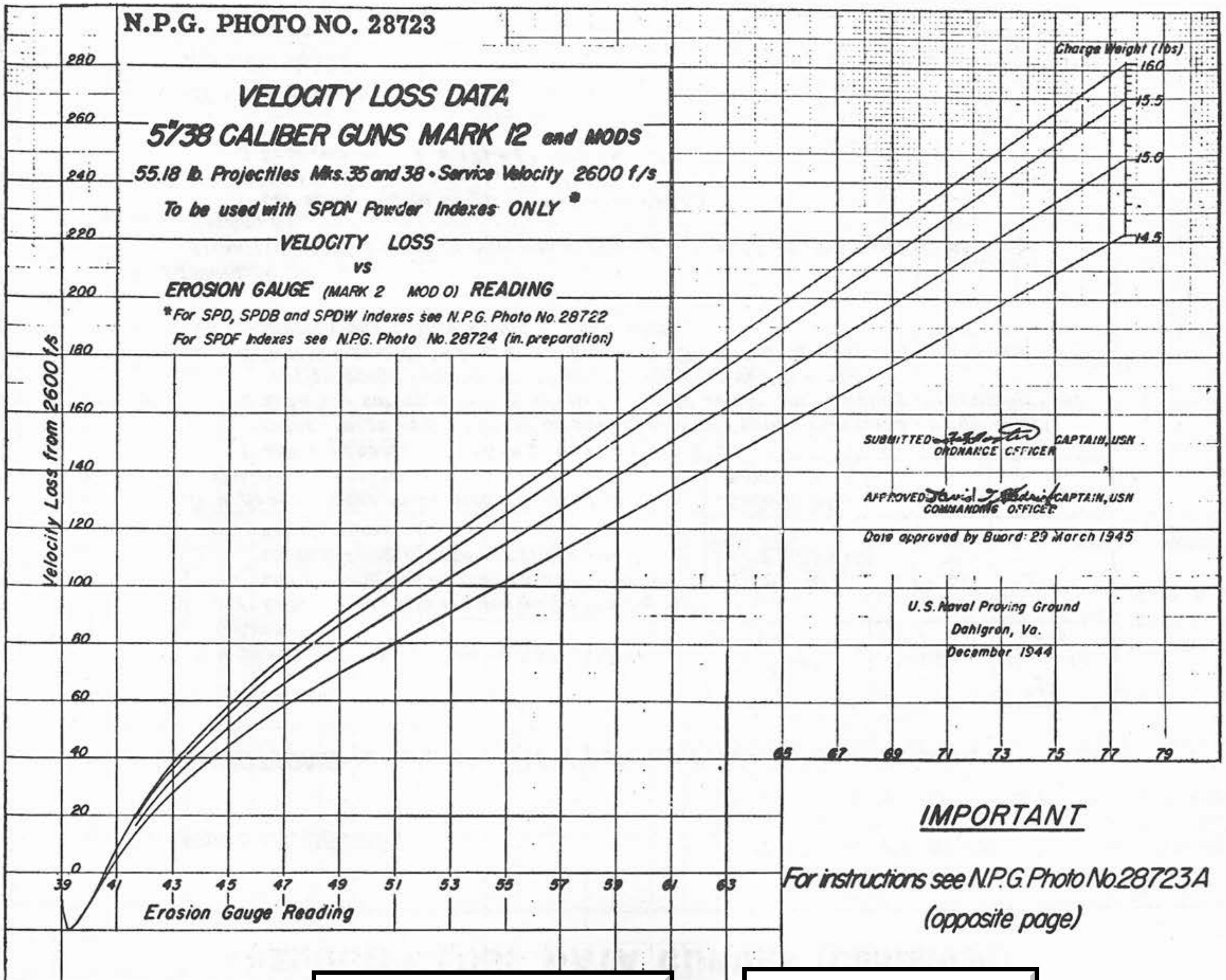
VELOCITY-LOSS DATA CURVES (Continued)



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N.P.G. Photo No. 28723A

INSTRUCTIONS for use of N.P.G. Photo No. 28723 (opposite page):

I Powder Index	II Charge Correction	III Velocity Loss
0 to 4103 4105 to 4120 4122, 4123, 4331 4347, 4348	0.15 lbs.	+21 f/s
5609 to 5616 5618	0	+6 f/s

A If powder index to be used is NOT listed in Column I:

1. Enter curves with erosion gauge reading and charge weight as marked on powder tank (interpolating if necessary) and obtain velocity loss.

