GUNNER'S MATE M 3 & 2

NAVAL TRAINING COMMAND

NAVY TRAINING COURSE NAVTRA 10199-B

Gene Slover's US Navy Pages

Phil Hays' Talos Missile Page

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INSIDE FRONT COVER

PREFACE

This Rate Training Manual was written to serve as an aid for enlisted men of the U. S. Navy and Naval Reserve who are preparing for advancement to the rates of Gunner's Mates M (Missiles) 3 & 2. It is one of a series of Rate Training Manuals designed to give enlisted men background information necessary for the proper performance of the duties of their rates.

The predominant factor in the selection of content for this publication has been the Manual of Qualifications for Advancement, NavPers 10868C. When supplemented by practical experience in the maintenance and repair of launching system equipment, this manual will help the GMM meet the Qualifications for Advancement.

This manual was prepared for the Naval Training Support Command by the Naval Personnel Program Support Activity, Training Publications Division, Washington, D.C. Acknowledgement is made to the Naval Ordnance Systems Command, Washington, D.C.: Naval Examining Center, Great Lakes, Illinois: and to the Gunner's Mates School, Great Lakes, Illinois, whose technical review, comments, ideas, and suggestions have been most helpful.

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THE UNITED STATES NAVY

GUARDIAN OF OUR COUNTRY

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

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

WE SERVE WITH HONOR

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

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

Our responsibilities sober us; our adversities strengthen us.

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

THE FUTURE OF THE NAVY

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

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

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

Never have our opportunities and our responsibilities been greater.

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Phillip Hays PhD LT USNR-R

April 2009

CHAPTER 1

THE GUNNER'S MATE (MISSILES) RATING

This training manual has been prepared to help men of the Navy and of the Naval Reserve meet the occupational qualifications for advancement to Gunner's Mate Missiles 3 & 2. The Gunner's Mate qualifications used as a guide in the preparation of this training manual are those contained in the Manual of Qualifications for Advancement in Rating, NavPers 18068-C. Therefore, the qualifications pertaining to your rating are not reproduced in this training manual. We suggest that you study the latest changes and revisions listed in NavPers 18068-C to get an idea of the scope of the skills and knowledge you must have to advance in rating.

This training manual has been organized in such a way as to give you a systematic understanding of your job. Chapter 2 discusses the fundamental fire control problem presented by a projectile or a guided missile. Chapter 3 introduces you to missiles and rockets and their principles of flight. Chapter 4 covers missile guidance and control techniques. Chapter 5 presents the functional requirements of guided missile launching systems. Chapter 6 combines fire control, guns and missiles, and launching systems into a weapons system. In chapter 7 you will study servomechanisms. Chapter 8 describes the use of hydraulics and pneumatics in missile systems. Chapter 9 describes many of the electrical devices used in launching systems and some of their applications therein. Since you are required to handle explosives and know how to maintain magazines, chapter 10 covers them. A new qualification for the GMM rating - small arms, landing party equipment and demolition - is covered in chapter 11. Chapter 12 includes information about general maintenance, such as maintenance aids and procedures. Chapter 13 reviews common test equipment and some troubleshooting hints. Chapter 14 discusses special test equipment used in keeping launchers in top working order. This chapter also covers several methods of replenishing missile firing ships. Chapter 15, the last chapter in this manual, tells about the paper work you do and the many sources of information needed to keep your equipment in good operating condition. Many of the publications you must use are classified. Basic Military Requirements. NavPers 10054-C, gave you basic rules for safeguarding classified publications and material that you use in your work.

The remainder of this chapter gives information on the enlisted rating structure, the Gunner's Mate rating, requirements and procedures for advancement in rating, and references that will help you in working for advancement and in performing your duties as a G M. This chapter also includes information on how to use Navy Rate Training Manuals. Therefore, it is strongly recommended that you study this chapter carefully before beginning intensive study of the remainder of this training manual.

THE ENLISTED RATING STRUCTURE

The two main types of ratings in the present enlisted rating structure are general ratings and service ratings.

GENERAL RATINGS identify broad occupational fields of related duties and functions. Some general ratings include service ratings; others do not. Both Regular Navy and Naval Reserve personnel may hold general ratings.

SERVICE RATINGS identify subdivisions or specialties within a general rating. Although service ratings can exist at any petty officer level, they are most common at the PO3 and PO2 levels. Both Regular Navy and Naval Reserve personnel may hold service ratings.

THE GUNNER'S MATE RATING

Prior to the introduction of missiles and rockets into the Navy, the Gunner's Mate rating was covered under the abbreviation of GM. This denoted the general rating to which all

Gunner's Mates belonged. The GM was the jack-of-all-trades in the ordnance field.

When guided missiles were added to the Navy's arsenal of weapons, the general rating of Gunner's Mate was given the responsibility of maintaining these systems. This action effectively bridged the gap for a period of time. Eventually, however, a decision was made to separate the general rating into three service ratings. One of these is to maintain gun and rocket launching systems and Basic Point Defense Missile System. This rating is designated GMG. Another service rating, GMM, was assigned to maintain missile launching systems, Still another service rating GMT, was established to maintain nuclear weapons, and recently, the ASROC launching group.

The GMT rating is separated from the other two service ratings up through the pay grade of E-9. The remaining two service ratings, GMG and GMM, remain separated up to and including E-7. At the E-8 and E-9 levels they are combined into the general rating of Gunner's Mate (GMCS and GMCM).

This means that the E-7 Gunner's Mate M, in order to advance, must be prepared to maintain conventional gun systems and rocket launching systems. In other words, an E-7 GMM taking an examination for E-8 will be examined on the qualifications expected of the GMG in addition to his own.

The GMM rating can be further subdivided into classes. Each class is assigned a Navy Enlisted Classification (NEC) number. The purpose of these codes is to assist in identifying personnel in a rating when a broad definition (such as GMM) is not enough. Code numbers are assigned to personnel with specialized skills and training. Examples of such codes are GM- 0986, assigned to gunner's mates who have graduated from the guided missile launching system Mk 10 maintenance course, and GM-0988 the number given to the GMM who has graduated from the Tartar Mk 13 GMLS and missile maintenance course. A complete list of the codes is found in the Manual of Navy Enlisted Classifications, NavPers 15105 (latest revision).

As a GMM you are responsible for maintaining guided missile launching systems. Also, you must prepare guided missiles for testing, and replace faulty missile components when tests indicate that this should be done. To be effective in these duties, you must have a broad background in many occupational fields.

A GMM must be a mechanic in order to maintain, adjust, and repair machinery such as loaders, rammers, hoists, blast doors, and magazine doors. You must learn the principles of machines and how to use handtools, gages, measuring instruments, and test equipment.

Another field you must have a thorough knowledge of is electricity. This knowledge is applied in working with electric motors and generators, switchboards, and control panels for the equipment in the launching system.

You must be knowledgeable in the field of electronics. You will make tests and repairs on vacuum tubes, transistors, magnetic amplifiers, and power supplies.

You must be a hydraulic and pneumatic specialist because many units based on hydraulic and pneumatic principles are used in the launching systems you will be assigned to.

GMM BILLETS

GMM is a seagoing rating. This is not to say that GMMs never get duty on the beach. They do. But most of the billets are on combatant ships. These ships range from the small destroyer escort types to the large attack carriers.

Your billet, as you know, is the place or job to which you are assigned. The billets aboard ship to which you may be assigned are in guided missile launching systems. Primarily your billet calls for a man who will assist a senior GMM in the maintenance of a portion of a system. For example, you may work under a GMM2 whose responsibility is to keep the A-side of a launching system in top working order.

We will not give a list of detailed duties that you will perform in a particular billet. But in general we can say that you will be simply an assistant who will work under the direction of a more senior petty officer. If you are a striker, he will supervise your work closely. If you are third class, supervision will be a little less close and you will be allowed to show more initiative in performing your job. Besides the occupational or professional duties, you will have certain military duties, as do all ratings in the Navy. These military duties include the manning of battle stations, watch standing, and other assignments related to the requirements for naval operations, management, and security. This manual is concerned with your occupational and technical duties - NOT your military duties.

YOUR PART IN NAVAL LEADERSHIP

The Navy and Marine Corps have a continuing program of moral leadership and character education to ensure that naval leadership is maintained at a consistently high level. The Navy stresses moral responsibility and personal example. In 1963 the Secretary of the Navy reissued General Order 21. The objective of this general order is to revitalize and reemphasize naval leadership in all of its aspects. The three major aspects of naval leadership are:

1. Technical competence
2. Personal example
3. Moral responsibility

As a petty officer you will have an important practical part to play in your shipboard leadership program. You may take charge of a group of strikers. This will put you in a position of leadership. You will have two responsibilities- to accomplish a mission and to take care of your men. The general principles and techniques of leadership are fully discussed in Military Requirements for PO 3 & 2, NavPers 10056-C. However, let's do a little thinking about how you can help to carry out General Order 21 on a day-to-day basis.

Assume for a moment that your mission aboard ship is to maintain a launcher, and you have strikers to assist you. Now a big part of your job is to learn everything you can about the launcher and to pass on your knowledge to your men. Technical competence is a major aspect of good leadership. But being a skilled technician is not enough. You must inspire your strikers to do their work as efficiently as possible.

A national characteristic of the American fighting man is that he wants to know why he is called upon to perform certain tasks. You must explain to your strikers the importance of their work and how it affects the overall fighting efficiency of your ship. Make the smallest mechanical task take on the nobility of a cause. During exercises or drills make them feel they are winning a war, not just turning knobs on equipment. Keep in mind they are the men who will fight by your side in combat. When led with courage, spirit, and intelligence, they will fight as willingly and as efficiently as any fighter in the world. But it is up to you to provide inspiration so that it will seep down to them.

To inspire your strikers and others, you must have a strong moral character. Some of the character traits you can develop by conscientious study and practice are loyalty, integrity, and quiet self-confidence.

Loyalty is one of the most essential factors of leadership. Experienced officers and petty officers say that they would rather have a loyal man who is not an excellent worker than a disloyal man who does excellent work. Loyalty to the country, to the Navy, to your ship, to your division, to your chief, to your senior petty officer, and to the men who work with and for you-these are the prime requisites of leadership. The surest way to get the respect and loyalty of your men is to be loyal yourself.

Everytime you feel the urge to criticize the handling of your ship's affairs, stop short. You are a part, and an important part, of your ship. How can you expect your strikers to be loyal if you are not?

Deal with your men squarely and honestly. If you do, you will win and hold their respect. Be dependable. This mark of integrity involves keeping promises promptly. A reputation of being a "square shooter" is worth every effort on your part. Help to build this reputation early by not tolerating "gun-decking" or other methods of falsifying reports.

Good leaders have a quiet self-confidence (not an arrogant or cocky manner) based on thorough knowledge of the job and a belief in their own ability. Confidence begets confidence. If you have confidence in yourself, you can inspire confidence in your men.

ADVANCEMENT

Some of the rewards of advancement are easy to see. You get more pay. Your job assignments become more interesting and more challenging. You are regarded with greater respect by officers and enlisted personnel. You enjoy the satisfaction of getting ahead in your chosen Navy career.

But the advantages of advancement are not yours alone. The Navy also profits. Highly trained personnel are essential to the functioning of the Navy. By each advancement, you increase your value to the Navy in two ways. First, you become more valuable as a specialist in your own rating, and second, you become more valuable as a person who can train others and thus make far-reaching contributions to the entire Navy.

HOW TO QUALIFY FOR ADVANCEMENT

What must you do to qualify for advancement? The requirements may change from time to time, but usually you must:

1. Have a certain amount of time in your present grade.

2. Complete the required military and rating manuals.

3. Demonstrate your ability to perform all the PRACTICAL requirements for advancement by completing the Record of Practical Factors, NavPers 1414/1.

4. Be recommended by your commanding officer, after the petty officers and officers supervising your work have indicated that they consider you capable of performing the duties of the next higher rate.

5. Demonstrate your KNOWLEDGE by passing written examinations on the occupational and military qualification standards for advancement.

Some of these general requirements may be modified in certain ways. Figure 1-1 gives a more detailed view of the requirements for advancement of active duty personnel; figure 1-2 gives this information for inactive duty personnel.

Remember that the qualifications for advancement can change. Check with your division officer or training officer to be sure that you know the most recent qualifications.

Advancement in rating is not automatic. Even though you have met all the requirements, including passing the written examinations, you may not be able to" 'sew on the crow" or "add a stripe." The number of men in each rate and rating is controlled on a Navywide basis. Therefore, the number of men who may be advanced is limited by the number of vacancies that exist. When the number of men passing the examination exceeds the number of vacancies, some system must be used to determine which men may be advanced and which may not. The system used is the "final multiple" and is a combination of three types of advancement systems.

Merit rating system
Personnel testing system
Longevity, or seniority, system

The Navy's system provides credit performance, knowledge, and seniority, and, while it cannot guarantee that anyone person will be advanced, it does guarantee that all men within a particular rating will have equal advancement opportunity.

The following factors are considered in computing the final multiple:

Factor	Maximum Credit
Examination score	80
Performance factor (Performance evaluation)	50
Length of service (years x 1)	20
Service in pay grade (years x 2)	20
Medals and awards	15
	185

All of the above information (except the examination score) is submitted to the Naval Examining Center with your examination answer sheet. After grading, the examination scores, for those passing, are added to the other factors to arrive at the final multiple; A precedence list, which is based on final multiples, is then prepared for each pay grade within each rating. Advancement authorizations are then issued, beginning at the top of the list, for the number of men needed to fill the existing vacancies.

HOW TO PREPARE FOR ADVANCEMENT

What must you do to prepare for advancement? You must study the qualifications for advancement, work on the practical factors, study the required rate training manuals, and study other material that is required for advancement in your rating. To prepare for advancement, you will need to be familiar with (1) the Quals Manual, (2) the Record of Practical Factors, (3) a NavPers publication called Bibliography For Advancement Study NavPers 10052, and (4) applicable rate training manuals. The following sections describe them and give you some practical suggestions on how to use them in preparing for advancement.

Quals Manual

The Manual of Qualifications for Advancement, NavPers 18068-C, gives the minimum occupational and military qualification standards for advancement to each pay grade within each rating. This manual is usually called the "Quals Manual," and the qualifications themselves are often called "quals" The qualification standards are of two general types: (1) military qualification

REQUIREMENTS *	E1 to E2	E2 to E3	#† E3 to E4	#E4 to E5	† E5 to E6	† E6 to E7	† E7 to E8	† E8 to E9
SERVICE	4 mos. service—or completion of	6 mos. as E-2.	6 mos. as E-3	12 mos. as E-4	24 mos. as E-5.	36 mos. as E-6. 8 years total enlisted service.	36 mos as E-7. 8 of 11 years total service must be enlisted.	24 mos. as E-8. 10 of 13 years total service must be enlisted.
SCHOOL	Recruit Training.		Class A for PR3, DT3, PT3, AME 3, HM 3, PN 3, FTB 3, MT 3.			Class B for AGC MUC, MNC. ††		
PRACTICAL FACTORS	Locally prepared check-offs.	Record of Practical Factors, NavPers 1414/1, must be completed for E-3 and all PO advancements.						
PERFORMANCE TEST			Specified ratings must complete applicable performance tests before taking examinations.					
ENLISTED PERFORMANCE EVALUATION	As used by CO when approving advancement.		Counts toward performance factor credit in advancement multiple.					
EXAMINATIONS **	Locally prepared tests.	See below.	Navy-wide examinations required for all PO advancements.				Navy-wide, selection board.	
RATE TRAINING MANUAL (INCLUDING MILITARY REQUIREMENTS)		Required for E-3 and all PO advancements unless waived because of school completion, but need not be repeated if identical course has already been completed. See NavPers 10052 (current edition).					Correspondence courses and recommended reading. See NavPers 10052 (current edition).	
AUTHORIZATION	Commanding Officer		Naval Examining Center					

* All advancements require commanding officer's recommendation.

† 1 year obligated service required for E-5 and E-6; 2 years for E-7, E-8 and E-9.

\# Military leadership exam required for E-4 and E-5. †† Waived for qualified EOD personnel.

** For E-2 to E-3, NAVEXAMCEN exams or locally prepared tests may be used.

Figure 1-1. — Active duty advancement requirements.

REQUIREMENTS *	E1 to E2	E2 to E3	E3 to E4	E4 to E5	E5 to E6	E6 to E7	E8	E9
TOTAL TIME IN GRADE	4 mos.	6 mos.	6 mos.	12 mos.	24 mos.	36 mos. with total 8 yrs service	36 mos. with total 11 yrs service	24 mos. with total 13 yrs service
TOTAL TRAINING DUTY IN GRADE †	14 days	14 days	14 days	14 days	28 days	42 days	42 days	28 days
PERFORMANCE TESTS			Specified ratings must complete applicable performance tests before taking examination.					
DRILL PARTICIPATION	Satisfactory participation as a member of a drill unit in accordance with BUPERSINST 5400.42 series.							
PRACTICAL FACTORS (INCLUDING MILITARY REQUIREMENTS)	Record of Practical Factors, NavPers 1414/1, must be completed for all advancements.							
RATE TRAINING MANUAL (INCLUDING MILITARY REQUIREMENTS)	Completion of applicable course or courses must be entered in service record.							
EXAMINATION	Standard Exam		Standard Exam required for all PO Advancements. Also pass Military Leadership Exam for E-4 and E-5.				Standard Exam, Selection Board.	
AUTHORIZATION	Commanding Officer		Naval Examining Center					

* Recommendation by commanding officer required for all advancements.

† Active duty periods may be substituted for training duty.

Figure 1-2. — Inactive duty advancement requirements.

standards and (2) occupational qualification standards.

MILITARY STANDARDS are requirements that apply to all ratings rather than to anyone particular rating. Military requirements for advancement to third class and second class petty officer rates deal with military conduct, naval organization, military justice, security, watch standing, and other subjects which are required of petty officers in all ratings.

OCCUPATIONAL STANDARDS are requirements that are directly related to the work of each rating.

Both the military requirements and the occupational qualification standards are divided into subject matter groups; then, within each subject matter group, they are divided into PRACTICAL FACTORS and KNOWLEDGE FACTORS. Practical factors are things you must be able to DO. Knowledge factors are things you must KNOW in order to perform the duties of your rating.

In most subject matter areas, you will find both practical factor and knowledge factor qualifications. In some subject matter areas, you may find both practical factor and knowledge factor qualifications. In some subject matter areas, you may find only one or the other. It is important to remember that there are some knowledge aspects to all practical factors, and some practical aspects to most knowledge factors. Therefore, even if the QUALS MANUAL indicates that there are no knowledge factors for a given subject matter area, you may still expect to find examination questions dealing with the knowledge aspects of the practical factors listed in that subject matter area.

You are required to pass a Navywide military/leadership examination for E-4 or E-5, as appropriate, before you take the occupational examinations. The military/leadership examinations are administered on a schedule determined by your commanding officer. Candidates are required to pass the applicable military/leadership examination only once. Each of these examinations consists of 100 questions based on information contained in Military Requirements for Petty Officers 3 & 2, Navpers 10056 and other publications listed in Bibliography For Advancement Study, Navpers 10052.

The Navywide occupational examinations for pay grades E-4 and E-5 will contain 150 questions related to. occupational areas of your rating.

If you are working for advancement to second class, remember that you may be examined on third class qualifications as well as on second class qualifications.

The Quals Manual is kept current by means of changes. The occupational qualifications for your rating which are covered in this training manual were current at the time the manual was printed. By the time you are studying this manual, however, the quals for your rating may have been changed. Never trust any set of quals until you have checked it against an UP-TO-DATE copy in the Quals Manual.

Record of Practical Factors

Before you can take the service-wide examinations for advancement, there must be an entry in your service record to show that you have qualified in the practical factors of both the military qualifications and the occupational qualifications. The RECORD OF PRACTICAL FACTORS mentioned earlier. is used to keep a record of your practical factor qualifications. This form is available for each rating. The form lists all practical factors. both military and occupational. As you demonstrate your ability to perform each practical factor appropriate entries are made in the DATE and INITIALS columns.

Changes are made periodically to the Manual of Qualifications for. Advancement and revised forms of Navpers 1414/1 are provided when necessary. Extra space is allowed on the Record of Practical Factors for entering additional practical factors as they are published in changes to the Quals Manual. The Record of Practical F actors also provides space for recording demonstrated proficiency in skills which are within the general scope of the rating but which are not identified as minimum qualifications for advancement.

Until completed. the NavPers 1414/1 is usually held by your division officer; after completion it is forwarded to the personnel office for insertion in your service record. If you are transferred before qualifying in all practical factors the incomplete form should be forwarded with your service record to your next duty station. You can save yourself a lot of trouble by making sure that this form actually is inserted in your service record before you are transferred. If the form is not in your service record you may be required to start all over again and requalify in the practical factors which have already been checked off.

Navpers 10052

Bibliography For Advancement Study, Navpers 10052 (revised), is a very important publication for any enlisted person preparing for advancement. This bibliography lists required and recommended rate training manuals and other reference material to be used by personnel working for advancement.

NavPers 10052 is revised and issued once each year by the Bureau of Naval Personnel. Each revised edition is identified by a letter following the Navpers number. When using this publication, be SURE that you have the most recent edition.

If extensive changes in qualifications occur in any rating between the annual revisions of NavPers 10052, a supplementary list of study material may be issued in the form of a BuPers Notice. When you are preparing for advancement, check to see whether changes have been made in the qualifications for your rating. If changes have been made, see if a Bupers Notice has been issued to supplement Navpers 1005 for your rating.

The required and recommended references are listed by pay grade in Navpers 10052. If you are working for advancement to third class, study the material that is listed for second class; but remember that you are also responsible for the references listed at the third class level.

In using Navpers 10052 you will notice that some rate training manuals are marked with an asterisk (*). Any manual marked in this way is MANDATORY - that is, it must be completed at the indicated rate level before you can be eligible to take the servicewide examination for advancement. Each mandatory manual may be completed by (1) passing the appropriate enlisted correspondence course that is based on the mandatory training manual; (2) passing locally prepared tests based on the information given in the training manual; or (3) in some cases, successfully completing an appropriate Navy school.

Do not overlook the section of NavPers 10052 which lists the required and recommended references relating to the military qualification standards for advancement. Personnel of ALL ratings must complete the mandatory military requirements training manual for the appropriate rate level before they can be eligible to advance.

The references in NavPers 10052 which are recommended but not mandatory should also be studied carefully. ALL references listed in Navpers 10052 may be used as source material for the written examinations, at the appropriate rate levels.

Rate Training Manuals

There are two general types of rate training manuals. RATING manuals (such as this one) are prepared for most enlisted ratings. A rating manual gives information that is directly related to the occupational qualifications of ONE rating. SUBJECT MATTER manuals or BASIC manuals give information that applies to more than one rating.

Rate training manuals are revised from time to time to keep them up to date technically. The revision of a rate training manual is identified by a letter following the NavPers number and the letter following this number in the most recent edition of List of Training Manuals and Correspondence Courses, NavPers 10061. (Navpers 10061 is actually a catalog that lists all current training manuals and correspondence courses; you will find this catalog useful in planning your study program.)

Each time a rate training manual is revised, it is brought into conformance with the official publications and directives on which it is based; but during the life of any edition, discrepancies between the manual and the official sources are almost certain to arise because of changes to the latter which are issued in the interim. In the performance of your duties, you should always refer to the appropriate official publication or directive. If the official source is listed in NavPers 10052, the Naval Examining Center uses it as a source of questions in preparing the fleet- wide examinations for advancement. In case of discrepancy between any publications listed in NavPers 10052 for a given rate, the Examining Center will use the most recent material.

Rate training manuals are designed to help you prepare for advancement. The following suggestions may help you to make the best use of this manual and other Navy training publications when you are preparing for advancement.

1. Study the military qualifications and the occupational qualifications for your rating before you study the training manual, and refer to the Quals frequently as you study. Remember, you are studying the manual primarily in order to meet these quals.

2. Set up a regular study plan. It will probably be easier for you to stick to a schedule if you can plan to study at the same time each day. If possible, schedule your studying for a time of

day when you will not have too many interruptions or distractions.

3. Before you begin to study any part of the manual intensively, become familiar with the entire book. Read the preface and the table of contents. Check through the index. Look at the appendixes. Thumb through the book without any particular plan, looking at the illustrations and reading bits here and there as you see things that interest you.

4. Look at the training manual in more detail to see how it is organized. Look at the table of contents again. Then, chapter by chapter, read the introduction, the headings, and the subheadings. This will give you a pretty clear picture of the scope and content of the book. As you look through the book in this way, ask yourself some questions:

- What do I need to learn about this?
- What do I already know about this?
- How is this information related to information given in other chapters?
- How is this information related to the qualifications for advancement?

5. When you have a general idea of what is in the training manual and how it is organized, fill in the details by intensive study. In each study period, try to cover a complete unit- it may be a chapter, a section of a chapter, or a subsection. The amount of material that you can cover at one time will vary. If you know the subject well, or if the material is easy, you can cover quite a lot at one time. Difficult or unfamiliar material will require more study time.

6. In studying anyone unit-chapter, section, or subsection-write down the questions that occur to you. Many people find it helpful to make a written outline of the unit as they study, or at least to write down the most important ideas.

7. As you study, relate the information in the training manual to the knowledge you already have. When you read about a process, a skill, or a situation, try to see how this information ties in with your own past experience.

8. When you have finished studying-a unit, take time out to see what you have learned. Look back over your notes and questions. Maybe some of your questions have been answered, but perhaps you still have some that are not answered. Without looking at the training manual, write down the main ideas that you have gotten from studying this unit. Don't just quote the book. If you can It give these ideas in your own words, the chances are that you have not really mastered the information.

9. Use enlisted correspondence courses whenever you can. The correspondence courses are based on rate training manuals or on other appropriate texts. As mentioned before, completion of a mandatory rate training manual can be accomplished by passing an enlisted correspondence course based on the rate training manual. You will probably find it helpful to take other correspondence courses as well as those based on mandatory manuals. Taking a correspondence course helps you to master the information given in the training manual, and also helps you see how much you have learned.

10. Think of your future as you study rate training manuals. You are working for advancement to third class or second class right now, but some day you will be working toward higher rates. Anything extra that you can learn now will help you both now and later.

SOURCES OF INFORMATION

Besides training manuals, Navpers 10052 lists official publications on which you may be examined. You should not only study the sections required, but should become as familiar as possible with all publications you use. One of the most useful things you can learn about a subject is how to find out more about it. No single publication can give you all the information you need to perform the duties of your rating. You should learn where to look for accurate, authoritative, up-to-date information on all subjects related to the military requirements for advancement and the occupational qualifications of your rating.

PUBLICATIONS YOU SHOULD KNOW

Some of the publications described here are subject to change or revision from time to time-some at regular intervals, others as the need arises. When using any publication that is subject to change or revision, be sure that 'you have the latest edition. When using any publication that is kept current by means of changes, be sure you have a copy in which all official changes have been made. Studying canceled or obsolete information will not help you to do your work to advance in rating; it is likely to be a waste of time, and may even be seriously misleading.

NAVORDSYSCOM Publications

As you might expect, the publication most often referred to in this manual as a source of amplifying information is the Ordnance Pamphlet (OP). OPs are the basic type of technical publications issued by the Naval Ordnance Systems Command (NAVORDSYSCOM). The equipment OP (which is the one you will most generally use) provides detailed instructions on operational theory, physical description of components, installation, maintenance, repair, and safety precautions for each item of ordnance equipment.

The manufacturer's technical manuals furnished with some items of equipment are valuable sources of information on operation, maintenance, and repair.

The OPs needed for your equipment will be aboard. If you feel a need for additional information, you can consult OP 0, the index of all OPs, for the titles and numbers of other publications, and then request them.

INSTRUCTIONS issued by the NAVORDSYSCOM are another source of information referred to in this manual. The purpose of these instructions is to pass out the details concerning the Command's policy in matters of operation and maintenance. The numbering system for the instructions is explained in chapter 15. The ones pertaining to the work of your division are filed in the office and additional copies of some may be kept in the work spaces.

BUPERS Publications

Some of the BUPERS publications that you will need to study or refer to as you prepare for advancement have already been discussed earlier in this chapter. The basic courses, published by BUPERS, will be referred to frequently in the manual. These include:

Basic Electricity, NavPers 10086-B
Basic Electronics, NavPers 10087-C
Fluid Power, NavPers 16193-B
Military Requirements for Petty Officer 3 & 2, Navpers 10056-C
Blueprint Reading and Sketching, Navpers 10077-C
Basic Machines, NavPers 10624-A
Basic Handtools, Navpers 10085-A

Large changes have been made in some of the revisions so be sure you have the latest revision of each book.

Since you will be working closely with Fire Controlmen and Gunner's Mates (Guns), you may find it useful to consult the rate training manuals prepared for those ratings.

Naval Ship Systems Command (NAVSHIPSYSCOM)

Missile launching systems and missile magazines must be installed and maintained to comply with ship's rules. These are given in NAVSHIPS Technical Manual, consisting of chapters, many of which are in pamphlet form. Use the table of contents to locate a particular chapter, and then use the index at the end of the chapter to find the topic you want.

The electricity used in your division is supplied by the ship, and ship's rules and regulations must be observed. These too, are given in the Technical Manual, along with some detailed instructions on care and repair of components.

TRAINING FILMS

Training films available to naval personnel are a valuable source of supplementary information on many technical subjects. Training films are listed in the United States Navy Film Catalog, NAVAIR 10-1-777 (formerly NAVWEPS 10-1-777-) published in 1969. Copies may be ordered in accordance with the Navy Stock List of publications and Forms, NAVSUP 2002. Monthly supplements to the Film Catalog are distributed to catalog holders.

When selecting a film, note its date of issue listed in the Film Catalog. As you know, procedures sometimes change rapidly. Thus some films become obsolete rapidly. If a film is obsolete only in part, it may sometimes be shown effectively if before or during its showing you carefully point out to trainees the procedures that have changed.

CHAPTER 2

HITTING A MOVING TARGET FROM A MOVING SHIP

As mentioned in chapter 1 of this training manual, the duties of the Gunner's Mate (Missiles) include the operation and maintenance of guided missile launching systems and associated handling equipment. Your duties as a GMM also include the handling and stowage of guided missiles and guided missile components, replacement and/or maintenance of components, assembly and inspection of missiles, and preparation of missiles for testing.

It would be fairly easy at this point to go right into the subject of guided missile launching systems and let it go at that. However, the launching system is only one part-though a very important part- of the overall shipboard weapons system.

As a GMM, you must know a great deal more about the launching system than merely the operation and maintenance of the mechanisms associated with it. To understand what the mechanisms do, you must know how they fit into the overall weapons system. Thus you must come to understand the basic fire control problem that must be solved to position a missile launcher, and to direct the missile to the target. You must also have a fairly good understanding of the guided missile which you are to launch- especially its propulsion system and warhead.

As a GMM you will be part of a weapons delivery team made up of Radarmen, Fire Control Technicians, and Gunner's Mate Technicians, to name some of the ratings directly involved. In studying this manual, you will come to know something of their jobs as, indeed, they will learn something about yours in their rate training manuals.

You learned some of the basics of fire control in Seaman, Navpers 10120-E, in the chapter on gunnery. With these ideas in mind, let us now take a brief look at some of the basic aspects of the shipboard fire control problems.

DEFINITIONS

A MISSILE may be defined as ANY object capable of being hurled, thrown, projected, or propelled, so as to strike a distant object.

An UNGUIDED MISSILE is a missile which is AIMED - but which CANNOT CONTROL its own trajectory, or flight path. A thrown rock is an example of an unguided missile.

A GUIDED MISSILE is a missile whose trajectory IS CONTROLLED during all or part of its flight, by mechanisms within the missile, or by responding to the missile guidance system.

A ROCKET is a missile which carries a propulsion system that is not dependent on the oxygen in the atmosphere.

Thus, the term MISSILE is a general one. The term ROCKET is specifically limited to missiles propelled by air-independent systems. The distinction between the two terms will become clearer to you later in this course. The important thing to remember now is that a rocket is limited in its meaning.

What is fire control? FIRE CONTROL can be defined as the practical application of exterior and interior ballistics, and the methods and devices used to control missiles, gun projectiles, torpedoes, and other weapons. Another way to put it, in terms of weapons, would be to say that fire control is the process of determining the exact relationship between a weapon and its target, and then using that information to get the weapon to strike or inflict damage on that target.

BASIC FIRE CONTROL PRINCIPLES

We will now cover briefly some basic fire control principles to give you an appreciation of the problems inherent in placing a missile or projectile on the proper trajectory. The principles will be covered in a simple and direct fashion, with no attempt to examine the mathematical aspects of the fire control problem.

(The details of the problem, for the most part, are the responsibility of Fire Control Technicians.)

To illustrate the basic principles of fire control, we will use a simple gunfire control situation. This method of presenting the problem is valid because missile concepts are similar to tried and proven gunnery principles. For example, the first experimental shipboard missile weapon system used modified gunfire control radars and computers to solve the missile fire control problem. Even the launching system used gun power drives to position the launcher. So you can see that there is a close relationship between gunnery and missilery ideas and equipment. As we progress through this chapter, we will point out the similarities and differences between the missile and gunfire control problems.

We will cover gunfire control principles as well as missile fire control concepts. As a GMM you should be familiar with the fire control problem. To advance in rating, a background knowledge of gunfire control is required. So, an early start in the study of gun and missile fire control will better prepare you to meet the professional (technical) qualifications for advancement in rating.

At the beginning of this chapter we distinguished between a guided missile and an unguided missile. Under our previous definitions, it may be said that a football, a bullet from a hunter's rifle, and a 5" projectile, as well as a thrown rock, are unguided missiles.

The problem of delivering a projectile from a gun to a target has been studied for years. Accurate computing devices have been developed to consider many factors before sending a projectile on its way to the target. These factors include target range and bearing, target course and speed, wind direction and speed, movements of the firing platform, and gun ballistics. When these and certain other factors have been determined, the gun may be fired. From that instant on, there is no control over the projectile's trajectory. It is "on its own." Whether or not it hits the target depends on the accuracy of the calculations prior to firing. If the calculations were inaccurate, and the projectile misses, corrections are introduced to bring the next one on the target. This process is repeated, if necessary, until the target is destroyed.

All of the calculations which go into the firing of a missile - whether it be guided or unguided - fall under the general heading of fire control. The term FIRE CONTROL SYSTEM denotes all of the equipollents necessary to achieve this objective.

ELEMENTS OF FIRE CONTROL SYSTEMS

It was stated earlier that a football falls under the category of a missile. Strangely enough, the "launching" of a football requires a fire control system which is in many ways similar to that required for guided missiles or unguided projectiles.

To place a missile - whether it be a football, gun projectile, or a missile - on a trajectory toward a target, there are three essential elements in the fire control system. These are:

1. A means of detecting the target and observing its movements. (Detection and tracking.)
2. A computing system which will accept various inputs and solve the fire control problem.
3. Communications channels which link the detecting equipment and the computing system.

Considering a football as a missile, the passer's eyes serve as the detection system. The passer's brain accepts detection information relayed from the eyes and computes the direction, elevation, and force which must be applied to the ball to place it on a trajectory to the receiver. In computing the proper direction, elevation, and force, the brain takes into consideration such factors as the thrower's motion, the instantaneous direction of the receiver, the direction and speed of the receiver's motion, and the direction and speed of the wind. If all of these are analyzed correctly, the missile launching system (in this case the passer's body) will release the ball with the proper force and in the proper direction to cause a "hit."

In this "human fire control" system, there are two obvious communication links. One of these connects the detection system (the eyes) to the computing system (the brain). The other connects the brain to the launcher - the body, or, more specifically, the arm.

We mentioned earlier that a bullet from a hunter's rifle also falls under the category of a missile. As in the football example, the eye serves as the detecting system, the brain as the computing system, and the body of the hunter and the rifle as the launching system.

Again, if the motions of the target are correctly detected and analyzed, the rifle should ultimately be correctly positioned in train and elevation to bring about a hit.

You will notice that there is one basic difference in the foregoing examples. In the case of the football player, the passer computed direction, elevation, AND force. In the case of the hunter, he computed only direction and elevation. The distinction lies in the fact that the force exerted on the football can be varied at the will of the passer. He may throw the ball 5 yards, or he may throw it 25 yards (or more). In the case of the hunter's rifle, the bullet will leave the rifle at essentially the same velocity (and with the same force) regardless of the distance or direction of the target. From experience, the hunter instinctively allows for this constant initial velocity as he leads his target in bearing and elevation.

By leading his target (a flying bird or running animal) in bearing we mean that the hunter must aim, not at where his target is now, but where he expects it will be when the bullet arrives. He also must aim slightly above the target because gravity pulls the bullet downward.

You will notice that the two key factors in placing a missile initially on its trajectory are bearing and elevation. If we have a rifle, 5" gun, or guided missile launcher initially aimed on the right bearing, and pointed in the proper direction above the horizontal (elevation), the missile will leave its launcher on the desired trajectory.

Earlier we said that the trajectory of a guided missile could be controlled after the missile left its launcher, whereas the trajectory of unguided missiles could not. This is an extremely important consideration, since a change in the target's motion (course and speed) while a projectile is in flight will cause a miss. The guided missile has been designed so that it can alter its trajectory while in flight. Even though the target's speed and direction may change after a guided missile has been launched, the missile guidance system will cause the missile to turn toward the target and yield a hit. The ways in which this is accomplished are described later in this course.

INFLUENCES ON TRAJECTORY BY OUTSIDE FORCES

Once a missile (guided or unguided) is launched, certain outside forces work on it during its entire flight. We will now look at the effects of some of these forces to give you an idea of some of the factors associated with the fire control problem.

Gravity

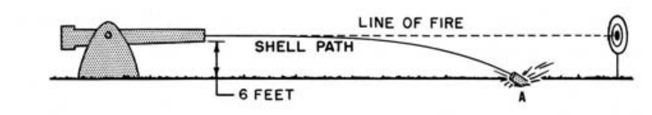
The primary natural force acting on a gun projectile or guided missile is gravity. The effects of gravity are felt throughout the entire universe. Everybody in the universe has a gravitational field which works on every other body in the universe. This has been stated mathematically in terms of mass and distance as follows:

Every body in the universe exhibits an attracting force on every other body which is proportional to the product of the mass of the bodies concerned, and inversely proportional to the square of the distance between them.

You have probably heard that the gravitational effects of the moon are considerably less than those on the earth. This is due to the fact that the moon has much less mass than the earth. The effects on the moon's gravity are readily apparent on earth as evidenced by the changing tides. The moon's closeness to the earth permits these effects to be detected. The planet Mars (in our solar system but much farther away than the moon) has a much stronger; gravitational field than the moon, but exhibits no apparent effects on the earth.

Let's come back to earth, and neglect the effects of gravitational fields other than our own. You have heard the old expression that everything that goes up must come down (long since proven dead wrong). For practical purposes, we can consider the expression to be true when the flight of a projectile or guided missile is considered. The earth's gravitational field is pulling on these objects throughout their entire flight.

In 1600, the Italian astronomer Galileo made an interesting observation about the pull of gravity. Legend has it that he dropped several objects of different weight from the Leaning Tower of Pisa, and noted that all of them struck the ground at about the same time. You may readily challenge this statement by persisting that a steel ball will fall faster than a feather. This occurrence is due to the air density rather than the difference in weight of the two objects. If a steel ball and a feather were dropped simultaneously from the same height in a vacuum, they I would strike the ground at precisely the same instant. Many experiments have shown that the pull of gravity causes a falling body to accelerate



12.1
Figure 2-1.—How gravity affects the trajectory of a projectile.

at the rate of about 32 feet per second (32 ft/sec^2). Acceleration is often expressed in terms of g's, one g being equal to an acceleration of 32 ft/sec^2.

Several simple formulas have been developed which will help you to understand the relationships of acceleration, distance, velocity, and time with respect to a freely falling body. For example, the distance a body will fall in a given amount of time may be computed by the formula:

$$d = 1/2\ gt^2$$

where d = distance in feet, t = time in seconds, and g = 32 ft/sec^2. By using this formula. we can show that a freely falling object will fall 16 feet the first second, i.e.:

$$d - (1/2)\ (32\ ft/sec^2)\ (1\ sec)^2 = 16\ ft$$

During the first two seconds, the body will fall (1/2) (32 ft/sec^2) (2 sec^2)2 = (32) (4) ÷ 2 = 64 ft.

To determine the velocity at any instant of fall, you can use the formula:

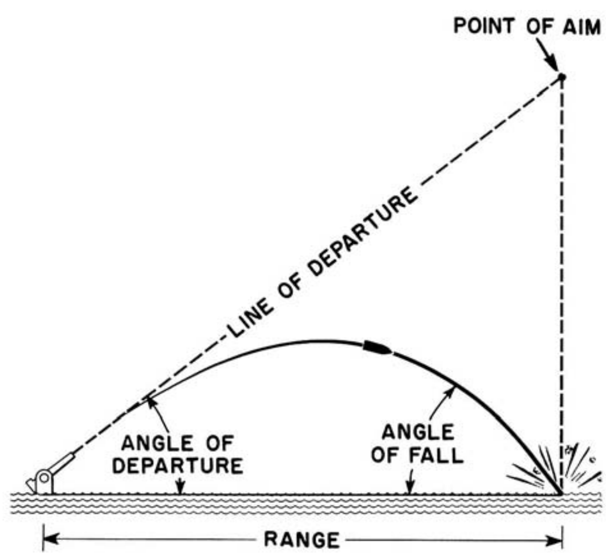
$$v = v_1 + gt$$

where v_1 is the initial velocity, g is 32 ft/sec^2, and t is the time in seconds. For example, at the instant of release, v_1 will equal zero. Therefore, the body would fall at the rate of 32 ft/sec at the end of the first second, since v = 0 + (32 ft/sec^2) (1 sec). At the end of 5 seconds, the same body would be falling at the rate of 160 ft/sec, i.e.:

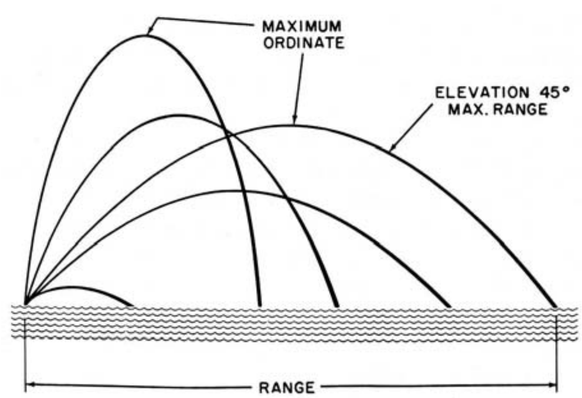
$$v = 0 + (32\ ft/sec^2)\ (5\ sec) = 160\ ft/sec$$

Now let's look at figure 2-1 to see how gravity affects the trajectory of a projectile. In this figure, the gun is pointed directly at the target. The line along the axis of the bore, which is extended from the end of the barrel, is called the LINE OF DEPARTURE or the LINE OF FIRE (LOF).

At the instant the projectile leaves the muzzle and is free from the constraining effects of the barrel, the pull of gravity begins to affect it. The projectile immediately starts to drop, and falls substantially short of the target. It



12.2
Figure 2-2.—Increased elevation produces increased range.



12.4
Figure 2-3.—Parabolic trajectories.

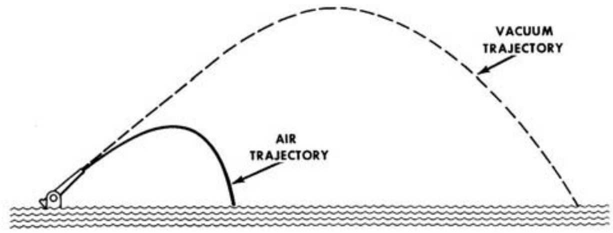
is obvious from the figure that the gun must be elevated to hit the target. Suppose the gun is elevated by the amount shown in figure 2-2. Note that the projectile again drops with respect to the line of departure, even though it is going up with respect to the horizontal. The angle between the horizontal and the line of departure is called the ANGLE OF DEPARTURE. The distance from the gun to the target is called the RANGE.

The two primary forces, neglecting air resistance, which work on a projectile in flight-gravity and the force imparted by the propellant charge - cause an unguided projectile to follow anyone of an infinite number of parabolic trajectories such as those shown in figure 2-3. From this figure, you can see that a gun elevation of 45° produces maximum range for a projectile. At gun elevations greater than 45°, the maximum ordinate (highest point on the trajectory) will be higher, but the range will be less. At elevations less than 45°, both the maximum ordinate and the range will be less.

The gun elevation necessary to compensate for the shape of the trajectory is called SUPER-ELEVATION. Thus, superelevation is the angle through which the gun in figure 2-1 would have to be elevated to hit the target. Superelevation is calculated for various types of projectiles by tests and observations at the Naval Weapons Laboratory, Dahlgren, Va., and is a factor in the elevation computations of the fire control problem.

Looking again at figure 2-1, an interesting point to be observed is that the fired projectile would strike the ground at point A in exactly the same amount of time that it would strike the ground if it were merely dropped from the end of the gun barrel. In both cases, the projectile would be a maximum of 6 feet from the ground. The constant acceleration of gravity would yield the same time of flight in either case. To increase projectile time of flight, the gun must be elevated above the horizontal and, neglecting air resistance, the angle of departure will equal the angle of fall (fig. 2-2). The initial (muzzle) velocity of the projectile will be equal to the striking velocity, and the time that it takes the projectile to proceed to its maximum ordinate will equal the time that it will take it to fall from its maximum ordinate to the height of the muzzle.

The force of gravity will affect a missile's trajectory just as it affects the trajectory of a gun projectile. To correct the gravity error, you just elevate the launcher the proper amount.



12.4

Figure 2-4.— Effects of air density on ideal trajectory.

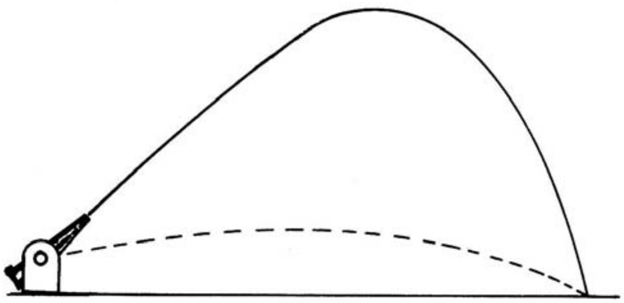
Effects of Air Density

Up to this point, the effects of air density on a projectile's flight path have been ignored. However, in actual practice, we must account for the density of the air, which causes significant changes in the ideal trajectories just discussed. Figure 2-4 shows how the air density might affect an ideal trajectory of a projectile fired in a vacuum. The effect of air is to set up a resistance against any body passing through it. The resistance causes both a loss in speed and a loss in range.

A peculiar thing about air resistance is that it increases rapidly as the speed of the body increases. Roughly, when the speed doubles, the retardation of the projectile becomes more than four times as great. Thus, if a projectile traveling at 1000 ft/sec were retarded 100 ft/sec every second, a projectile traveling 2000 ft/sec might be slowed as much as 400 ft/sec every second. Just as an object passing through water creates waves that retard its movement, an object passing through air creates air waves. The effects of shape, size, speed, and angle of attack of an object upon air movements will be discussed in the next chapter with regard to effect on missile flight.

With a little thought you can see what air resistance does to the shape of the ideal trajectory. The longer the projectile travels through the air, the slower it goes. Shortening of the trajectory will be more noticeable at the far end. The high point of the trajectory will not be at the middle as it would be in a vacuum, but will be nearer the point of impact than it is to the gun.

The way to compensate for air resistance is to increase range by additional elevation. In figure 2-5, the dotted line shows the trajectory of a projectile in a vacuum. Notice how much

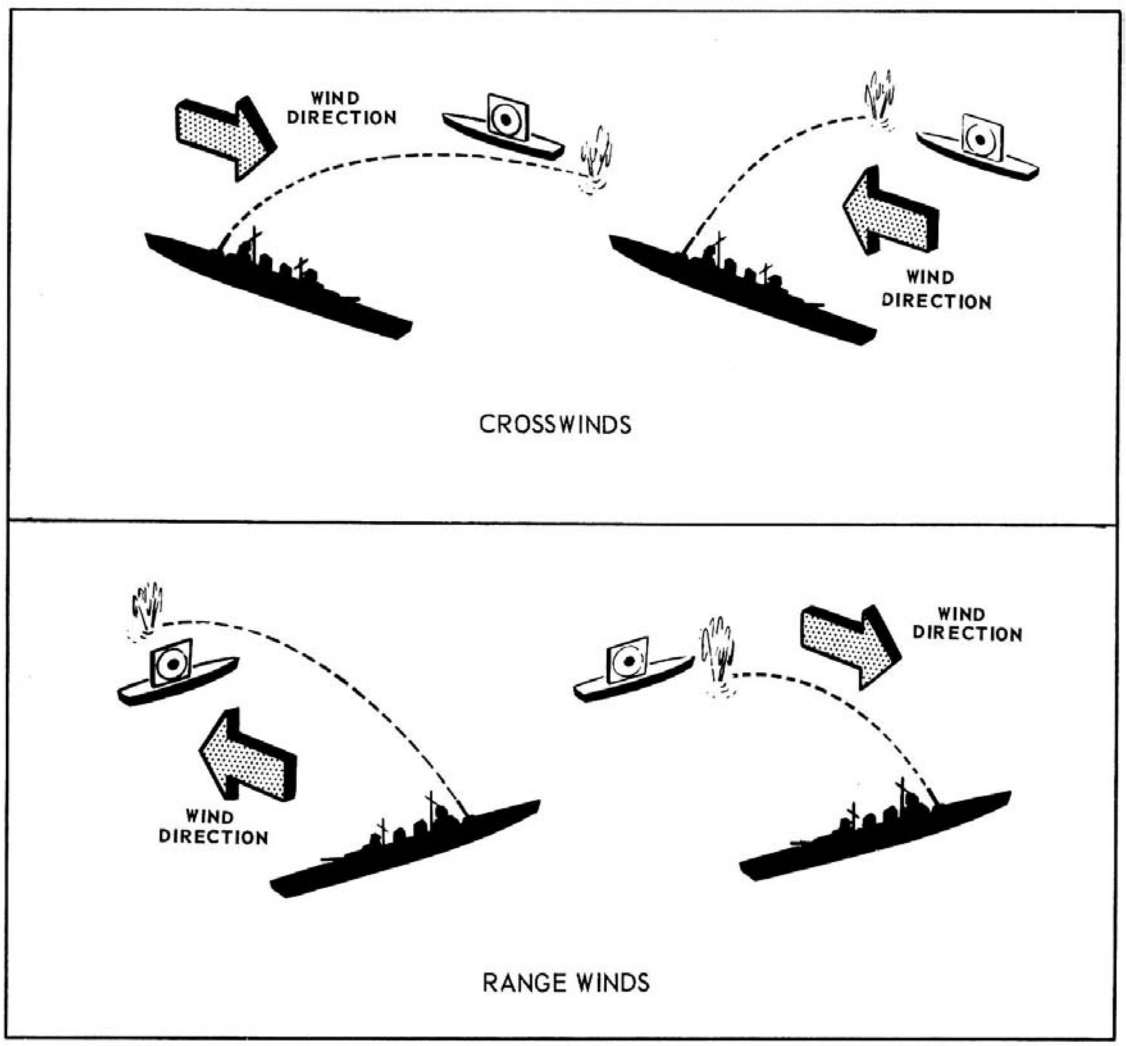


12.5
Figure 2-5.—The way to compensate for air resistance.

additional elevation the gun must have to fire the projectile the same range through air (solid line trajectory).