B If powder index to be used IS listed in Column I:

1. Add the charge correction given in Column II to the charge weight marked on powder tank and obtain corrected charge weight.
2. Enter the curves with this corrected charge weight (interpolating if necessary) and erosion gauge reading and obtain velocity loss due to erosion.
3. To this loss add the loss given in Column III to obtain velocity loss due to both erosion and charge weight as assembled.

EXAMPLE:

Given Index SPDN 4103 (charge weight marked on tank 14.78 lbs) and Erosion Gauge Reading 65.1

1. Corrected charge weight is 14.78 + .15 = 14.93 lbs.
2. Velocity loss due to erosion is 171 f/s.
3. Total velocity loss is 171 + 21 = 192 f/s

U.S. Naval Proving Ground
Dahlgren, Va.
December 1944

Date approved by BuOrd:
29 March 1945

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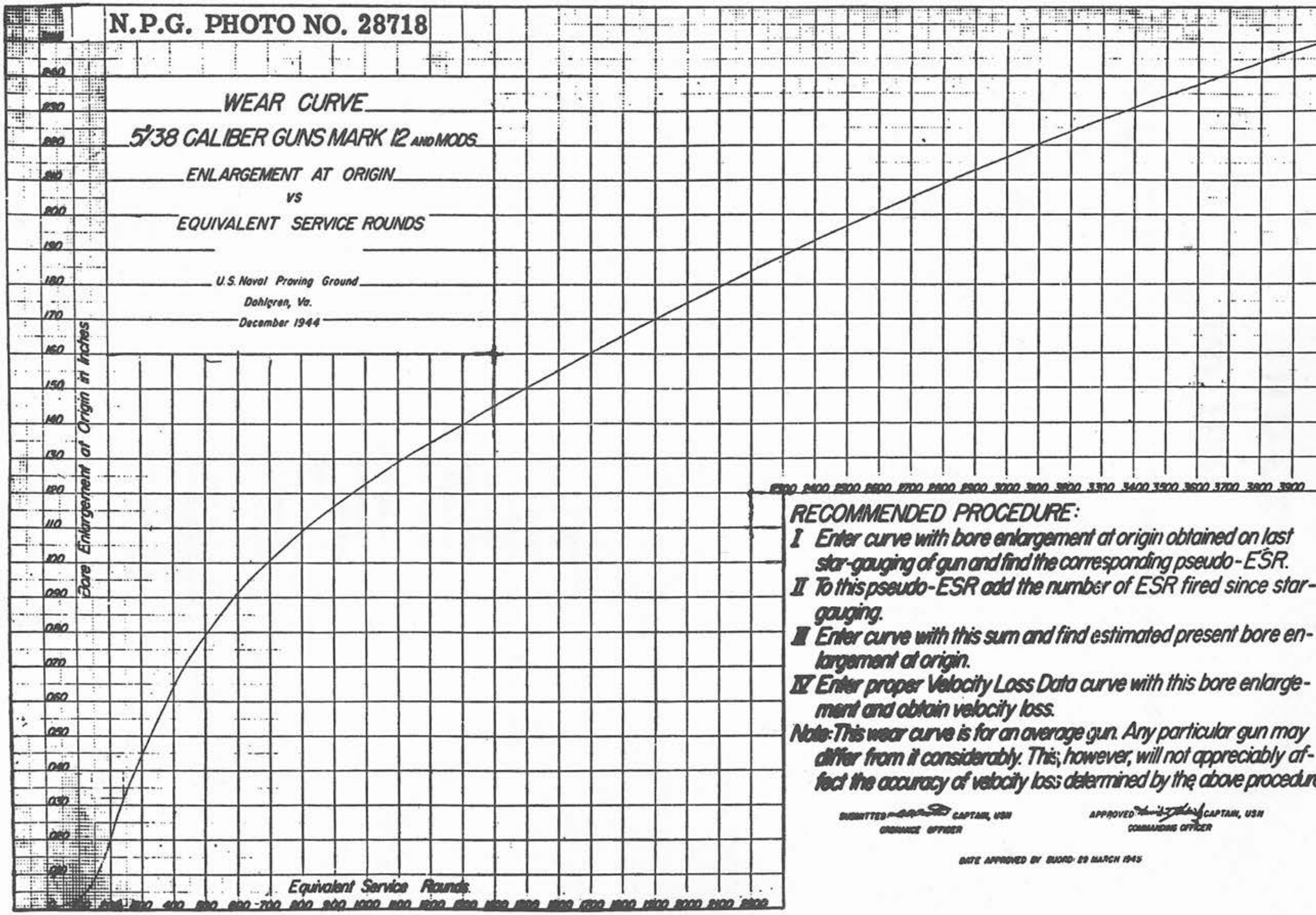
VELOCITY-LOSS DATA CURVES (Continued)



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