It would be a very simple matter to compensate for air density in the gunfire control problem if the density were constant in all localities. Actually, air density depends in great measure on temperature and barometric pressure. Needless to say, these two factors are continuously varying. Moreover, air density decreases with altitude along the trajectory, as does temperature.

The shape of the projectile also makes a difference. Obviously, the bigger around the projectile is, the more air will push against it. A pointed nose makes it easier for the projectile to push its way through the air, and thus reduces resistance. Boat-tailing, or tapering, the after end of the projectile reduces the drag



12.8
Figure 2-6.—Wind effects on projectile.

resulting from air turbulence behind the projectile, and this also reduces resistance.

Guided missiles, like any physical body, are affected by air density. To make their passage through air easier, guided missiles are streamlined. They also contain instruments that measure air density. At high altitudes, where the air is thin, the control surfaces of a missile must deflect more to turn a missile a given amount. The air density measuring device provides a signal to the missile's control system, telling It to increase or decrease the amount of rudder required for a particular maneuver.

Wind

Another natural force which works on a guided missile or projectile is wind. You will remember that the football player takes the wind into account before throwing a forward pass. If you have ever played football on a windy day, you will remember that a well-aimed forward pass may have curved to the right or left, or fallen short of or beyond the point where you wanted it to land.

Wind has exactly the same effect on a projectile in flight. The effect of wind can be seen in figure 2-6. If the wind blows from the left, the projectile will turn to the right, and vice versa. If the projectile is headed into the wind, its range will be decreased. If it travels with the wind, the range will be increased. You can see that effects of wind must be considered in the solution of the fire control problem.

A wind that is blowing at right angles to the projectile's line of fire is a "crosswind." If it is blowing along the LOF, either with' or against the projectile, it is called a "range wind."

If the wind is blowing along the LOF against the projectile, the projectile will fall short of the target. To compensate for this, we must elevate the gun to increase the range of the projectile. If the wind is b1owing with the projectile, the projectile will land beyond the target. To compensate for this, we must depress (lower) the gun or launcher to decrease the range.

If the wind is blowing from the right (at 90° to the LOF), the projectile will land to the left of the target. To compensate for this, we must train the gun or launcher to the right. If the wind is blowing from the left at 90° to the LOF, the projectile will land to the right of the target. To compensate for this we must train the gun or launcher to the left. The corrections for both types of wind are shown in figure 2-7.

The examples given here are special cases. Obviously, wind does not always blow directly at right angles to the line of fire or directly along it. If the wind were cooperative enough to perform in this manner, it would be a relatively simple matter to compute the wind corrections. In most cases, the wind will be at some other angle to the LOF. To correct for wind, it is necessary to resolve the true wind into components in line with and perpendicular to the LOF. When this is done, each component can be treated individually and the proper gun setting or launcher adjustments made.

Immediately after firing, a projectile is traveling at such a high speed that the wind does not affect its flight very much. As the projectile slows down during its flight, the wind effects become more noticeable. Hence, the longer a projectile remains in flight, the more its trajectory will be altered by the wind, so that the wind deflection increases with range. While the effects of wind on missile trajectory are modified by the powered flight, they must be included in the calculations. Wind effects can be especially noticeable on long-range missiles, such as intercontinental ballistic missiles. The computations are further complicated by the decreasing mass of the rocket or missile as the fuel burns up.

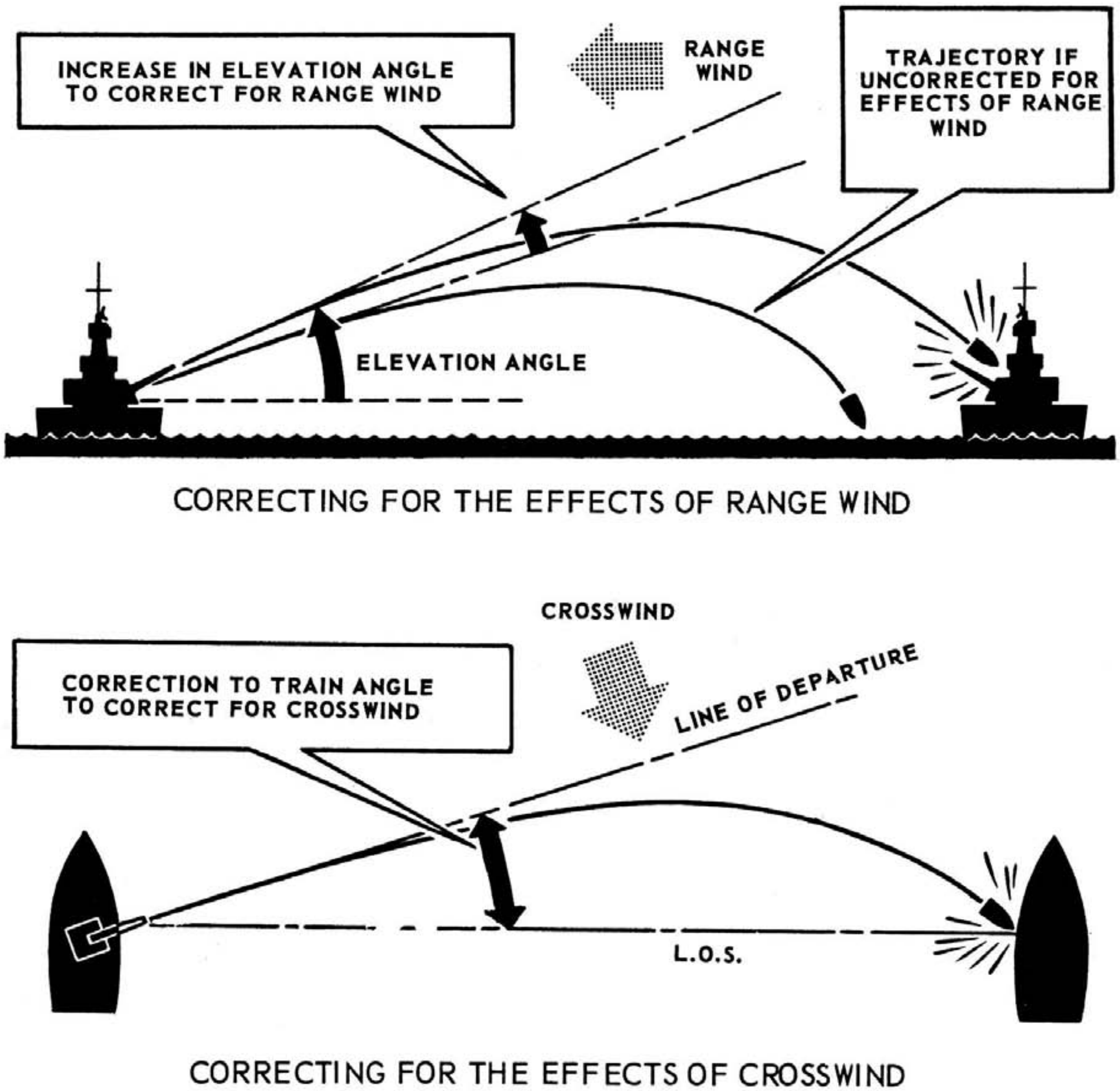
Two other factors which affect the trajectory are wind speed and projectile size. Obviously, the greater the wind velocity, the greater the effect on the projectile. At the same initial velocity, a heavy projectile would be affected less by wind than would a light one.

Corrections for the effects of wind are only approximate, because wind speed and direction are usually different at various levels. For instance, the wind might be blowing from the north on the surface of the ocean, and from the south at an altitude of 6000 feet. In such a case, a projectile's trajectory would be affected differently as it is acted on by the winds at various altitudes.

Wind conditions at different altitudes are sometimes determined by observations from airplanes or by observing the movements of small balloons. If it is found that a projectile's trajectory will take it through winds which move in different directions, a "weighted ballistic wind" may be used to compute gunsetting or launcher corrections.

If the projectile's trajectory is low, and passes through winds of one direction only, surface wind is used to compute corrections.

In the upper air, winds blow up and down as well as horizontally. These vertical winds can lift the projectile or hold it down, and thus lengthen or shorten the range. Because these winds are extremely difficult to measure, and



12.9
Figure 2-7.—Correcting for wind.

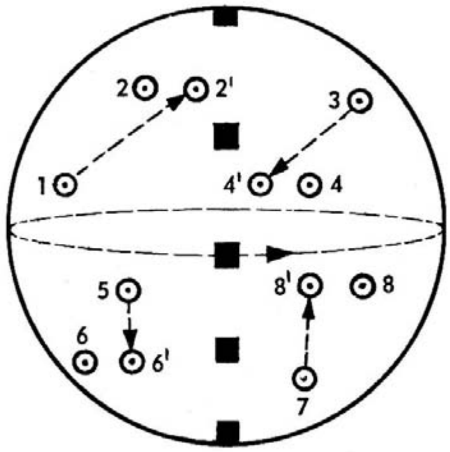
actually have little practical effect, they are not considered in fire control computations.

The guided missiles that concern you are boosted into the air. This boost portion of flight is very short, about 5 seconds. During this time the missile is essentially an unguided projectile. Wind, gravity, and air density affect it just as they would a gun projectile. After the boost period is over, the missile enters its guided phase of flight. Even then, these external forces are still at work. But they are corrected for by control surface (wing or tail) movements. To correct for wind and gravity effects during the boost phase, corrections are included in launcher elevation and train orders. Air density is taken care of by booster thrust design.

Corio1is Effect

The Corio1is effect (named after the French scientist Corio1is) also has an effect on the trajectory of a missile or projectile. Although not compensated for in all fire control problems, the Corio1is effect is worth discussing since it becomes important especially with respect to long range gunfire and missiles.

The effect is based on the fact that the different points on the earth's surface have different velocities around the axis of the earth. In figure 2-8 the object at the Equator has a velocity of about 1000 miles per hour around the



33.136
Figure 2-8.—Coriolis effects.

earth's axis. The two objects between the Equator and the poles will have a considerably smaller velocity. The objects at the poles will have zero velocity.

If we fire a projectile from point 1 toward point 2 and do not correct for the Coriolis effect, it will be deflected to the right of the target, as shown by the dotted lines. In this case, the velocity of the launching point is greater than that of the target. The launching point component of velocity will cause the projectile's deflection to the right, and cause it to strike at point 2'.

Now assume that we fire from point 3 to point 4, again failing to correct for the Coriolis effect. The projectile will again be deflected to the right of the target, landing at point 4'. In this case, the launch point has a smaller velocity than the target point.

From the foregoing, we can say that if the Coriolis effect is not corrected for, a projectile will be deflected to the right of the target in the Northern Hemisphere due to the difference in velocity of points at different latitudes.

In the Southern Hemisphere, the effect is reversed; that is, a projectile is deflected to its left. This can be seen when firing from point 5 toward point 6 in the illustration. The higher velocity at point 5 (relative to point 6) will cause the projectile to be deflected to its left, landing at point 6'. If we fire in a northerly direction in the Southern Hemisphere, the projectile will still be deflected to its left as shown by points 7, 8, and 8'.

Therefore, we can say that if the Coriolis effect is not corrected for. a projectile will always be deflected to the left of the target in the Southern Hemisphere.

The curvature of the earth. too, is of little significance in short-range firing, but must be included in the computations for long-range shots.

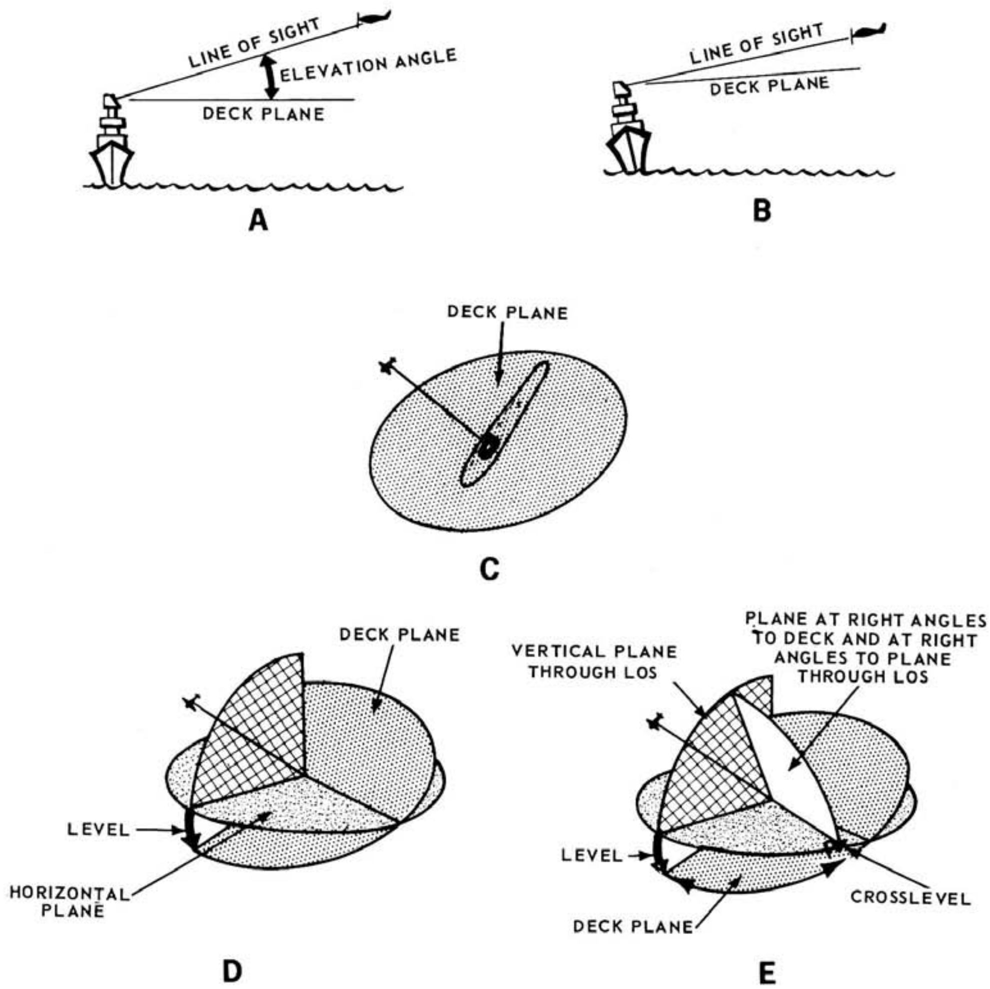
Stabilization

Another very important factor which must be taken into consideration is solving the shipboard fire control problem is stabilization. In figure 2-9A, we show a ship whose deck plane is horizontal. In this case, the target elevation and bearing noted by the detecting equipment is referenced correctly to the horizontal plane. Now look at figure 2-9B. In this illustration you can see that the pitch and roll of the deck causes the values of target elevation to vary, since they are measured from the tilting deck plane. Since a ship is continuously rolling and pitching, the amounts by which the deck plane varies from the horizontal plane must be continuously measured and compensated for in the solution to the fire control problem. (Although not shown. bearing will also vary because of the roll and pitch.)

Stabilization information consists of two quantities -level and crosslevel. Level is the angle between the deck plane and the horizontal plane, measured in a vertical plane through the line of sight. CROSSLEVEL is the angle between the deck plane and the horizontal plane measured in a plane at right angles to the vertical plane through the line of sight at right angles to the deck. Figure 2-9C, D. and E show the relationships of level and crosslevel to the planes involved. Level and crosslevel angles are continuously measured by the ship's STABLE ELEMENT, and are a significant factor in the correct solution to the fire control problem.

Trunnion Tilt

Guns and missile launchers are mounted between trunnions, which tilt as the deck rolls and pitches. Trunnion tilt corrections are corrections necessary to keep the guns or launchers pointing along the line of fire despite the tilting of the trunnions. In figure 2-10, you can see that a tilting deck would cause a miss if the tilt were not compensated for. Thus, trunnion tilt must also be measured continuously and corrected for in the gun or launcher train and elevation orders.



83.1

Figure 2-9.—The effect of ship roll and pitch on the fire control problem: A. Ship's deck horizontal; B. Roll and pitch tilt the deck angle; C. Plane of reference; D. Angle of level; E. Angle of cross-level.

Parallax

Another factor to be considered in the fire control problem is parallax. In figure 2-11, the detecting equipment is trained on a target on the port beam. You can see that only one of the guns would hit the target if all were trained on the port beam.

The problem of parallax stems from the fact that the guns and launchers are displaced from the tracking (fire control director) equipment. Thus, the line of sight between the tracking equipment and the target does not coincide with the line of sight between the guns and launchers and the target.

The director must correct its orders for LOF so lines of sight from the guns and launchers in different parts of the ship will all converge on the target. The farther the gun or launcher is from the director, the greater the horizontal parallax correction will be. Figure 2-11B shows how the guns are brought to bear on the target when the parallax has been compensated for. Figure 2-11C shows that an elevation correction is also necessary since the gun and tracking equipment are

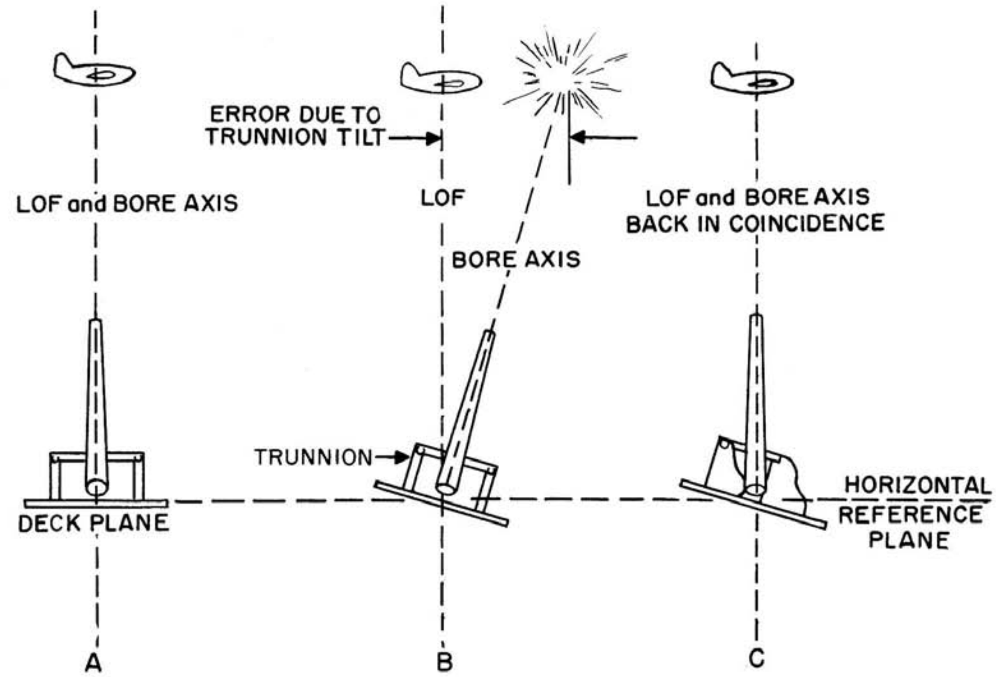


Figure 2-10.—Trunnion tilt and fire control: A. Deck level—a hit without corrections; B. Trunnion tilt not compensated for—projectile misses; C. Correction made for trunnion tilt—projectile hits.

at different heights. Actually, the parallax corrections are relatively small angles (greatly exaggerated in the figures) which change the gun orders only slightly. Moreover, parallax may be corrected for with little difficulty, since the guns and launchers are at fixed distances from the tracking equipment on any given ship.

It is important to mention that parallax effects become more significant at short ranges such as those shown in the figures than they would be at long ranges. At extremely long ranges, the effects become negligible.

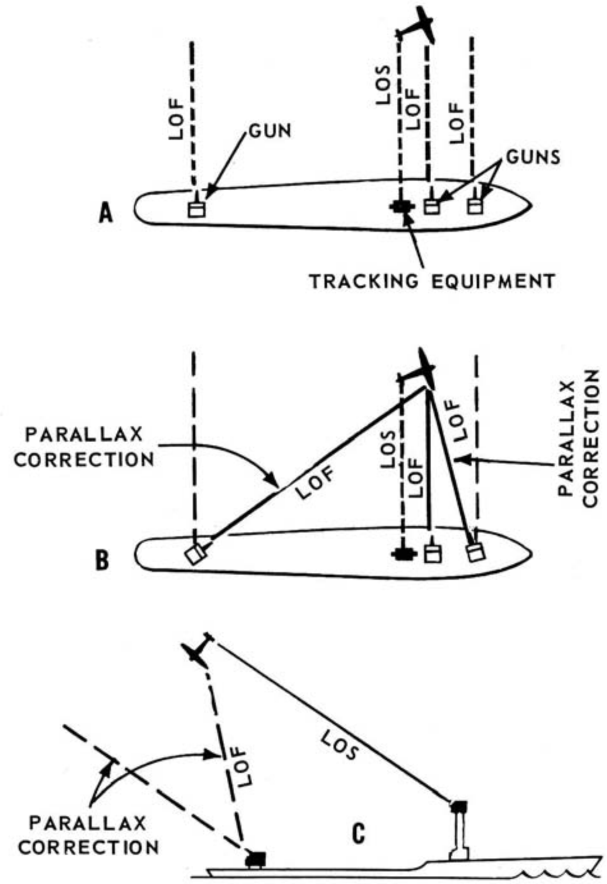
EFFECTS OF INTERIOR FORCES

Interior ballistics is the study of what happens while the projectile travels through the bore of the gun from the instant of firing. Since missiles are fired from launchers and do not pass through a bore, you can readily see that some of the factors will not affect the trajectories of missiles. Both gun barrel and launcher give the initial direction to the projectile or missile.

Initial Velocity

The "send-off", of a projectile or missile makes a big difference in how far and how fast it goes. In the old days when each gun was hand loaded by tamping in a measured quantity of gunpowder, wadding, and shot, the result was not predictable. With the manufacture of ammunition rounds in factories according to precise standards, it became possible to prepare range tables for all sizes and types of ammunition. Until the more recent replacement by automatic computations, range tables were consulted in all gunnery computations. While Navy officers still had to learn how to figure where their shots would land, the range tables were a convenient source of prefigured data for every type of ammunition in the Navy.

The initial velocity for missiles is furnished by the booster. Its size, weight, and type of propellant determine the initial velocity of the missile.



83.3

Figure 2-11.—Parallax correction: A. Cause of parallax problem; B. Correction of horizontal parallax; C. Correction of vertical parallax.

Condition of Propellant

With composition, size, shape, quantity, configuration, and containment of the propellant all determined with exactitude before you receive the projectiles or missiles, what influence does the work of Gunner's Mates have in initial velocity? The condition of the propellant at the time of use can have great influence. One of these conditions is the temperature. Another condition is humidity. Temperature and humidity of the missile storage spaces must be carefully regulated. A higher temperature results in greater energy release, and therefore the booster propellant "burns up" faster.

Drift

Another factor that affects the trajectory of a projectile is drift. Drift is not a simple effect; it's the product of the interaction of three other factors - namely, the clockwise spin of the projectile, the force of gravity, and air resistance. As the spinning projectile moves through the air, it tends to point slightly above the trajectory, and the air pressure on its underside develops a thrust that tends to tumble the projectile end over end. But like any other rapidly spinning mass, the projectile reacts to a thrust tending to displace its axis of spin by precessing gyroscopically. (You'll learn more about gyroscopic action as you learn more about fire control, so we won't go into detail about it at this point.) In this case, the precessing movement is a slow turn to the right. The result is that the projectile's course is deflected to the right-relatively slowly at first, but more and more as the trajectory lengthens.

The direction of drift depends entirely on the direction of rotation of the projectile. Every rifled weapon in the Navy (with one exception - the .45 caliber pistol) causes projectile spin to the right (that is, clockwise as viewed from the projectile base), and drift to the right.

Drift increases with range, but it is completely independent of wind. Since missiles are not fired from rifled barrels, this type of deflection does not occur.

WHY WE NEED FIRE CONTROL INSTRUMENTS

Picture yourself on the deck of a modern warship, charged with the responsibility of directing the ship's gunfire. The target is visible on the horizon and it is up to you to tell the gunner how he must elevate and train his guns in order to score a hit on the enemy. You are familiar with the corrections that must be applied and you know how they are calculated. So, first you determine range and bearing' 'by eye"; then you must correct for drift, wind, air resistance, earth's curvature, and rotation of the earth. You must determine the target's course and speed, predict its future position, allow for own ship's motion, predict future range and deflection, and correct for level and crosslevel. You work rapidly and after a half-hour or so, you come up with the answer. By that time the target has disappeared or has blown you out of the water.

The solution of the modern fire control problem cannot be reached rapidly nor accurately enough without the help of various fire control

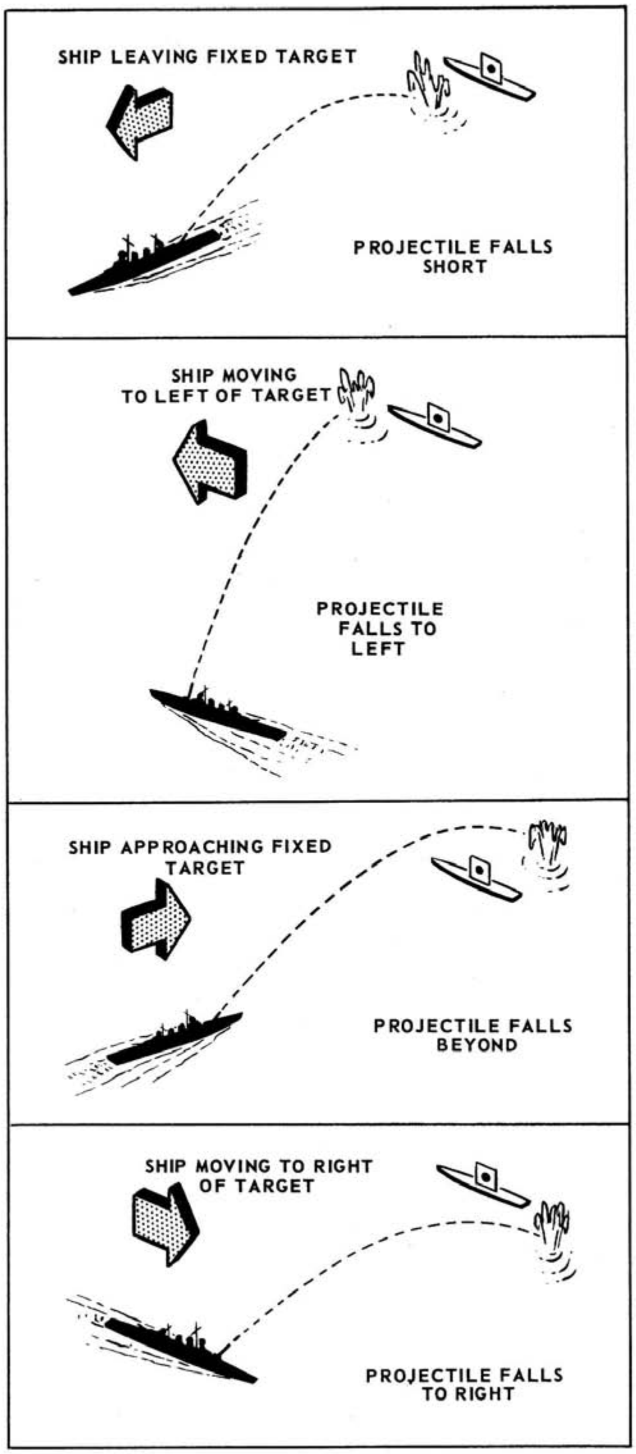


Figure 2-12.—Errors in gunfire caused by movement of own ship when target is fixed.

equipments and related equipment. A hit or miss method is intolerable; modern fire control instruments are essential to get the most out of our expensive, modern weapons. Gunner's Mates need to know the basic principles of fire control.

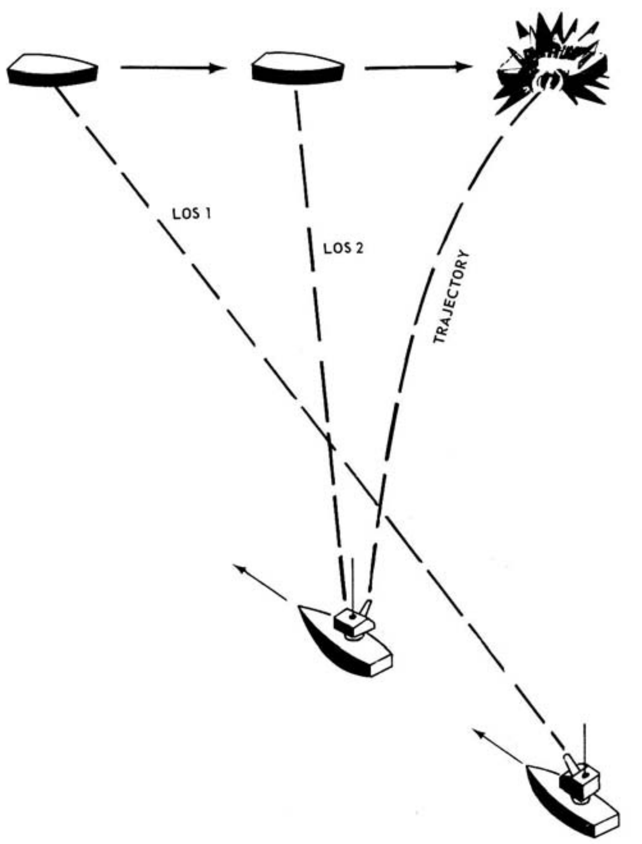
HITTING A MOVING TARGET FROM A MOVING SHIP

From what has been discussed to this point, you know that we must offset a gun or launcher from the line of sight (LOS) between the tracking equipment and the target to compensate for such factors as superelevation, air density (gunfire only), wind, stabilization, and parallax. Important as these factors are in the ultimate correct solution to the fire control problem, they must be accurately related to the movements of own ship and target if we are to come anywhere close to getting a hit.

Thus far, we have been discussing various factors affecting the fire control problem as though the target were standing still. In the vast majority of cases, the target is moving- either on the surface of the sea, or in the air over it. The movement of the target with respect to the firing ship is by far the most important factor in the computation of the fire control solution and the correct positioning of the guns and launchers.

In any fire control problem involving a moving target, the target must be led - just as the duck hunter leads the duck or the passer in a football game leads his receiver running down the field. For a surface ship target, the problem is relatively simple. The first thing to be considered is the motion of own ship. Figure 2-12 shows how the motions of the firing ship will cause errors in the projectile trajectory if not compensated for. In the first part of the figure, the firing ship is headed away from the stationary target at, say, 5 knots. With own ship's course and speed not compensated for, the projectile falls short. If the firing ship's speed were greater in the same direction, the projectile would fall short by an even greater amount. The next three parts of the figure show that different courses of the firing ship with relation to the target will produce similar errors. By taking own ship's course and speed into consideration in the solution of the problem, these effects are compensated for and the errors are nullified.

Now, let us see what happens when the target starts moving. Figure 2-13 shows a situation in which the firing ship and target ship are both moving. You can see that if we fired at the instantaneous position of the target - that is, along the line of sight - the target would have moved to a new location while the projectile was in flight. We therefore must predict a future position of the target which will permit the gun to be offset from the line of sight by the amount necessary to cause a hit. To do this we must first know the target's course and speed, as well as our own.



83.4

Figure 2-13.—Movement of target and own ship affect line of sight.

APPLICATION OF FIRE CONTROL PRINCIPLES

Fire control systems vary on different ships and for different gun and weapon systems. In all modern systems, computations of the effects of the various forces, internal and external, that affect the trajectory of projectiles and missiles, are made automatically.

SOLVING THE SURFACE PROBLEM

Earlier we said that a detection system, a computing system, and communications links were the elements of a fire control system. Figure 2-14 shows how these elements are linked together with a gun and a launcher.

For the detection system we use a radar set. The radar uses the transmission and reception of electromagnetic radio frequency energy to provide us with information as to the target's precise location with respect to our own ship at any given time. This information is automatically transmitted to the computer in the form of target ranges and bearings. The computer automatically compares the range and bearing information with elapsed time and continuously generates target course and speed.

The computer also accepts course and speed information automatically from own ship's gyro and pitometer log, certain inputs (such as initial velocity), air density, wind speed and direction, level and cross1eve1 signal information from the ship's stable elements, trunnion tilt, and parallax corrections, in some cases Corio1is effect, and other inputs which have a lesser bearing on the problem. In addition, it automatically compensates for supere1evation (defined earlier in this chapter). (The use of a pitometer 1og in measuring own ship's speed is described and illustrated in Basic Machines, NavPers 10624-A, page 61.)

The computer continuously analyzes all of this information (some of which may be set in by hand, depending on the system involved), and comes up with a continuous solution to the problem. This solution consists primarily of two continuously generated quantities:

1. The angle by which the line of fire must be offset from the line of sight in bearing. This angle is called sight deflection.
2. The angle which the line of fire must be offset from the line of sight in elevation. This angle is called sight angle.

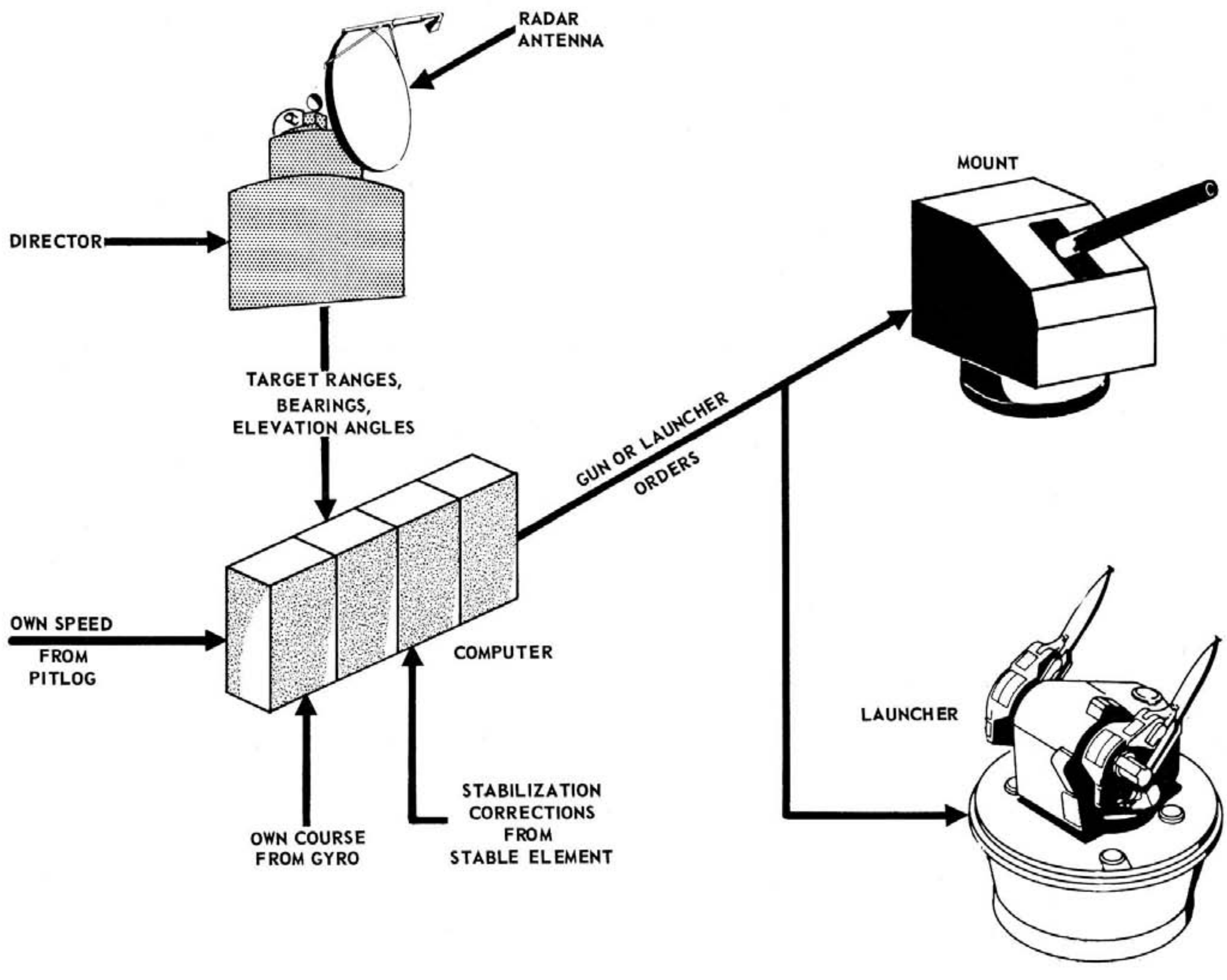


Figure 2-14.— Elements of simplified fire control system.

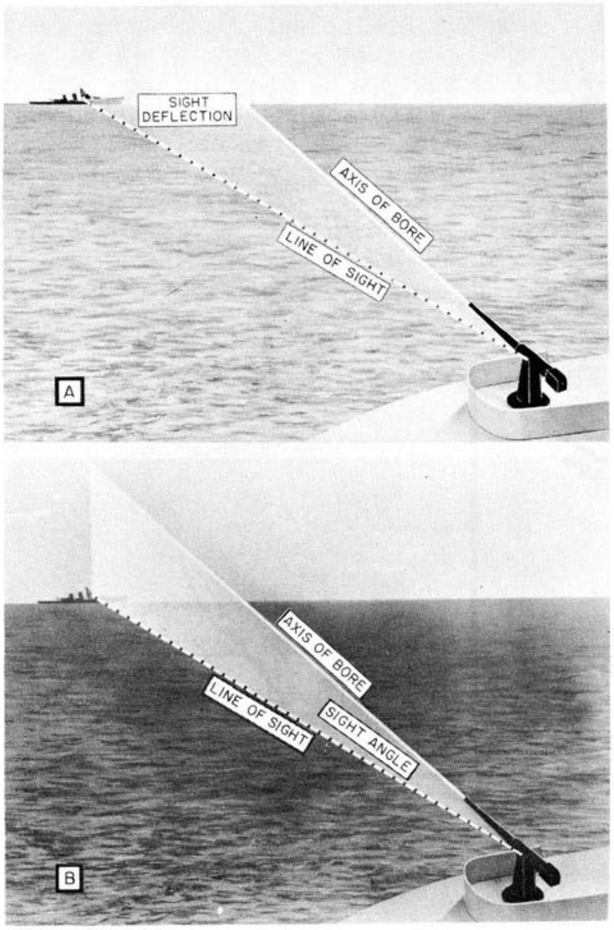
These quantities (fig. 2-15) are generated continuously and automatically. After they are corrected for roll and pitch, they arrive as gun train and elevation orders at the mount power drives, thus causing the gun barrel to continuously lead the target by the amount necessary to yield a proper trajectory.

SOLVING THE ANTIAIRCRAFT PROBLEM

The gun antiaircraft problem is somewhat more complicated than the surface problem because target altitude is involved, and also because of the greater speed of air targets.

Figure 2-16 shows an aircraft approaching a ship. Again, the line of sight represents the instantaneous direction and range from the detecting equipment to the target. As with the surface problem, firing along the line of sight would be to no avail, since the target would have passed to a new position during the time of flight of the projectile. In computing the air target's course and speed, the target elevation angles are continuously measured by the ship's detecting equipment in addition to the bearings and ranges. As in the case of the surface target, own ship motions and target motions (in this case bearings, ranges, and elevation angles) are used to position the gun or launcher to lead the target by the correct amount.

It is worthwhile mentioning here that any changes in target course and speed (surface or air problem) are quickly recognized by the detection equipment, and the new information fed to the computer, which immediately corrects the solution and the gun orders. The original predicted target position is continuously



84.198
Figure 2-15.—Offset of gun from line of sight: A. Sight deflection; B. Sight angle.

and automatically revised as information is received by the computers and the corrections are sent to the gun or launcher.

The line of sight to the moving air target in figure 2-16 assumes that the ship's deck remains horizontal, which is rarely the case. Corrections for roll and pitch of the ship are included in the computation for the correct line of fire to be used in order to hit the target where it will be at the time calculated.

Figure 2-17B shows that sight angle for the air target includes allowance for target elevation angles. Compare it with figure 2-17 A. The line of sight establishes the relationship between the target and the gun. Sight angle and sight deflection are measured from the line of sight to the line of fire. However, for an air target (fig. 2-17B) , the line of sight is not in the horizontal plane but in the slant plane. The angles are measured from the slant plane.

THE BEAM-RIDER MISSILE AA FIRE CONTROL PROBLEM

So far in this chapter, we have emphasized the gunfire control problem. Now let's change our thinking a little and look at the fire control problem presented to one type of beam-rider missile. We won't have to shift our mental gears very much because, as you will see, there is very little difference between the two problems. In the gun problem we pointed a gun at an airplane with enough lead angle to compensate for target motion during projectile flight and to correct for the effects of wind, drift, gravity, and initial velocity. Basically, the only difference

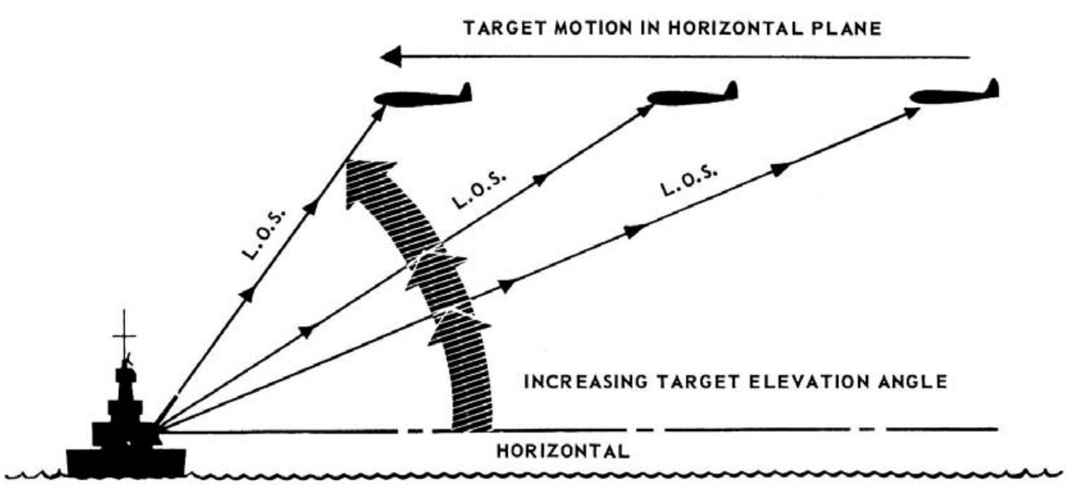


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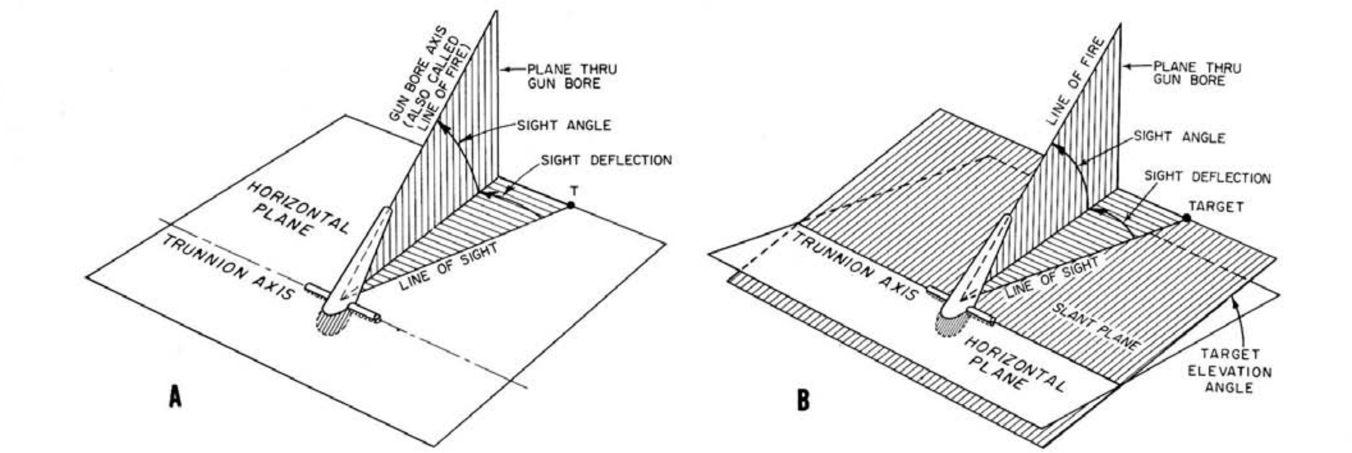
Figure 2-16.—Changing elevation angles for air target.



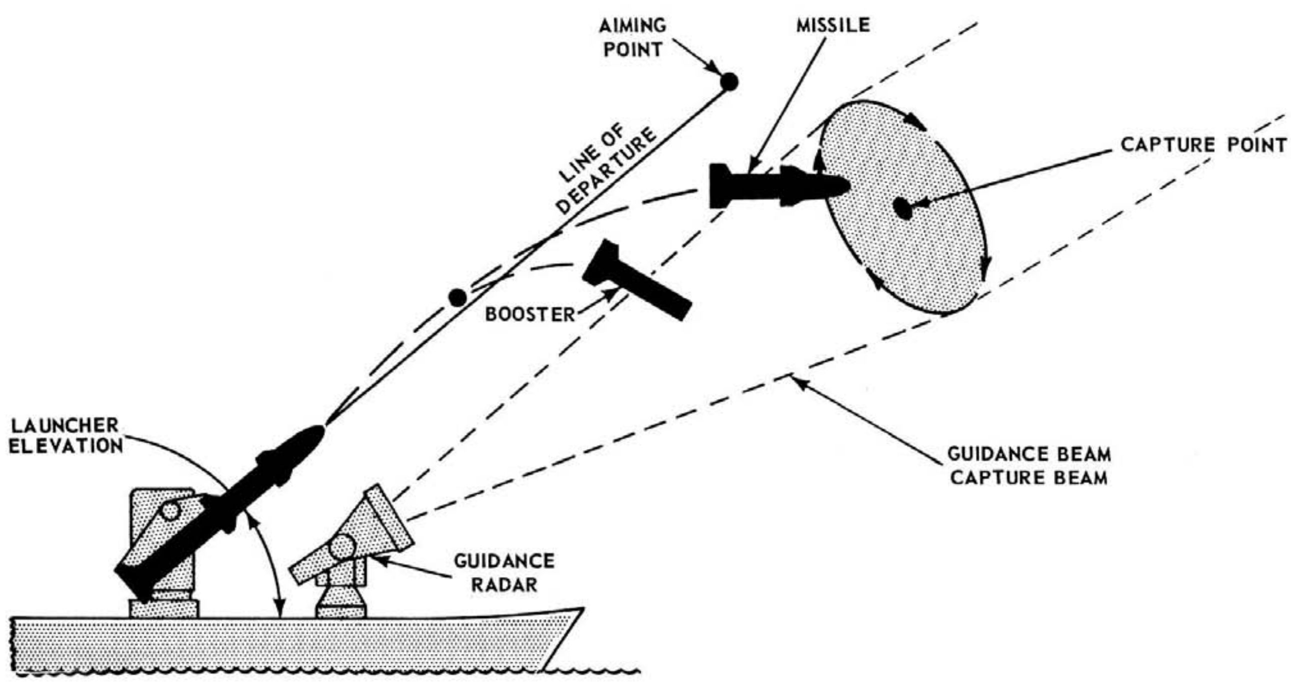
12.11:.17

Figure 2-17.—Sight angle and sight deflection: A. In the surface problem; B. In the air problem.

between the gun and beam-rider missile problems is the target. Instead of pointing the launcher in the general direction of a physical target, we point it at a big radar beam. This beam is called the guidance beam. The missile is launched along a curved line (trajectory) which intercepts a point within the guidance beam called the capture point. Figure 2-18 illustrates the beam- rider fire control problem.

After the search radar has located the attacking aircraft, the tracking and guidance radar follows the aircraft with its beam. The missile follows or "rides" the beam to the target. The booster case drops off after booster burnout, and the missile continues onward.

Before the missile can follow the guidance beam, it must come within the area of the beam. that is, it must be captured by the beam in order



83.6

Figure 2-18.—Simplified beam-rider missile fire control problem—capture phase.

to be controlled by it. The missile must be aimed into the beam, not at the enemy aircraft in the distance, which may maneuver out of the way. In figure 2-18 you see that the "aiming point" is outside the beam, but that is because corrections for the effects on missile trajectory (air density, gravity, wind, etc.) will deflect the trajectory so the missile enters the radar beam and comes under its control.

You can visualize the guidance beam as a big circle several hundred yards wide with a small dot near the center. The dot symbolizes the capture point. In real life, of course, it is invisible. And so is the radar beam. If guided missile launchers had sights like guns have, you could look through them during missile launch and see only the sky. From an abstract and mathematical point of view, however, you would be looking at a point in space. Figure 2-18 shows this abstract point in more concrete form and it is labeled, simply, capture point. The fire control missile computer continuously figures out where the guidance beam and the capture point are. The computer determines the launcher train and elevation orders based on beam position and ballistic factors. These order are electrical signals which position the launcher. The missile is fired and if the lead angle is accurate, the missile hits the capture point and is captured by the beam. Once the beam has control of the missile, the missile is guided to a point high in the atmosphere. The missile rides the guidance beam until it intercepts the target (fig. 2-19).

While figure 2-19 shows the missile, flying straight to the target, in actual practice this is far from the case. The target is moving rapidly; the radar beam follows it, and the missile follows the beam. The target may change its course, and this may mean sharp changes in the course of the radar beam and the missile that rides it. A missile is subject to the same forces as a gun projectile while in flight. Corrections to the trajectory are calculated before the missile is fired, so it will have a correct start on its flight.

Lead angle is made up of two corrections- lead due to target motion, and lead due to ballistics. Assume that lead because of target motion is correct. If the missile is launched on a line pointed directly at the capture point, the missile will miss the capture point. Why? Because ballistic corrections have not been added to launcher train and elevation orders. These ballistic factors are (1) parallax, (2) gravity, and (3) wind deflection.

Parallax

Figure 2-20 shows what happens if the missile's trajectory is not corrected for parallax. The missile trajectory and guidance beam are offset, and the trajectory does not intercept the capture point. If we launched a missile under these conditions, the result would be a missile "by the deep-six." Like the gunfire control equipment, missile fire control equipment is spread out over the ship. The launcher and the guidance radar are physically offset along the centerline of the ship and also are at different heights above the deck of the ship. Therefore, if the launcher and radar are positioned at the same bearing and elevation angles, the line of fire of the launcher will be parallel to the guidance beam. As you know, the amount these parallel lines are offset from each other is called parallax. To compensate for parallax, the launcher bearing and elevation angles are offset toward the guidance beam. Then the launcher line of fire intersects the guidance beam, and the missile trajectory will intersect the capture point. Time to beam capture is very short, about 5 seconds after launch; booster burnout occurs about 1 sec second before this.

Gravity

In figure 2-21 you can see the effect of gravity on the missile's trajectory. For clarity, we have neglected the parallax and wind effects. Between launch and capture, gravity acts on the missile. At the instant when the missile should be captured by the guidance beam, it is actually some distance below the capture point. To compensate for the gravity effect, the launcher must be elevated so that the launcher line of fire intersects a point above the capture point. This is the same technique used in gunfire control to compensate for the effect of gravity. The name is the same too - superelevation correction.

Wind

Figure 2-22 illustrates the effects of wind on the missile trajectory. Once again, other effects are ignored. The wind tends to blow the missile off course during the period between launch and capture. Since the missile is not guided during this portion of its flight, wind corrections must be made before launch. The fire control computer calculates these corrections and sends them to the launcher. Therefore. the launcher is offset from the guidance radar line of sight

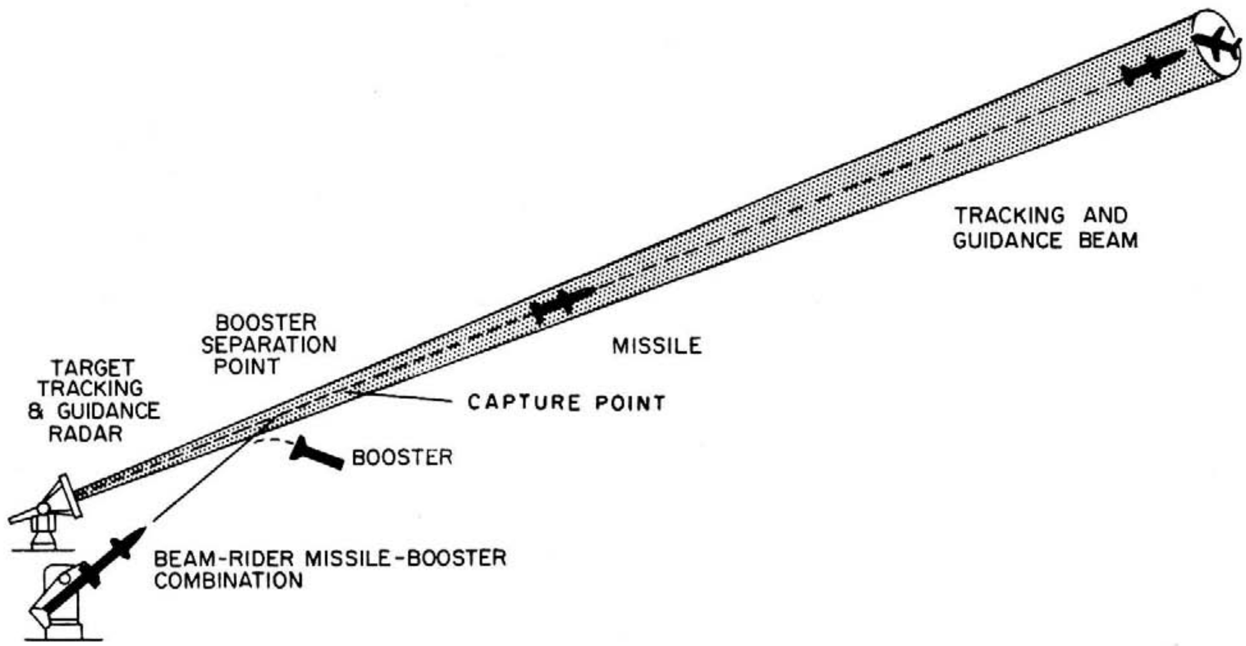


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Figure 2-19.—Beam-rider missile follows the radar beam to the target.

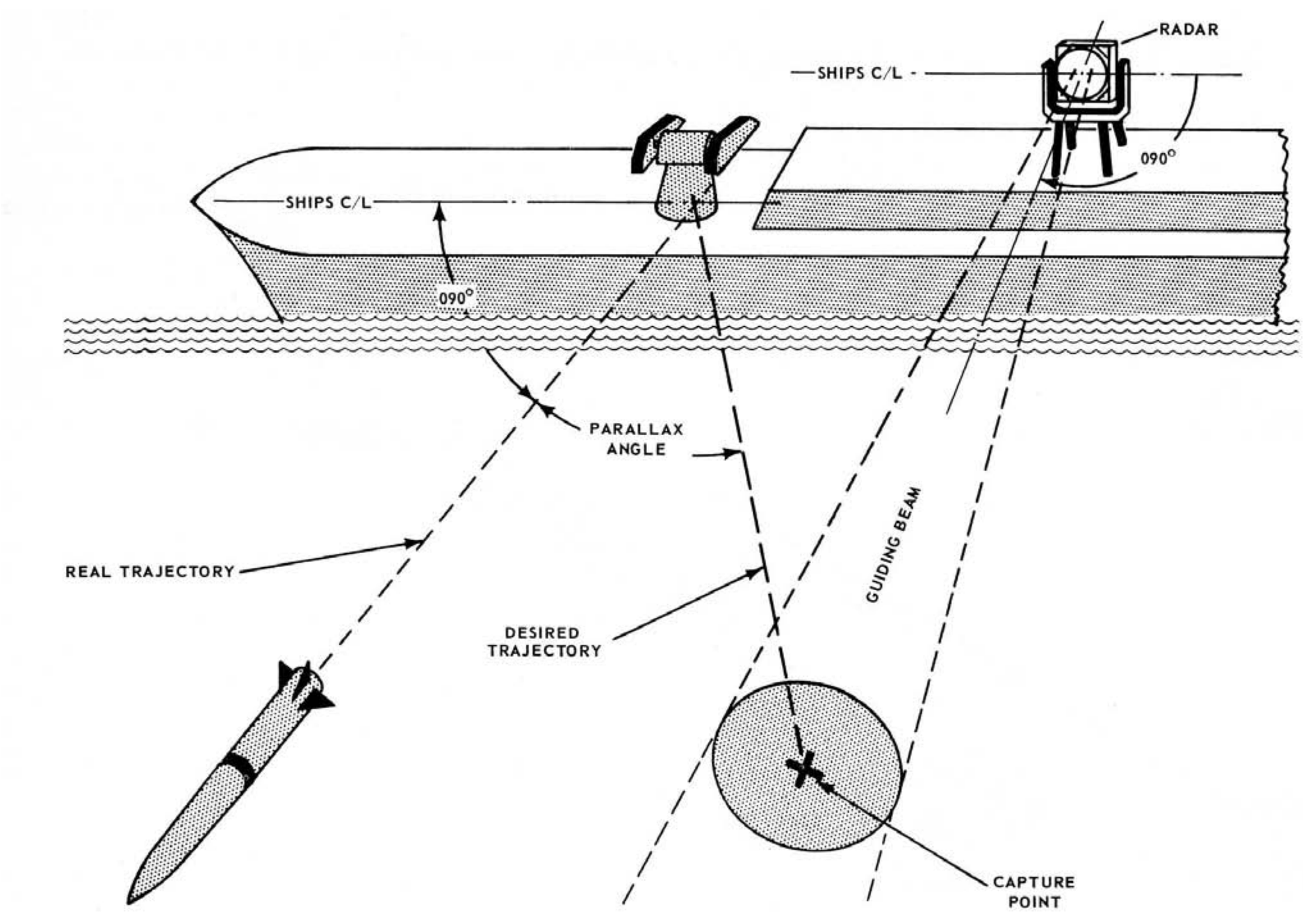

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Figure 2-20.—Effect of parallax on a guided missile's trajectory (flight path) during boost.

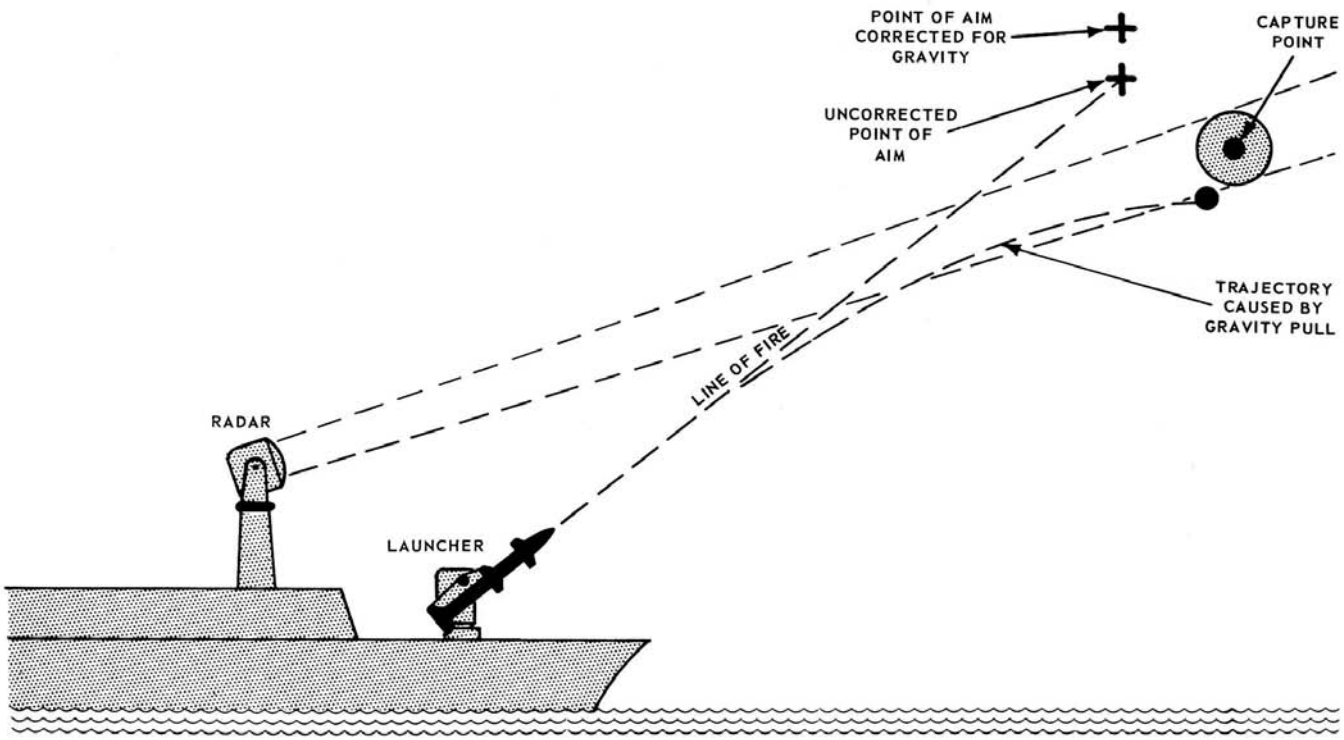

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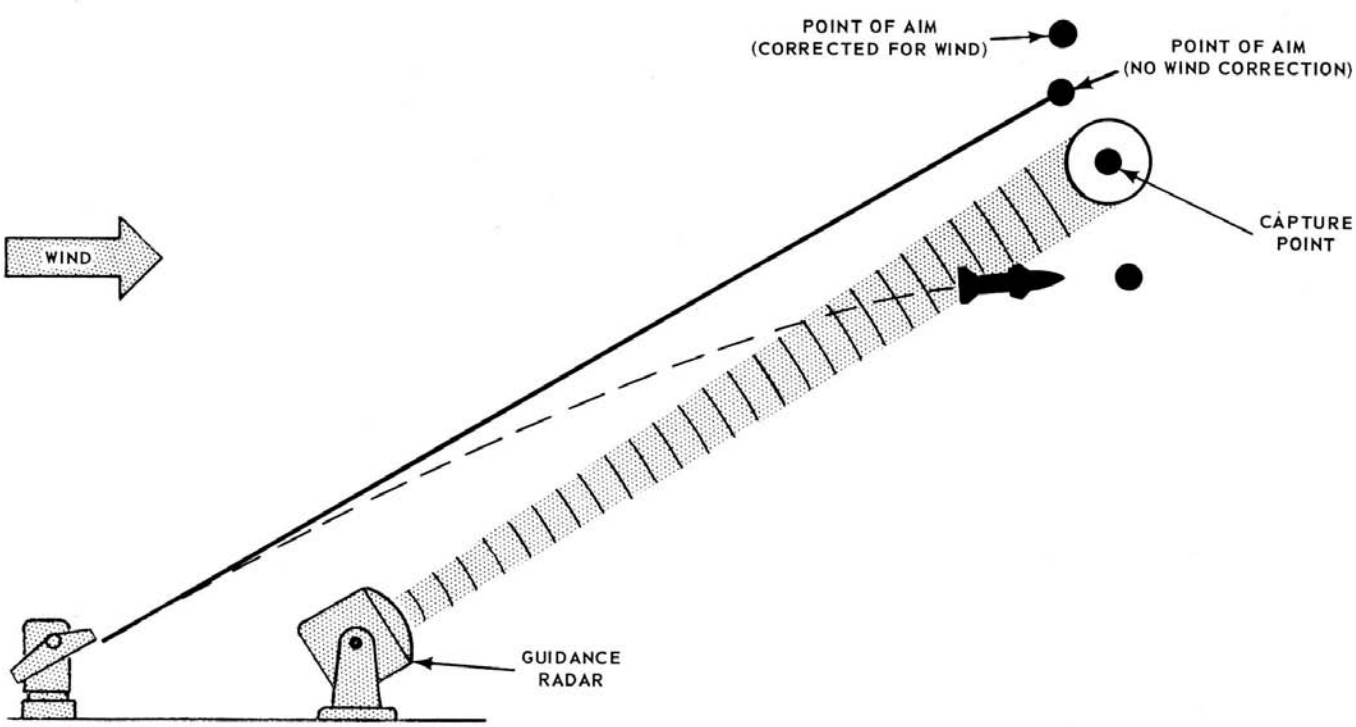
Figure 2-21.—The effect of gravity on a missile's flight path during the boost phase.



83.9
Figure 2-22.—Effect of wind on a guided missile's flight path.

by an amount proportional to the speed of the wind, and in a direction opposite to that of the wind. Now the wind will blow the missile into the guidance beam at the capture point.

The correction for wind includes not only true wind (atmospheric) speed and direction, but also apparent wind, caused by the ship's movement.

SUMMARY

This chapter has briefly covered some of the more important aspects of the surface and air fire control problems. You have seen that the correct solution of a fire control problem depends on many factors. First of all, the target must be detected and tracked. Detection and tracking require an equipment such as radar, which will continuously and automatically provide target bearings and ranges. In the air problem, it must also provide continuous information regarding the elevation angles of the target. This information must be automatically transmitted to a fire control computer, which will compare it with own ship's motion as measured by gyrocompass and pitometer log. In addition, the computer also takes into consideration such factors as level and crosslevel information from the stable element, superelevation, trunnion tilt, wind speed and direction, parallax, in some cases Coriolis effect, air density, and powder temperature (in missile FC computers). The resulting gun and missile orders are continuously generated by the computer and are electrically transmitted to the gun (or launcher) train and elevation power drives, thus causing the line of fire to lead the line of sight by the proper amounts in bearing and elevation. There are many more details of computation in the solution of the fire control problem for guns and missiles, but these are not covered in this text.

Later chapters of this training course will show you in greater detail how a modern weapons system operates. The next chapter will discuss the flight principles and propulsion units of guided missiles.

You may be asked yourself, "Why should I learn more about fire control?" One answer to that question might be: You'll be able to see how important your job is.

The quals for your job require you to know the basic principles of missile flight control, ballistics, and fire control variables. The same forces of nature (wind, air density, gravity, etc.) that affect projectile flight also affect missile flight. The man made thrust force has some variations from guns to missiles, but the principles are the same. As you advance, you must learn how various components function in fire control. The same types of components were used for gun fire control before missiles were invented.

CHAPTER 3

PRINCIPLES OF MISSILE FLIGHT AND JET PROPULSION

INTRODUCTION

In this chapter and the next we will take up the subject of guided missiles in general. As a GMM, the information in these two chapters will help you to understand the missiles used in the launching systems. Also, the information here represents a substantial portion of the knowledge required by your advancement qualifications.

Specifically, this chapter deals with basic flight principles, the principle of jet propulsion, and the various types of missile propulsion systems. Chapter 4 covers missile components such as SERVOMECHANISMS and GYROS, and the various types of missile guidance systems. You are urged to study these two chapters carefully since the remainder of this course will concentrate primarily on launching systems. Whatever knowledge you can gain in chapters 3 and 4 will be of considerable help to you in understanding the material which follows.

MISSILE AERODYNAMICS

Guided missiles launched from surface ships have their flight paths within the earth's atmosphere, so it is important that you understand some basic aerodynamic principles.

Aerodynamics may be defined as the science that deals with the motion of air and other gases, and with the forces acting on bodies moving through these gases.

THE ATMOSPHERE

The atmosphere is a gaseous envelope surrounding the earth to a height of roughly 250 miles. Although there is some difference of opinion as to where the atmosphere ends and space begins, the limit defined above is quite generally accepted. So far as tangible evidence goes, the 750-mile upper limit of the aurora borealis is the "top" of the atmosphere. The behavior of the electrical discharges indicates that elements of air are present, although extremely rare.

As mentioned in chapter 2, one of the most important characteristics of the atmosphere is that air density changes with altitude. As altitude increases, air density decreases significantly. At sea level, the density of air is about .076 pound per cubic foot. At 20,000 feet, air density is only about .0405 pound per cubic foot. Because of the decrease in air density with altitude, a missile flying at 35,000 feet encounters less air resistance-that is, has less drag-than a missile flying close to sea level.

Air pressure also varies with altitude. The pressure acting on each square inch of the earth's surface at sea level is actually the weight of a column of air one inch square, extending from sea level to the outer limits of the atmosphere. On a mountain top, this column of air would be shorter, and so the weight (pressure) acting on ' each square inch would be less. Therefore, air pressure decreases as altitude increases.

Another characteristic of the atmosphere which changes with altitude is temperature (see fig. 3-1). But, unlike density and pressure, temperature does not vary directly with altitude. From sea level to about 35,000 feet, the temperature drops steadily at a rate of approximately 3 1/2°F per thousand feet. It then remains fairly constant at -67°F up to about 105,000 feet. It then increases at a steady rate until another constant- temperature zone is reached. This zone lasts for several miles. Then the temperature starts decreasing. The procedure repeats itself - that is, a second temperature minimum is reached, and after a short constant-temperature zone, it starts rising again. These temperature minimums mark the boundaries between the four regions in the atmosphere: the troposphere, the stratosphere, the mesosphere, and the thermosphere, shown in figure 3-2. In this figure the regions beyond are simply labeled "outer space," but they may be divided into further layers, according to the findings of space probes and explorations of recent times.

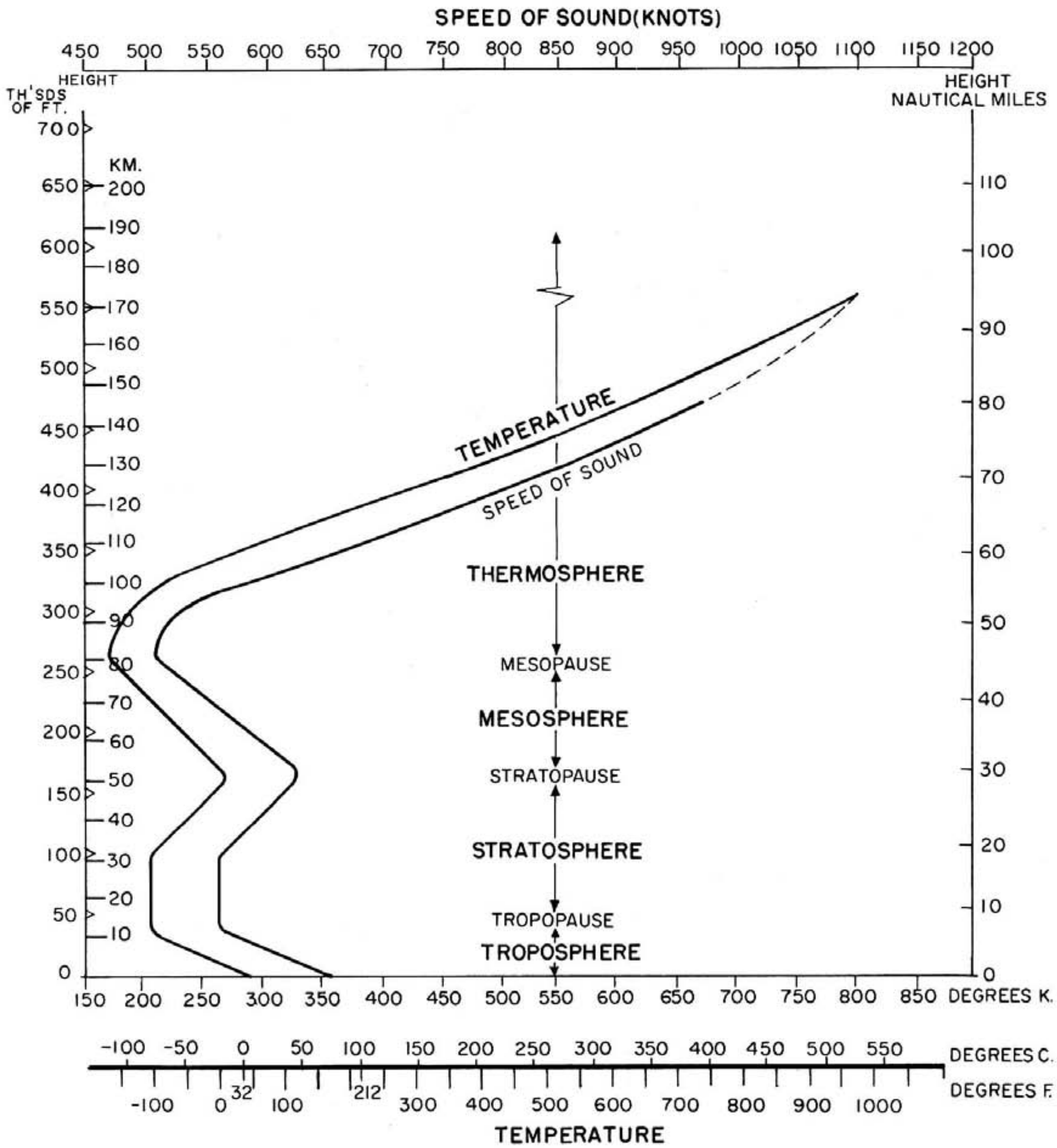


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Figure 3-1.—The vertical structure of the atmosphere.

Troposphere

The troposphere is the lowest layer of the atmosphere and extends from the surface of the earth to a height of 10 miles. This is not a firm figure, as the height of the troposphere varies over different parts of the earth. Near the poles it may be only 4 miles. It is made up mostly of nitrogen and oxygen, and accounts for three- fourths of the weight of the atmosphere. Within this layer temperature decreases with altitude, and it is here that clouds, snow, rain, and the seasonal changes occur.

Because the troposphere is dense, aerodynamic surfaces can be used efficiently to control missiles. However, this high density causes a large amount of drag. You will remember from chapter 2 that the dense lower atmosphere slows down a projectile. It will have the same effect on a missile. The German V-2, rocket which was used to bomb England during World War II, was slowed down from 3300 to 1800 mph as it passed through the troposphere. The friction of the air also causes extremely high skin temperatures on missiles or reentry craft, high enough to melt common metals.

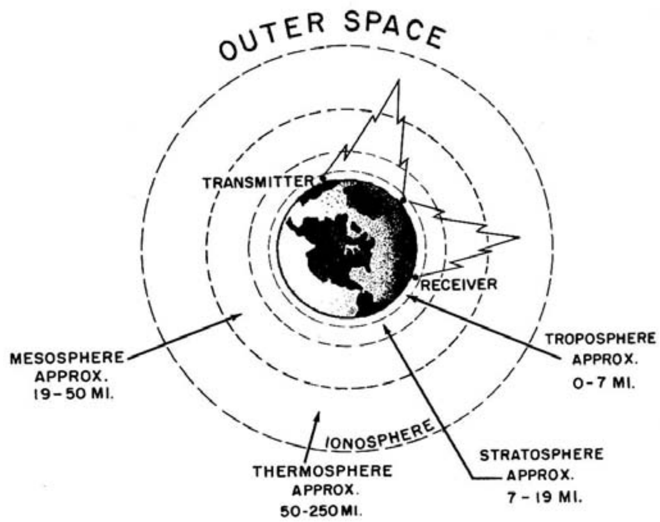


Figure 3-2.—Atmospheric regions around the earth. 33.21

Stratosphere

The stratosphere is the layer of air above the troposphere. Its upper limits are around 20 miles above sea level. In this region temperature no longer decreases with altitude, but stays nearly constant and actually begins to increase in the upper levels. Higher temperatures in the upper levels are caused by ozone which is heated by ultraviolet radiation from the sun. (Ozone is a gas which is produced when electricity is discharged through oxygen.) The composition of the stratosphere is similar to that of the troposphere; however, there is practically no moisture in the stratosphere. There are almost no clouds and no storms, and an almost complete absence of dust. At the earth's surface the air contains about 21 percent oxygen, but this decreases to a small value in the stratosphere, while the percent of hydrogen rises from 0.01 percent to 95 percent. The air is said to be "thin" and will not support human life nor air breathing engines. Propeller-driven vehicles cannot penetrate this region because of the low air density, and aerodynamic surfaces have greatly reduced effect in controlling missiles. But increases in missile speeds are possible because thrust is used more for acceleration and less to overcome drag.

Mesosphere

Above the stratosphere is the mesosphere, extending from about 19 miles to 50 miles. Within this region the minim\lm temperature is reached at about 47 1/2 nautical miles (fig. 3-1), decreasing from about 7°C at its lower edge to -100°C at its upper limit. Ozone is generated in this region and it is the seat of transformation of most primary into secondary radiation. Intense meteor trains reach down into the mesosphere and their brilliant combustion gave rise to the belief that this was a region of comparatively high temperature.

Intermediate Layers

In figure 3-1 you find the words "tropopause," "stratopause," and "mesopause." These are applied to rather narrow regions between the layers described above. In each case, they are the regions of transition from one type of atmosphere to the next one, and are likely to have turbulence because of the inversion or reversal characteristics.

Thermosphere

The thermosphere starts at about 47 1/2 nautical miles (fig. 3-1) and extends to the ionosphere. Sometimes the two areas are considered as the ionosphere as they have a continuing upward trend in temperature. The increase in temperature IS due to the presence of ozone, which is formed by the action of ultraviolet rays from the sun on the oxygen in the atmosphere. Tremendous fluctuations of wind speed (70 knots or more) occur on a daily basis. These fluctuations are referred to as atmospheric tides.

Ionosphere

Above the thermosphere, ranging up to about 250 miles above sea level, is the ionosphere. This is a region rich in ozone, and consists of a series of electrified layers. The ionosphere is extremely important because it refracts (bends) radio waves (fig. 3-2). This property enables a radio transmitter to send waves to the opposite side of the world by a series of refractions and reflections taking place in the ionosphere and at the surface of the earth. The characteristics of the ionosphere vary with daylight and darkness, and also with the four seasons. The term "ionosphere" is used particularly in referring to the electrical characteristics of the region, while "exosphere" is the name used when referring to the meteorological aspects.

Higher Atmospheres

The reaches of space beyond the ionosphere have not been fully explored and much of the information about them is conjecture. Much information about the upper air has been transmitted to earth from orbiting satellites and spacecraft which have carried instruments to measure radiation, temperature, and other information that could be measured.

Weather information, and reports of meteorites and micrometeorites are recorded. There is still a great deal more to learn about space. If you read different writers on the subject, you will find variations in statements about the size of atmospheric zones and even differences in names for the regions. As conjecture is replaced by real information, these differences will be resolved.

Several belts of high intensity charged particles, called Van Allen Belts, surround the earth in space. They were discovered by the early U. S. satellites, Explorer I and Explorer II, in 1958. The zones fluctuate and it is believed solar flares or other phenomena of the sun cause the changes. It is almost certain that the outer zone owes its existence to ionized solar gas ejected from the sun.

BASIC FLIGHT PRINCIPLES

The principles of low speed aerodynamics which underlie the operation of most aircraft also apply to missiles, at least in the first few seconds of flight. Before we discuss high speed missile flight, let us consider the motions and forces that are common to both guided missiles and conventional airplanes flying at low speeds.

BASIC MOTIONS

Like any moving body, the guided missile executes two basic kinds of motions: rotation and translation. In pure rotation all parts of a body pivot about the center of gravity, describing concentric circles around it. In movements of translation, or linear motions, the center of gravity of a body moves along a line, and all the separate parts follow lines parallel to the path of the center of gravity. Any possible motion of the body is composed of one or the other of these motions, or is a combination of the two.

Since missiles are free to move in three dimensions, we describe their motions by using a reference system containing three reference lines, or axes. The missile axes (fig. 3-3A) are mutually perpendicular lines which intersect at the center of gravity of the missile.

A missile can make three kinds of rotary movements: pitch, roll, and yaw. Pitch, or turning up or down is rotation about the lateral or Y axis of the missile (fig. 3-3B).

The missile rolls, or twists, about the longitudinal axis, which is the reference line running through the nose and tail and designated the X axis in figure 3-3C. It yaws, or turns to the right or left, about the Z or vertical axis (fig. 3-3D). Rotary motions about all three of these axes are controlled by devices within the missile. Hereafter, these axes will be referred to as the pitch axis, the roll axis, and the yaw axis.

The second type of movement is called translation. Translation includes any linear movement of the missile. For example, a sudden gust of wind or an air pocket could throw a missile a considerable distance off its trajectory without causing any significant angular movement. If you have ever flown in an airplane, this should be fairly easy to understand. If the plane hits an air pocket, it may drop sever al hundred feet, but still maintain a straight and level altitude. Any linear movement, regardless of direction, can be resolved into three components: lateral movement, vertical movement and movement in the direction of thrust. So, besides the three angular degrees of movement, we have three linear degrees of movement. A missile in flight can therefore be said to have six degrees of movement, or freedom.

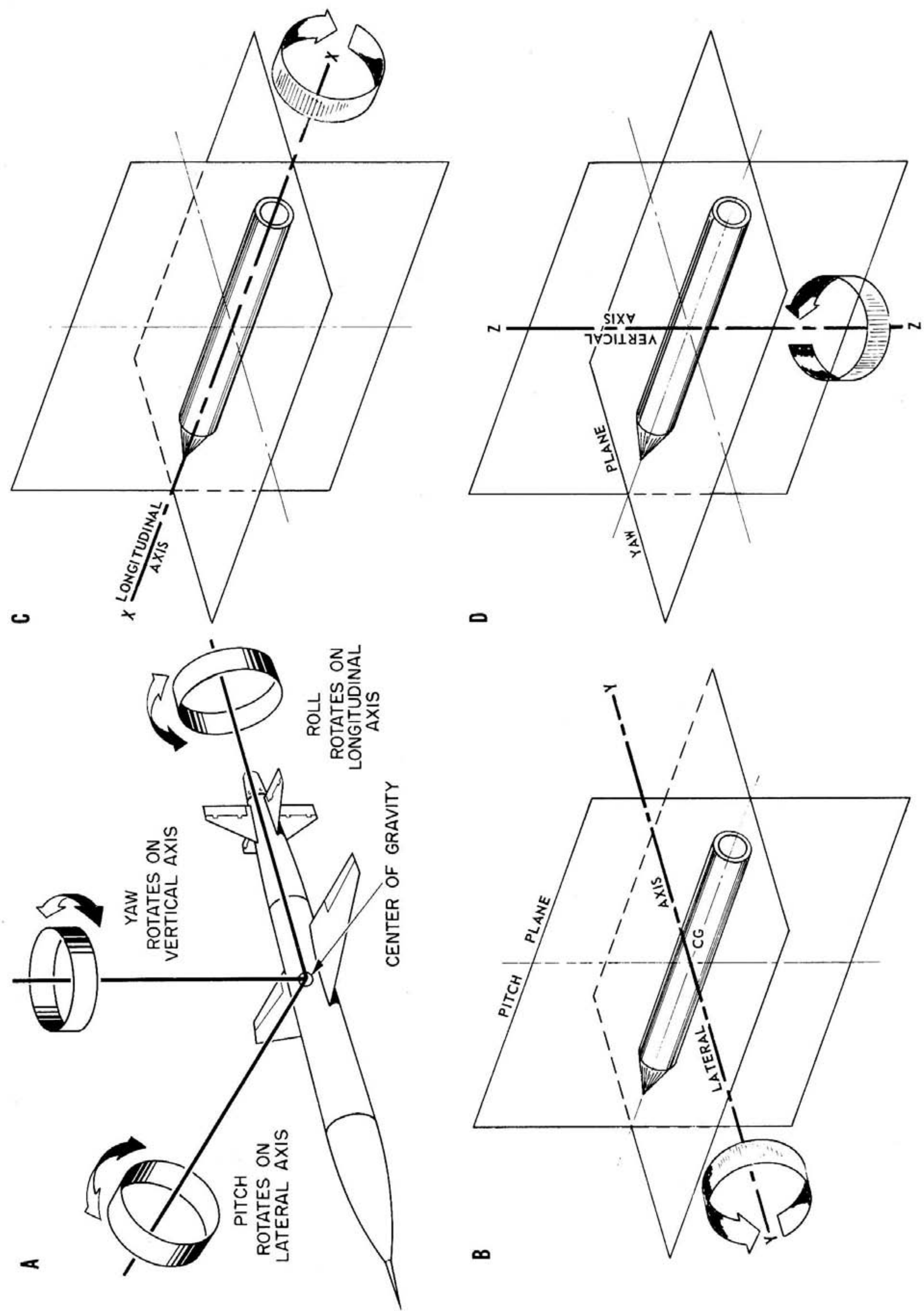
In an airplane. the pilot checks his instruments or visually observes angular and linear movement. On the basis of his observations, he repositions the control surfaces as necessary to keep the plane where he wants it.

Since we don't have a pilot in a guided missile to note these movements, we install devices that will detect them, as will be discussed in chapter 4.

AERODYNAMIC FORCES

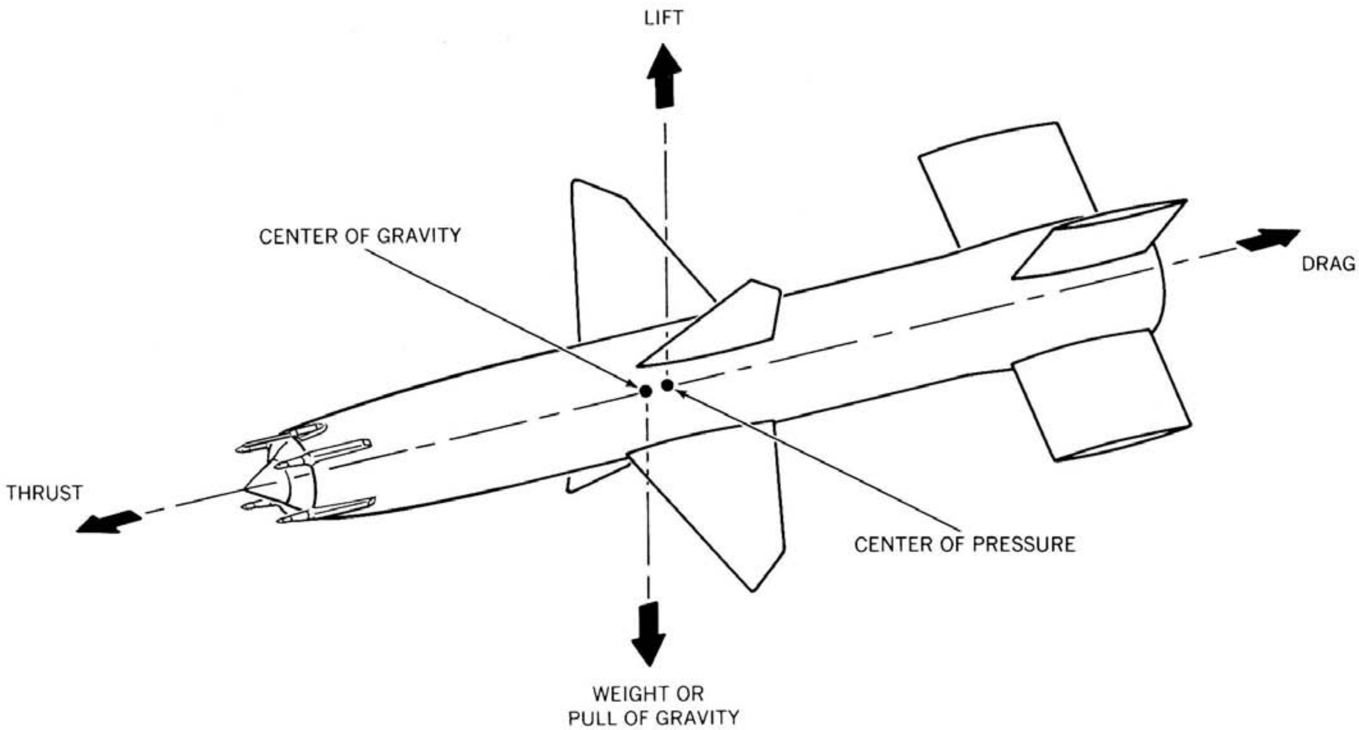
The principal forces acting on a missile in level flight are thrust, drag, weight, and lift. Like any forces, each of these is a vector quantity. You will remember from your study of Mathematics, Navpers 10069-C, that a vector has magnitude (length) and direction. These forces are illustrated in figure 3-4.

Thrust (force) is directed along the longitudinal axis of the missile and is the force



33.22(83A)

Figure 3-3. —Rotational movements about missile axes: A. Pitch, roll, and yaw axes are mutually perpendicular; B. Pitch axis and plane; C. Roll axis and plane; D. Yaw axis and plane.



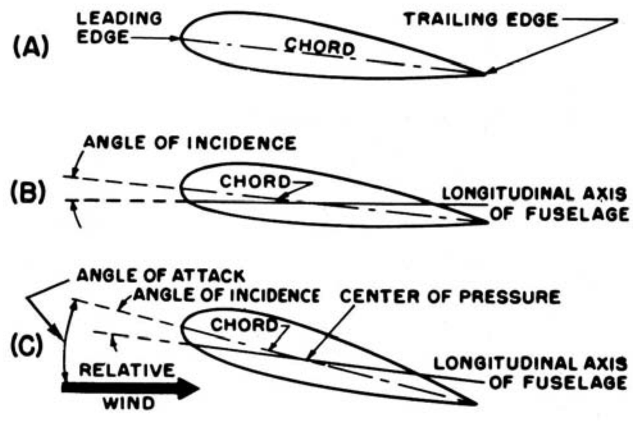
33.23
Figure 3-4.—Principal forces acting on a moving missile.

which propels it forward at speeds sufficient to sustain flight. Drag is the resistance air offers to the passage of the missile through air, and is directed rearward. The weight of the missile is the pull of gravity on the missile, and is directed downward toward the center of the earth. Opposed to the force of gravity is lift, an upward force which supports the missile. Lift is directed perpendicular to the direction of drag.

Lift is produced by means of pressure differences. The primary factor contributing to lift is that the air pressure on the upper surface of an airfoil (wing) must be less than the pressure on the underside. The amount of lifting force provided is dependent to a large extent on the shape of the wing. Additional factors which determine the amount of lift are the wing area, the angle at which the wing surface is inclined to the airstream (angle of attack), and the density and speed of the air passing around it. The airfoil that gives the greatest lift with the least drag in subsonic (less than the speed of sound) flight has a shape similar to the one illustrated in figure 3-5.

Some of the standard terms applied to airfoils are included in the sketch. The foremost edge of the wing is called the leading edge, and that at the rear the trailing edge (fig. 3-5A). A straight line between the leading and the trailing edges is called the chord. The distance from one wingtip to the other (not shown) is known as the SPAN. The angle of incidence (fig. 3-5B) is the angle between the wing chord and the longitudinal axis of the fuselage. In figure 3-5C, the large arrow indicates the relative wind, the direction of the airflow with reference to the moving airfoil. The angle of attack is the angle between the chord and the direction of the relative wind.

In actual flight, a change in the angle of attack will change the airspeed. But if for test purposes we maintain a constant velocity of the airstream while changing the angle of attack, the results on the nonsymmetrical wing will be as shown in figure 3-6. The sketches show a wing section at various angles of attack, and the effect these different angles have on the resultant force and the position of the center of pressure. The burble point referred to in



33.24A
Figure 3-5.—Nomenclature for parts of a subsonic airfoil.

figure 3-6C and D is the point at which airflow over the upper surface becomes rough, causing an uneven distribution of pressure. Note that the center of pressure changes with the angle of attack.

The relative wind strikes the tilted surface, and as the air flows around the wing, different amounts of lifting force are exerted on various points on the airfoil. The sum (resultant) of all these forces is equivalent to a single force acting at a single point and in a particular direction. This point. is called the center of pressure. From it, lift can be considered to be directed perpendicular to the direction of the relative wind.

The dynamic or impact force of the wind against the lower surface of the airfoil also contributes to lift, but no more than one-third of the total lift effect is provided by this impact force.

ACCELERATION

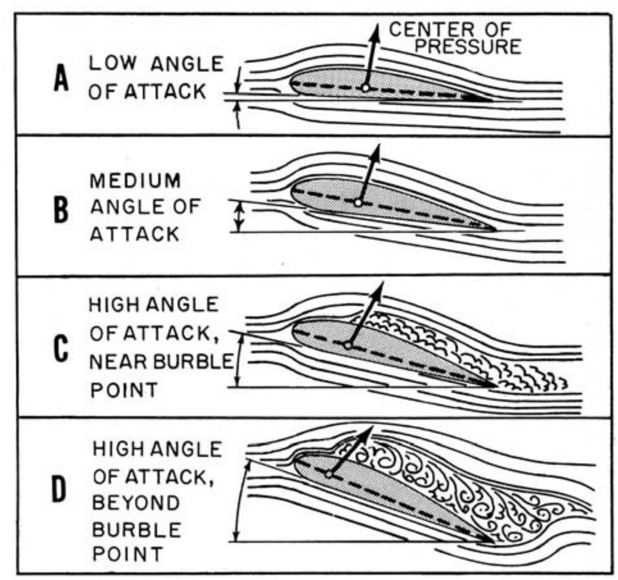
Acceleration is rate of change, either in speed or in direction of motion or both. A missile accelerates in a positive or negative sense as it increases or decreases speed along its line of flight. It also accelerates in a positive or negative sense as it changes direction in turns, dives, pullouts, and as a result of gusts of wind. During accelerations a missile is subjected to large forces which tend to keep it flying along its original line of flight. This is in accordance with Newton's first law of motion which states:

A particle remains at rest or in a state of uniform motion in a straight line unless acted upon by an external force.

Like gravity, acceleration is measured in terms of g's. The acceleration of a body in free fall is said to be one "g." Missiles making rapid turns or responding to large changes in thrust will experience accelerations many times that of gravity, the ratio being expressed as a number of "g's." The number of "g's" which a missile can withstand is one of the factors which determines its maximum turning rate and the type of launcher suitable for the weapon. The delicate instruments contained in a missile may be damaged if subjected to accelerations in excess of design values.

MACH NUMBERS AND SPEED REGIONS

Missile speeds are expressed in terms of Mach numbers rather than in miles per hour or knots. The Mach number is the ratio of missile speed to the local speed of sound. For example, if a missile is flying at a speed equal to one half the local speed of sound, it is said to be flying at Mach 0.5. If it moves at twice the local speed of sound, its speed is then Mach 2.



33.24B
Figure 3-6.—Effect of angle of attack on air flow and center pressure.

Local Speed Of Sound

The speed expressed by the Mach number is not a fixed quantity, because the speed of sound in air varies directly with the square root of air temperature. For example, it decreases from 760 miles per hour (mph) at sea level (for an average day when the air is 59~) to 661 mph at the top of the troposphere. The speed of sound remains constant (with the temperature) between 35,000 feet and 105,000 feet, then rises to 838 mph, reverses, and falls to 693 mph at the top of the stratosphere. Thus, you can see that the speed of sound will vary with locality.

The range of aircraft and missile speed is divided into four regions which are defined with respect to the local speed of sound. These regions are as follows.

SUBSONIC FLIGHT, in which the airflow over all missile surfaces is less than the speed of sound. The subsonic division starts at Mach 0 and extends to about Mach 0.75. (The upper limit varies with different aircraft, depending on the design of the airfoils.)

TRANSONIC FLIGHT, in which the airflow over the surfaces is mixed, being less than sonic speed in some areas and greater than sonic speed in others. The limits of this region are not sharply defined, but are approximately Mach 0.75 to Mach 1.2.

SUPERSONIC FLIGHT, in which the airflow over all surfaces is at speeds greater than sound velocity. This region extends from about Mach 1.2 upward.

HYPERSONIC FLIGHT, in which the time of passage of the missile is of the order of relaxation time. (Relaxation time is the time required for molecules of air to adjust themselves after the passage of the body.) Mach numbers on the order of 10 may be considered as hypersonic. Velocities that are not hypersonic at sea level may become so at high altitudes, since relaxation times will be longer where densities are relatively low.

Subsonic Flight

At subsonic speeds, sustained flight is dependent on forces produced by the motion of the aerodynamic surfaces through the air. If the surfaces of airfoils are well designed, the stream of air flows smoothly over, under, and around them. And the air stream conforms to the shape of the airfoil. If, in addition, the airfoils are set to the proper angle, and if motion is fast enough, the airflow will support the weight of the aircraft or missile.

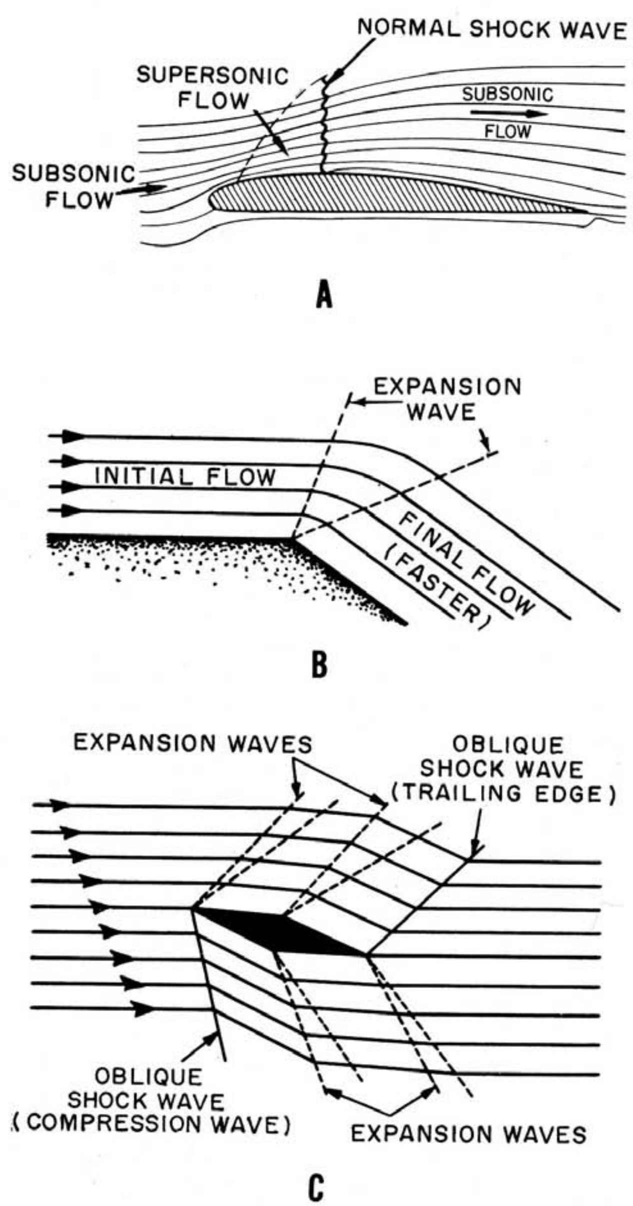
Since most modern missiles are supersonic, with only a few seconds of flight in the subsonic region of speed, the forces that affect missile flight at supersonic speeds are of more importance to you.

Missile Speed and Air Flow

A missile thrusting its way through the atmosphere may be compared to a boat pushing its way through the water. You can see the effect on water, so picture the air waves the same way. A boat moving slowly through the water gently pushes the water out of the way, but if it speeds up, the water is churned up into rushing waves that require increased thrust to push through. An object pushing through the air produces small pressure disturbances in the air, and each pressure wave expands equally in all directions, moving at the speed of sound. As long as the object is moving more slowly than the air waves, there is no buildup of pressure waves, but as the speed increases, the air waves begin to pile up in front of the object. When the speed of the object reaches the speed of sound the pressure waves can no longer outrun it, and the piled up airstream just ahead of the object collides with the unmoved air farther ahead, which a moment before was completely undisturbed. This causes a shock wave at the boundary between the air stream and the undisturbed air. The air stream is reduced in speed very rapidly and at the same time the pressure, density, and temperature increase. A normal shock wave is usually very strong, and the air passes through without changing direction (fig. 3-7A), but always changes from supersonic to subsonic velocity. In an oblique shock wave (fig. 3-7C), the airstream changes direction upon passing through the transition marked by the wavefront. These waves are produced in supersonic airstreams at the point of entry of wedge- shaped or other sharply pointed bodies. The change in speed, density, pressures, and temperature are generally less severe than with normal perpendicular shock waves.

STABILITY AND LIFT IN MODERN MISSILES

So far we have discussed the principles of producing lift by the use of cambered (curved) wings. Cambered wings are still used on conventional aircraft, but are not used on most



33.27-.30

Figure 3-7.—Movement of air over airfoils:
A. Formation of normal shockwave;
B. Expansion waves;
C. Airflow about a supersonic wing.

present day guided missiles. Most operational missiles use streamlined fins to provide stability and some lift.

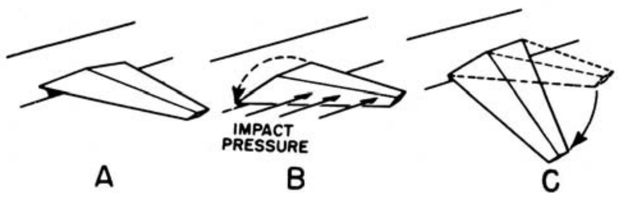
In some missiles lift is achieved entirely by the thrust of the main propulsion system. The Navy's Polaris missile, for example, has no fins.

The flight of an arrow is an example of the stability provided by fixed fins. The feathered fins on an arrow present streamlined airflow surfaces which ensure accurate flight. Since supersonic missile fins are not cambered, a slightly different lift principle is involved than with the conventional wing. At subsonic speeds a positive angle of attack will result in impact pressure on the lower fin surface which will produce lift just as with the conventional wing. At supersonic speeds, the formation of expansion waves and oblique shock waves also contributes to lift. Figure 3-7B shows the upper surface of a supersonic fin. Due to the fin shape, the air is speeded up through a series of expansion waves. This results in a low pressure area above the fin. Figure 3-7C shows the fin cross section. Beneath the fin, the force of the airstream (dynamic pressure) and the formation of oblique shock waves result in a high pressure area. The differences in pressure above and below the fin produce lift.

Control Surfaces, External

Movable fins, called control surfaces, provide a means for controlling missile flight attitude. A control surface provides control by presenting an obstacle to airflow. This causes a force (due to impact pressure) to be exerted on the surface. The magnitude of the force depends on the angle between the control surface and the direction and speed of airflow. In figure 3-8, we are looking at one effect of control surface movement.

Fixed (stabilization) fins and movable control surfaces may be located in several ways on the missile. In figure 3-9A and B, we see two possible combinations. In the first, control is achieved by movement of control surfaces located at the missile's center of gravity. In the second, ~ control is achieved by movement of tail surfaces. ; Other combinations are possible, and are used in some operational missiles. The important thing for you to remember is that control is attained due to impact pressure exerted on the control surfaces, and that fixed fins contribute primarily to stability. If you have ever watched an airplane being landed and noticed how the pilot tilted



33.31
Figure 3-8. —Control surface deflection: A Control surface in neutral position; B. Control surface tilted; C. Impact pressure of air causes missile roll.

certain portions of the wings, folded other parts, and extended other portions, you have some conception of how movement of missile wings, fins, tails, or other control surfaces can be used to change the course of the missile.

FIN DESIGNS. - Supersonic fins are symmetrical in thickness cross section and have a small thickness ratio - the ratio of the maximum thickness to the chord length. The double wedge, shown in figure 3-10, has the least drag for a given thickness ratio, but in certain applications is inferior because it lacks strength. As you saw in figure 3-7C, the air flows over and under a double wedge airfoil without developing a severe shock wave.

The modified double wedge has a relatively low drag (although its drag is usually higher than a double wedge of the same thickness ratio) and is stronger than the double wedge. The biconvex, shown in figure 3-10, has about one-third more drag than a double wedge of the same thickness ratio. It is the strongest of the three but is difficult to manufacture.

The planform of the fins - the outline when viewed from above - is usually either of the delta-modified delta (raked tip) or rectangular types shown in figure 3-11A. These shapes considerably reduce unwanted shock wave effects.

Figure 3-11B shows some of the movable parts of control surfaces that help to offset unstabilizing forces and to keep the missile on course. The ailerons on the wings help in roll control. When one aileron is raised, the other is lowered; the wing with the raised aileron moves down and the other moves up. Elevators attached to the horizontal tail fins are raised or lowered together and help in pitch control. The rudders on the vertical tail fins may be used for tail

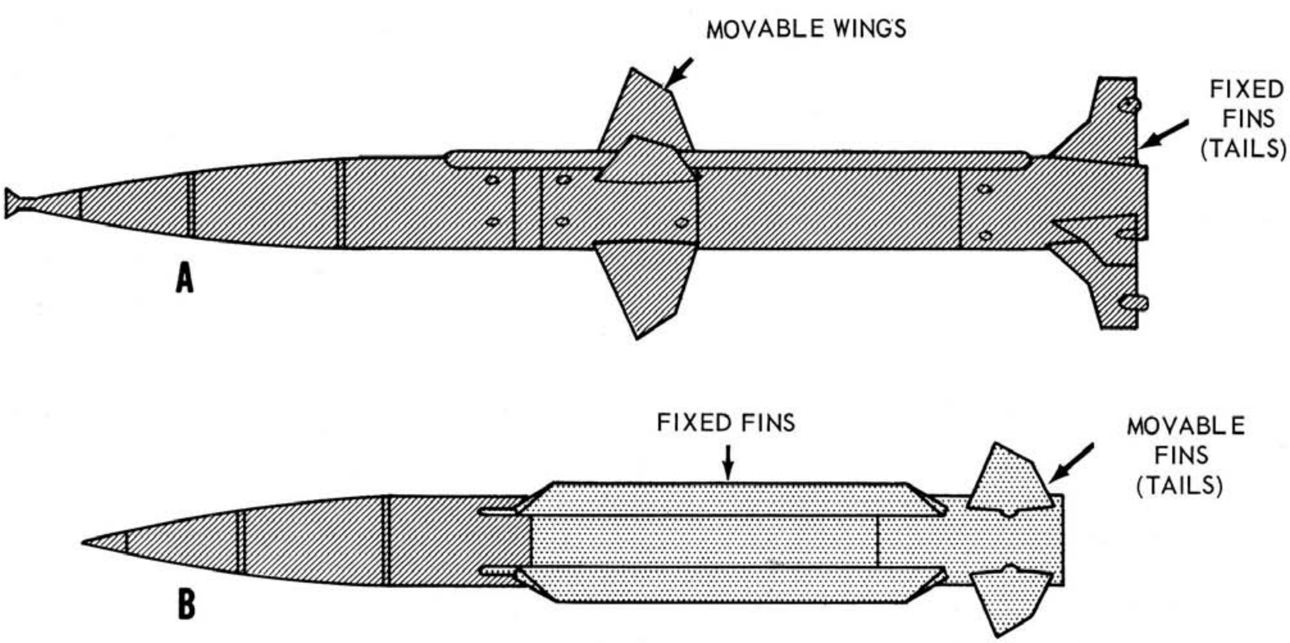


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Figure 3-9. —Arrangement of exterior control surfaces on missiles: A. Movable surfaces at center of gravity; B. Movable tail surfaces.

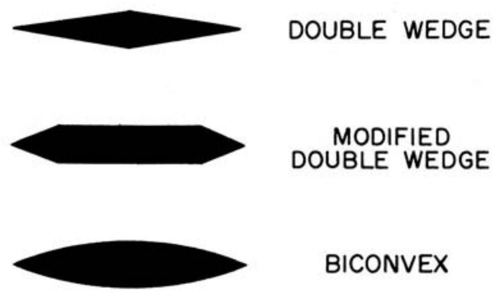

Figure 3-10.—Cross sections of supersonic airfoils. 33.33

control. If one rudder is moved to the right, the tail moves to the left and the missile yaws to the right. In most missiles in present use, the movements of the various parts are caused by the hydraulic system in the missile, which receives instructions electrically as to what moves are necessary to keep the missile on its course.

The Bullpup missile uses a form of tab (fig. 3-11B) as a method of control. Some of the newer missiles combine two devices, such as an elevator and an aileron, into an elevon, which allows control of both pitch and yaw by a single control mechanism.

ARRANGEMENT OF FINS. - Fins are mounted on the airframe in several arrangements, some of which are shown in figure 3-12. The CRUCIFORM is the most popular tail arrangement. It is used in surface-to-air missiles. Both the INLINE and INTER-DIGITAL cruciform arrangements are widely used, especially for supersonic missiles.

Control Surfaces, Internal

We mentioned earlier that some missiles do not have external control surfaces such as wings, fins, and tails. They may have small control surfaces that must be supplemented by other means of control. Two types have been used as auxiliary controls-exhaust vanes and jet control.

Exhaust vanes are control surfaces mounted directly in the exhaust path of a jet or rocket engine (fig. 3-13B). When the exhaust vanes are moved they deflect the exhaust, resulting in a change in the direction of thrust so as to keep the missile pointed in the desired direction. Even when the missile has just begun to move after launching, the exhaust velocity is very high. One disadvantage is that the tremendous heat of the exhaust makes the life of the vanes very short. The German V-2 missile used exhaust vanes of carbon; these lasted, on the average, about 60 seconds before they were burned up completely. Various forms of vanes are used and may be called jet vanes, jetevators, or jetevons. Some are fixed and some are movable.

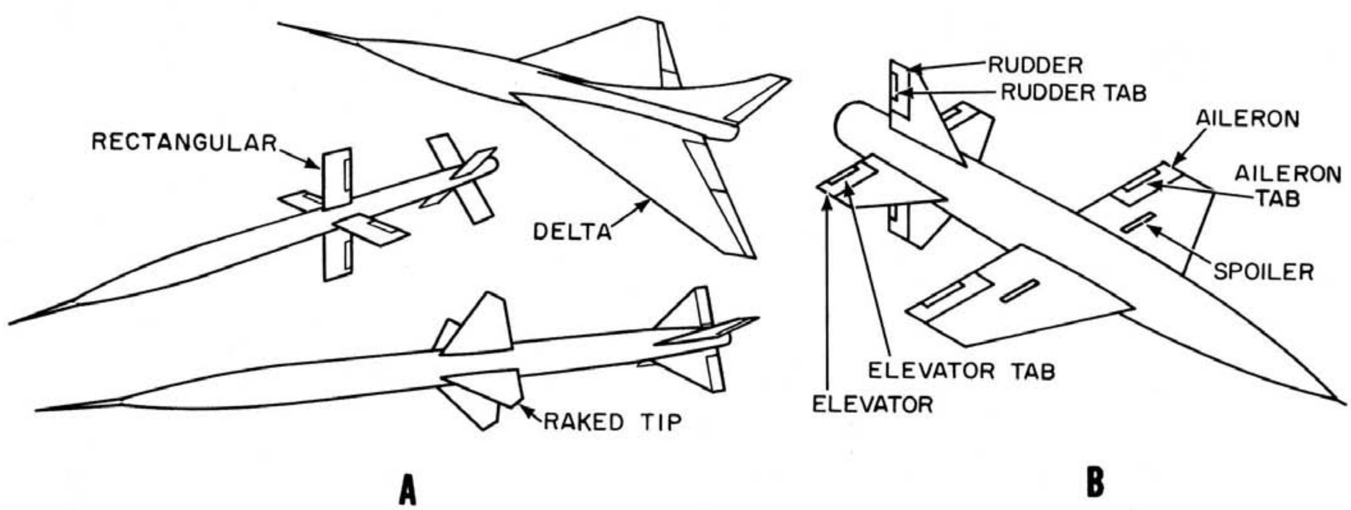

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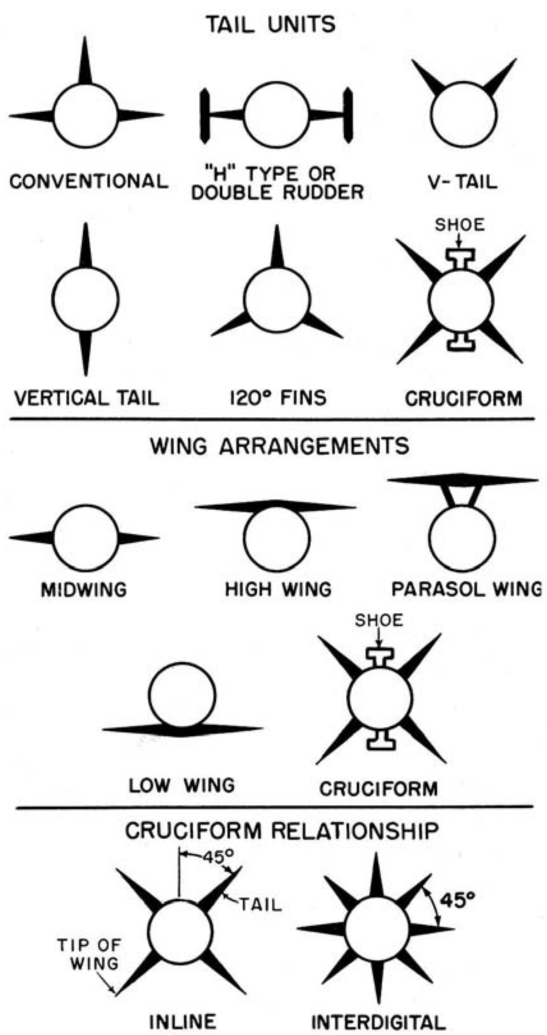
Figure 3-11.—External control devices on missiles: A. Plan forms of airfoils; B. Movable parts of fixed airfoils.



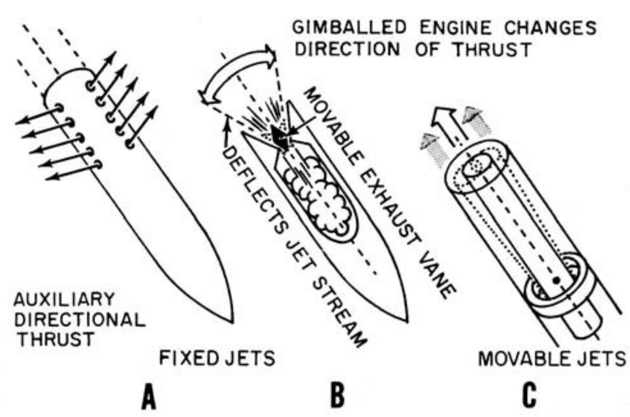
33.35
Figure 3-12.—Arrangements of airfoils on missiles.

Movable jets are another method of controlling the flight attitude of a missile. One method is to mount the engine itself in gimbals (fig. 3-13C), and turn the whole engine to deflect the exhaust stream. This system requires that the engine be fed with flexible fuel lines, and the control system that turns the engine must be very powerful. Also, it cannot control roll of the missile. To get control of all axes, two gimbal- mounted jets may be positioned in the missile. Both jets must be free to move in any direction, and must be able to respond to signals from any of the three control channels (pitch, roll, and yaw). Another system uses four movable jets mounted in the aft end of the missile. Two jets control yaw, two control pitch, and all four together control roll. Sometimes a fifth jet is fixed in the middle, in the space between the movable jets.

Fixed steering jets (fig. 3-13A) are placed around (inside) the missile so as to give directional control by exerting a force in one direction or another. Heat shields are necessary to protect the main body of the missile against the heat of exhaust from the jets. The use of these auxiliary jets makes it possible to eliminate all outside control surfaces. Missiles and spacecraft that reach into the higher, rare atmospheres, where external control surfaces are of little use, must depend on internal control means.

MISSILE AIRFRAMES

The airframe of a guided missile serves the same purpose as the airframe of the conventional aircraft: it carries the necessary components and controls to ensure proper flight. But, since the guided missile is essentially a one-shot weapon, the body structure can be simpler in structure than that of a conventional aircraft. Missile bodies are designed so that inner components are readily available for testing, removal, and repair. The major components are mounted to form independent units. Adequate room is provided to permit slack in electrical cables and harnesses so that inner sections can be removed easily during maintenance.



33.177:.181
Figure 3-13.—Jet control of flight attitude: A, Fixed jets; B. Exhaust vanes; C. Gimballed engine.

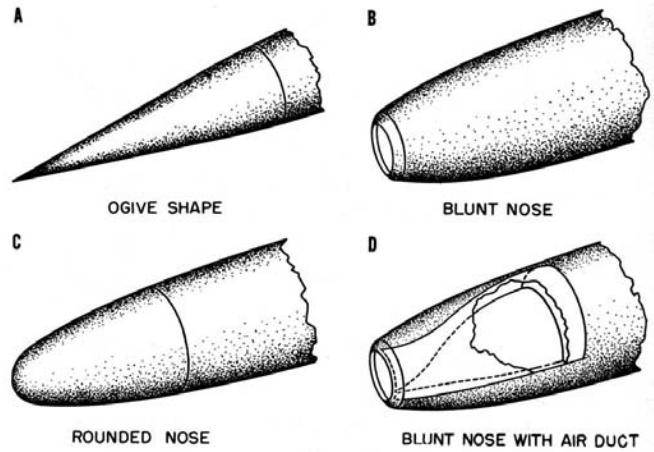
The configuration of a guided missile is the principal factor controlling the drag and lift forces that act on it as it passes through the atmosphere. Supersonic missiles must be designed for minimum drag. Both lift and drag are directly proportional to the square of missile speed. The shape of the nose, the body, and external control surfaces (if used) must be scientifically designed to obtain a maximum of lift and a minimum of drag.

Another effect that must be considered in missile design is that of heat. Heat results not only from friction as the missile passes through the atmosphere, but also from the temperature rise caused by the ram effects as the air is compressed by the speeding missile. A significant part of the development effort for long-range ballistic missiles has been devoted to development of nose cones capable of withstanding extreme temperatures.

Most missile bodies are slender cylindrical structures similar to those shown in figure 3-9. Several types of nose sections are used. If the missile is intended for supersonic speeds, the forward section may have a pointed arch profile in which the sides taper in lines called ogive curves (fig. 3-14A). Missiles which fly at lesser speeds may have blunt noses as shown in figure 3-14B. Rounded noses which house radar equipment may look like the one in figure 3-14C. Figure 3-14D shows an air-breathing missile nose which includes the duct for the ramjet propulsion system. The nose design of our ICBM has been modified several times, each one made to meet the need of the missile design with the least drag effect.

Most modern missiles are made up of several sections. Each section is a cylindrical shell machined from metal tubing rather than a builtup structure with internal bracing. Each shell contains one of the essential units or components of the missile, such as the propulsion system, the electronic control equipment, the warhead, or the fuze assembly.

Sectionalized construction has the advantage of strength with simplicity, and also provides ease in replacement and repair of the components since the shells are removable as separate units. The sections are joined by various types of connections designed for simplicity of operation. Access ports are sometimes provided in shells, through which adjustments can be made prior to launching.



33.41
Figure 3-14.—Missile noses.

MISSILE PROPULSION SYSTEMS

Guided missiles must travel at high speeds to be effective. To reach high speeds, missiles use jet propulsion. This chapter will introduce the theory of jet propulsion and several types of propulsion systems. Before you can understand how jet propulsion works, you need to know the basic laws of physics that apply to gases and liquids; then you can see how they are applied in jet propulsion of missiles.

GASES UNDER PRESSURE

Before taking up propulsion systems, let us look at the way gases are affected by variations in pressure and temperature. As a Gunner's Mate (Missile) you will use pressurized gases in many ways. Gases at high temperatures and pressures are used in the main propulsion systems of missiles. These gases may be in the form of high pressure air (or other inert gases) stored in flasks, or in the form of fuel combustion products.

From the safety standpoint it is especially important that you understand the theory of pressurized gases. Gases under pressure can be extremely dangerous if not handled in accordance with the applicable safety precautions. Many of these precautions will be presented later in this manual.

Theory

If you put a pint of milk into a quart bottle, the milk does not expand and fill the entire bottle. However, if you fill an inflatable life jacket with a CO_2 cartridge, the gas expands to occupy a much greater volume than it did formerly. You can easily measure the volume of a liquid, but the volume that a gas will occupy depends on the pressure to which it is subjected. Also, gases expand when heated, and contract when cooled. Since the volumes of gases depend on pressure and temperature, we must establish a standard of temperature and pres sure for measuring volume.

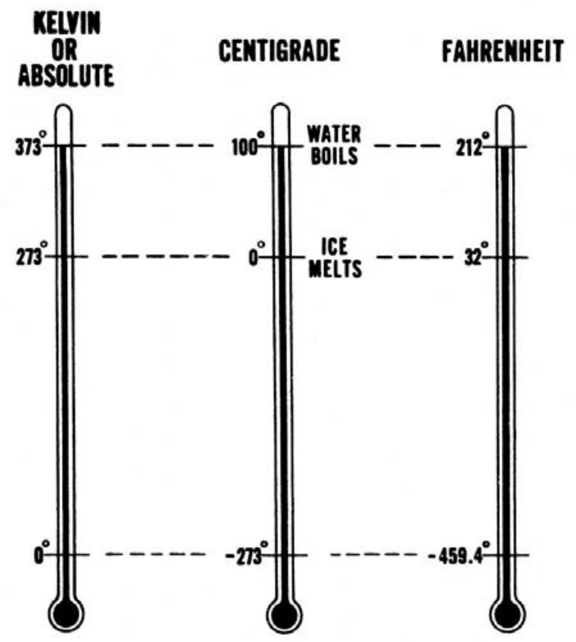
ABSOLUTE PRESSURE. - Although we live at the bottom of an ocean of air, we do not feel the pressure which the atmosphere exerts on us because it is equal in all directions. Atmospheric pressure at sea level will support a column of mercury 30 inches high. This pressure is equal to 14.7 psi (pounds per square inch).

In all problems involving the laws of gases, pressure should be figured in pounds per square inch absolute, which is the gauge pressure plus 14.7 psi at sea level.

Absolute Temperature

The temperature of a gas can be measured with respect to an absolute zero value. This value, which is usually expressed in terms of the centigrade scale, represents one of the fundamental constants of physics. (The relationship between the Centigrade and Fahrenheit scales can be seen in figure 3-15.) It was established experimentally during a series of tests made in the study of the kinetic theory of gases.

According to this view, a gas, like other forms of matter, is composed of molecules made up of combinations of atoms. Normally, the molecules of any substance are in constant motion. In the gaseous state, the motions are assumed to be entirely random. That is, the molecules move freely in any direction and are in constant collision, both among themselves and with the walls of the container (fig. 3-16A). The moving particles possess energy of motion, or kinetic energy, the total of which is equivalent to the quantity of heat contained in the gas. When heat is added, the total kinetic energy is increased. When the gas is cooled, the thermal agitation is diminished and the molecular velocities are lowered.



33.11(33)
Figure 3-15.—Temperature scales.

The molecules do not all have the same velocity, but display a wide range of individual velocities. The temperature of the gas, according to the kinetic theory, is determined by the average energy of the molecular motions. PRESSURE is accounted for by considering it as resulting from the bombardment of the walls of the container by the rapidly flying molecules. The particles are considered to have perfect elasticity, so that they rebound from the walls with the same velocities with which they strike them.

In accordance with the kinetic theory, if the heat energy of a given gas sample could be reduced progressively, a temperature would be reached at which the motions of the molecules would cease entirely. If known with accuracy, this temperature could then be taken as the absolute zero value. It was the purpose of the experiments mentioned above to establish the existence and value of this temperature, which was predicted by the kinetic theory.

Since any change in the temperature of a gas causes a corresponding change in the pressure, it was necessary to consider temperature, pressure, and volume together. Hydrogen gas was enclosed in a cylinder containing a movable piston, so that the volume could be adjusted to maintain the initial pressure. The experiment was started with the gas at a temperature of 0° centigrade.

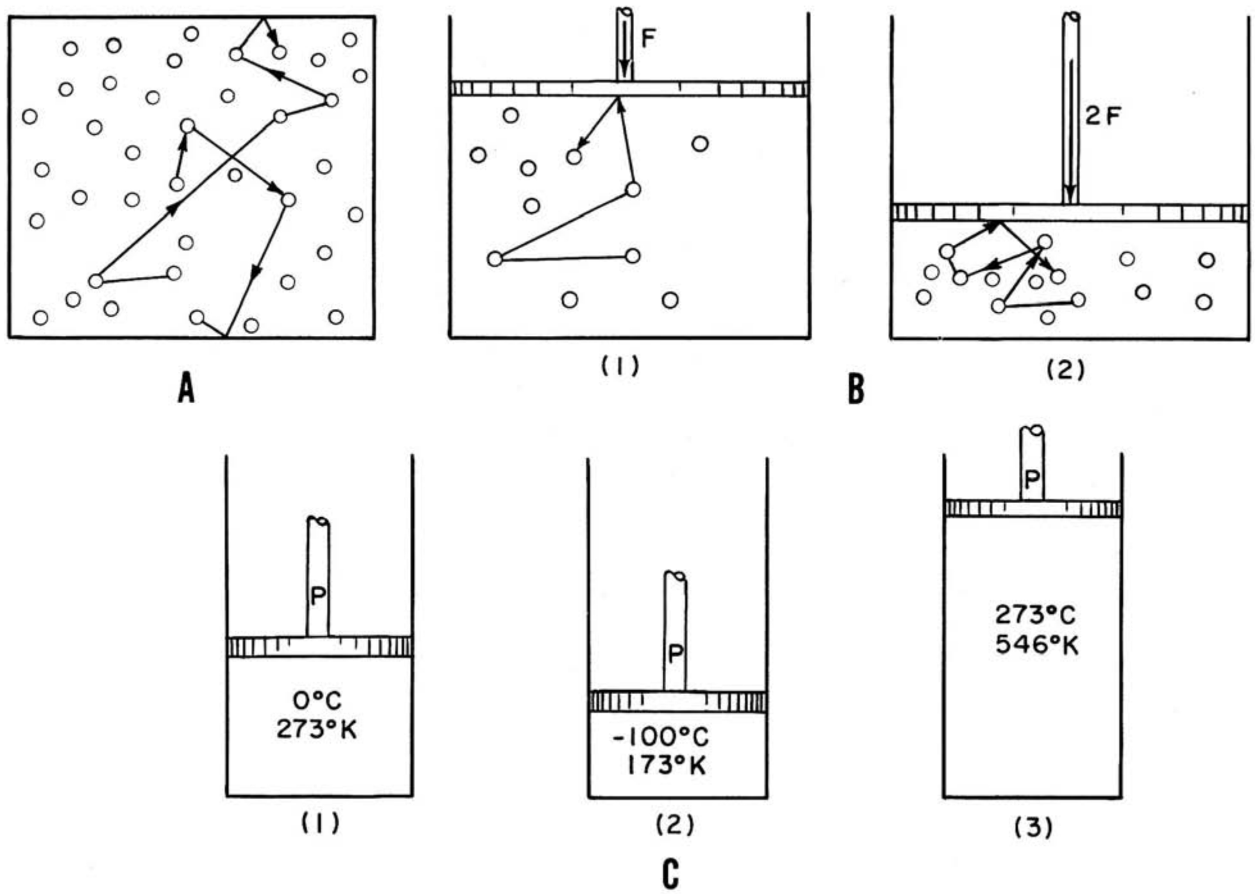


Figure 3-16.—Laws of gases: A. Collision of gas molecules; B. Boyle's Law, where gas volume is halved and pressure doubled; C. Charles' law, showing changing volume at different temperatures, with pressure constant.

It was found that when the gas was cooled enough to drop the temperature by 1°C, the volume had to be decreased by moving the piston in order to keep the sample at the same pressure. The new gas volume was then equal to 272/273 the volume at 0°C. As the temperature was lowered further, the volume (for constant pressure) decreased by an amount equal to 1/273 the initial volume for each decrease of one centigrade degree.

If, however, the volume was kept constant by keeping the piston unchanged in position, it was found that the pressure varied at the same rate. That is, it decreased by an amount equal to 1/273 the pressure at 0° C for each drop of 1 ° in the temperature.

The same rates of change of volume and pressure were found to be present in all gases; and they were uniform over a wide range of temperature. All these facts led to the conclusion that if any gas were cooled to -273°C (actually -273.16°), with the pressure kept constant, the volume would shrink to zero. However, all known gases change to the liquid state before this temperature is reached. Also, if the volume were maintained at the initial value, the pressure would approach zero as the temperature approached this same value. It was then assumed that -273°C represents the theoretical absolute zero point at which all molecular motion ceases, and no more heat remains in the substance.

The existence of absolute zero cannot be determined directly by observing the volume of gas cooled to -273°C, since all gases are converted to the liquid state before this temperature is reached. In many experiments, however, this condition has been approached closely, the actual temperature reached being within a small fraction of a degree of the theoretical zero value.

THE KELVIN SCALE. - When temperatures are measured with respect to -273°C they are said to be expressed in the absolute, or Kelvin, scale. Specific absolute temperatures are designated by the letter K. Thus, 0° C is equivalent to 273° K, 20° C equals 293° K, and 100° C equals 373° K. The relationship between the three temperature scales is shown in figure 3-15. The Kelvin scale is used in scientific work. In formulas, Kelvin temperatures in general are represented by T and Centigrade or Fahrenheit temperatures by t.

Gas Laws

The natural laws that affect the behavior of gases were determined by experiments by scientists long ago. The first of these is Boyle's law (Robert Boyle, 1627-1691), which is stated as follows:

> "The volume of any dry gas, the temperature remaining constant, varies inversely with the pressure on it; that is, the greater the pressure, the smaller the volume becomes."

Figure 3-16B illustrates this law, showing the volume halved when the pressure is doubled, where F represents force applied. In the second part of the picture, there are twice as many gas molecules per unit of volume (density is double), and twice as many collisions per second.

This law may be stated as an algebraic formula:

$$V_1 P_1 = V_2 P_2$$

where V_1 and P_1 refer to the original volume and pressure, and V_2 and P_2 refer to the new volume and pressure. This equation is true only if the temperature has remained the same. Although this law was formulated for a perfect or ideal gas, it holds closely for ordinary gases except under high compression, when a modified equation is applied.

A second gas law has to do with the effects of changes in temperature:

All gases expand and contract to the same extent under the same change of temperature, provided there is no change in pressure. In general, when the pressure is kept constant, the volume of a gas is proportional to its absolute temperature (Kelvin). This is known as Charles' law. See figure 3-16 C. It is also known as the Gay-Lussac law.

In equation form this becomes:

$$\frac{V_1}{V_2} = \frac{T_1}{T_2}$$

where V is the volume and T is the absolute temperature (Kelvin).

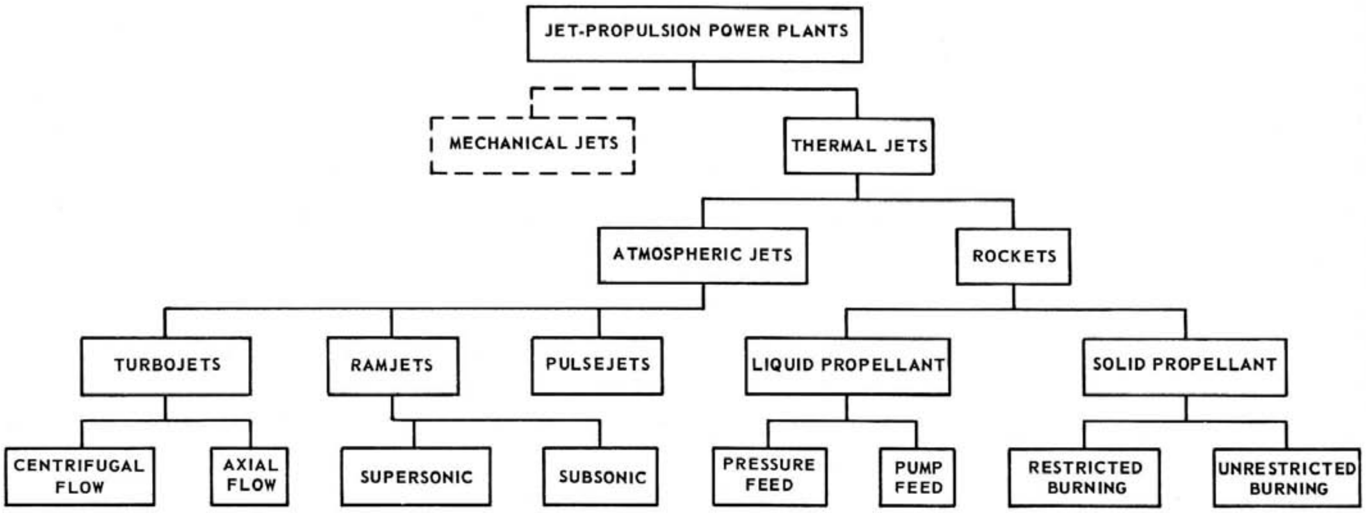
Finally, since the volume of a gas increases as the temperature rises, it is reasonable to expect that if a confined sample of gas were heated, its pressure would increase. Experiments have shown that the pressure of any gas kept at a constant volume increases for each degree centigrade rise very nearly 1/273 of its pressure at 0° C. Because of this finding it is convenient to state this relationship in terms of absolute temperatures. For all gases at constant volume, the pressure is proportional to the absolute temperature.

The first two formulas (Charles' law and Boyle's law) may be combined to give the general gas law, by which the effect may be computed of the variation of any or all of the three quantities - pressure, volume, and temperature - at the same time.

It is not likely that you will have to perform computations with any of these formulas, but the effects of the gas laws influence your daily work. Although air is a mixture of gases, it obeys the same laws. You have just studied how changes in air density and pressure affect missile flight. The combustion gases formed by the burning propellant inside the missile respond to the same laws. Gases that you use in various ways in your work aboard ship, such as compressed air, oxygen, and carbon dioxide, conform to the gas laws. A number of the safety regulations are necessary because of the way these gases behave. You can see there are plenty of reasons why you should know how gases react to different situations.

PRINCIPLE OF JET PROPULSION.

The principle of jet propulsion is based on Sir Isaac Newton's third law of motion which



33.12
Figure 3-17.—Classification of jet powerplants.

states that "For every action there is an equal and opposite reaction." As an example of the reaction principle, remember your firefighting training in boot camp. You will probably recall your first experience with a large diameter high pressure firehose. With the hose pressurized and the nozzle closed, a single man can handle the charged firehose; but as soon as the nozzle is opened, two or three men are required. The reason for this is that as soon as water is permitted to escape from the nozzle, reaction to this water flow causes the nozzle to buck or kick in the opposite direction. The amount of reaction or "thrust" is equal to the force of the escaping water. This force can be determined by measuring the mass and velocity of the water which escapes.

The two most common methods by which we produce thrust are by mechanical means (pumps or fans), and by thermal means (chemical reaction). The firehose is an example of a mechanical jet. Another example of the mechanical jet may be found in nature. The squid draws water into its body and then by muscle contraction forces this water rearward through a small opening at an increased velocity, thus propelling itself forward.

In guided missiles we are concerned with thermal jets - those that operate by reaction to the exhaust of combustion gases. It is a common misconception that a jet engine is dependent on the atmosphere to obtain its thrust, or force, in the direction of motion. (Air- breathing jets require air for oxygen to support combustion of the propellant.) Actually, thrust is the reaction to the ejection of exhaust gases. If you take a firehose and direct the water stream against a wall, the reaction force experienced is the same as if the wall were not there. To continue the analogy, missile thrust is the same regardless of whether the missile is in the atmosphere or in the vacuum of space. Jet engines are frequently called reaction motors, since the exhaust gases produce the action while the opposite motion of the missile or aircraft represents the reaction.

Figure 3-17 charts the types of jet propulsion systems. The systems falling under the heading of rockets are those which carry within themselves all the materials necessary for their operation. In most rockets these materials include an oxidizer. An oxidizer is a substance which contains the oxygen necessary to support combustion of the fuel. (You will remember that a rocket was defined earlier as a missile with an independent propulsion system.) Rockets are sometimes referred to as air-independent units, since they do not rely on the oxygen in the atmosphere.

The atmospheric jets, on the other hand, depend on air to support combustion. Both the rocket and the atmospheric jet receive their thrust as a reaction to the exhaust of combustion gases.

It should be remembered that the rocket is the only jet engine capable of operating outside the earth's atmosphere.

Present day surface-to-air missiles have either ramjet or solid propellant propulsion systems. In this section we will discuss only these two types.

COMPONENTS OF JET PROPULSION SYSTEMS

To achieve high thrust, it is necessary to produce large quantities of exhaust gases at high temperatures and pressures. To produce these exhaust gases, jet propulsion systems consist of a combustion chamber, an exhaust nozzle, and a fuel supply.

Combustion Chamber

The combustion chamber is that part of the system in which the chemical action (combustion) takes place. Combustion is necessary to provide thrust. Useful thrust cannot be attained in an atmospheric jet unless the combustion products are exhausted at a velocity greater than that of the intake gases (air). The chamber is usually called a cylinder, although it may have the shape of a sphere. It must have the proper length and diameter to produce a chamber volume suitable for complete and stable combustion.

In all thermal jets, the heat energy released by the combustion process is converted to kinetic energy through expansion of the gases of combustion as they pass through the exhaust nozzle.

Exhaust Nozzle

An exhaust nozzle is a nonuniform chamber through which the gases generated in the combustion chamber flow to the outside. Its most important areas are the mouth, throat, and exit. These areas are identified in figure 3-18. The function of the nozzle is to increase the velocity of the gases. The principle involved was announced many years ago by a Swiss physicist, Daniel Bernoulli. Bernoulli's principle applies to any fluid (gas or liquid). It may be stated as follows: "Provided the weight rate of flow of a fluid is constant, the speed of the fluid will increase where there is convergence in the line. It will decrease where there is a divergence in the line." Figure 3-19 illustrates this principle. The velocity of the fluid will increase at point 1. At the point of divergence, point 2, the speed of the fluid will decrease.

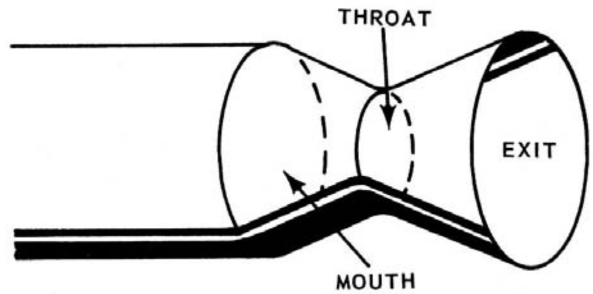


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Figure 3-18.—Location of nozzle areas.

The increase in speed between points 1 and 2 is caused by a conversion of potential energy (fluid pressure) to kinetic energy. Thus, the pressure drop of the fluid through the restriction is proportional to the velocity gained. When the fluid reaches point 2, the kinetic energy is again converted to potential energy. At point 2, the fluid velocity decreases, and the pressure of the fluid increases.

This relationship also holds true for subsonic flow of gases. In the convergent nozzle in figure 3-20A, the speed will increase up to the speed of sound, depending on the degree of convergence. In the divergent nozzle in figure 3-20B, gases at subsonic speeds will slow down, depending on the degree of divergence.

Gases at supersonic (faster than sound) speed behave differently. As these gases pass through the divergent nozzle, their velocity is INCREASED because of their high state of compression. The drop in pressure at the point of divergence causes an instantaneous release of kinetic energy. This imparts additional speed to the gases. To obtain supersonic exhaust velocity, the DeLaval nozzle in figure 3-20C is commonly used. This nozzle

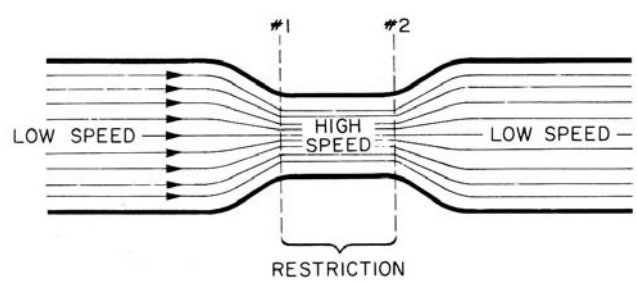

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Figure 3-19.—Fluid flow through a restriction.

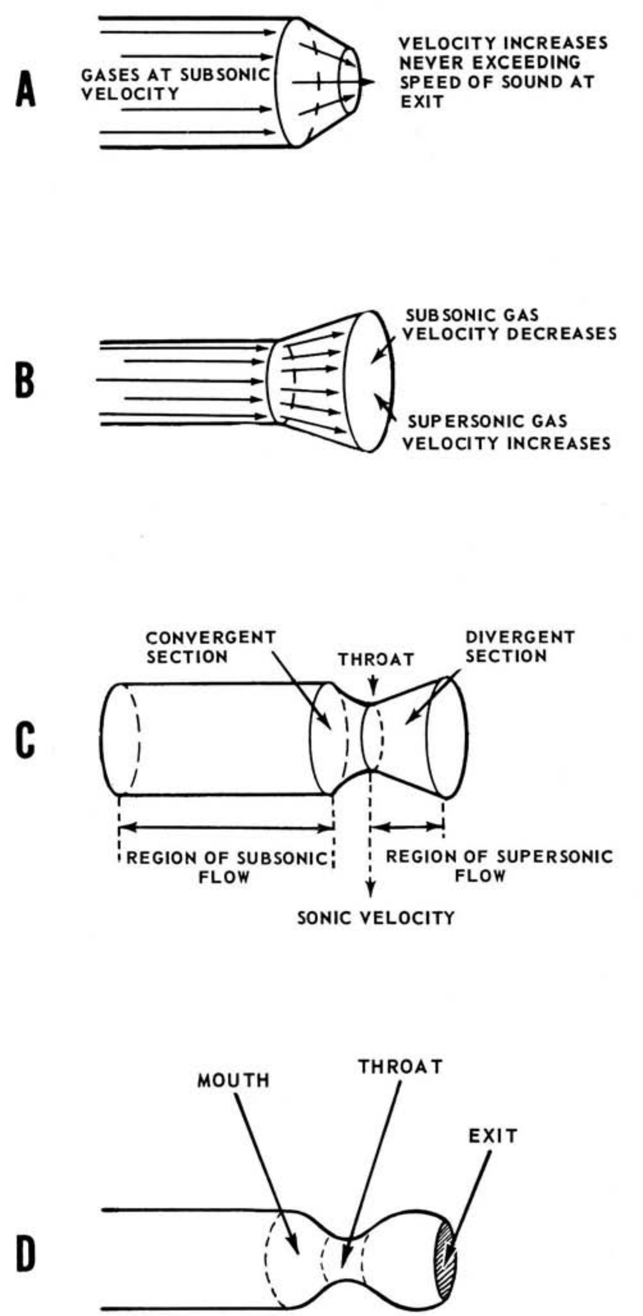

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Figure 3-20.—Gas flow through nozzles: A. Subsonic flow through a convergent nozzle; B. Flow through a divergent nozzle; C. Convergent-divergent nozzle (DeLaval); D. Prandtl nozzle.

first converges to bring the subsonic flow up to the speed of sound. Then the nozzle diverges, allowing the gases to expand and produce supersonic flow.

The Prandtl nozzle (fig. 3-20D) is more efficient than the straight-coned DeLaval nozzle but is more difficult to engineer and produce. It increases the rate of flow at a higher rate than the normal convergent-divergent type. The shape of the nozzle determines the characteristic of the gas flow, which must be smooth.

Other nozzles of increasing importance are the adjustable area type, in which the nozzle area is varied to suit varying combustion environmental conditions. The best size for the nozzle throat is different for different propellants. The nozzle must be designed for a specific set of propellant and combustion characteristics to obtain higher velocity and increased thrust.

Fuel Supply

The fuel supply consists of solids, liquids, gases, or various combinations of these. However, fuels in the gaseous state are rarely us~ in missiles. Liquids or solids have a higher density than most gases, even when the latter are highly compressed; thus a larger quantity of solid or liquid fuel can be carried in a given space. Many factors must be considered when selecting the fuel or fuels to be used in a certain missile. Among these factors are cost, availability, safety, ease of handling and storage, storage life, and amount of "push" it will furnish to the missile.

ROCKET FUELS. - Several means have been worked out for rating, or comparing, various rocket fuels (propellants). Comparison is made by determining total impulse. Total impulse is the product of the thrust in pounds times burning time in seconds. Or,

I_T (Total Impulse in lb-sec) =
T (Thrust in lbs) x t (Duration in secs).

Solid propellants are rated, or compared, on the basis of specific impulse. Specific impulse is the amount of impulse produced by one pound of the propellant. Stated in formula:

I_{sp} (Specific Impulse in lb-sec/lb) =

$$\frac{I_T \text{ (Total Impulse in lb-sec)}}{W \text{ (Weight of Solid Fuel in lbs)}}$$

A common method of comparing liquid propellants is on the basis of specific thrust. Specific thrust is equivalent to specific impulse [or solid propellants but derived in a slightly different way. Specific thrust is defined as the thrust in pounds divided by the rate of fuel now in pounds per second. Or,

$$T_{sp} \text{ (Specific Thrust in lbs/lb/sec)} = \frac{\text{T (Thrust in lbs)}}{\text{W (Weight Rate of Flow in lb. per sec)}}$$

Specific thrust is expressed in seconds.

You sometimes may see the term "specific impulse" used for liquid as well as solid propellants. However, the term "specific thrust" more correctly brings out the correct meaning for liquids. As for solid propellants, it would be impractical to attempt to measure the weight rate of flow; therefore, specific impulse is used for comparison of solid fuels.

Specific propellant consumption is another term of importance in liquid propellant systems. [t is the reciprocal of specific thrust. It is defined as the propellant flow in pounds per second necessary to produce one pound of thrust. Or,

$$\text{Specific Propellant Consumption} = \frac{\text{Weight Rate of Flow (lbs/sec)}}{\text{Thrust (lbs)}}$$

Other terms you should know are mixture ratio and exhaust velocity.

Mixture ratio designates the relative quantities of oxidizer and fuel used in the propellant combination. It is numerically equal to the weight of oxidizer flow divided by weight of fuel flow. (Many liquid propellants are stored in separate containers, one holding the oxidizer, the other containing the fuel, until the moment of use.)

Exhaust velocity is determined theoretically on the basis of the energy content of the propellant combination. The actual velocity of the exhaust gases is of course less than this theoretical value since no jet engine can completely convert the energy content of the propellant into exhaust velocity. Thus, effective exhaust velocity is sometimes used and is determined on the basis of thrust and propellant flow:

$$\text{Effective Exhaust Velocity} = \frac{\text{Thrust (lbs)}}{\text{Mass Rate of Flow (lbs/sec)}}$$

Solid Propellants

The ingredients of a solid propellant are mixed so as to produce a solid of specified chemical and physical characteristics. Some examples of materials used in making solid propellants are asphalt-oils, nitroglycerin, asphalt-potassium perchlorates, black powder with ammonium nitrate, and other recently developed combinations. The finished product takes the shape of a grain, or stick. A charge may be made up of one or more grains. Do not think of a grain of propellant as the size of a grain of sand or a grain of wheat. It may be that small, but it may be several feet long, see figures 3-30 and 3-31. Combustion of solid propellants will be discussed later in this chapter.

An ideal solid propellant would:

1. Have a high specific impulse.
2. Be easy to manufacture from available raw materials.
3. Be safe and easy to handle.
4. Be easily stored.
5. Be resistant to shock and temperature.
6. Ignite and burn evenly.
7. Be non-water-absorbent.
8. Be smokeless and flashless.
9. Have indefinite service life.

It is doubtful if a single propellant having all of these qualities will ever be developed. Some of these characteristics are obtained at the expense of others, depending on the performance desired.

Liquid Propellants

The liquid propellants are classified as monopropellants or as bipropellants.

Monopropellants are those which contain within themselves both the fuel and oxidizer, and are capable of combustion as they exist. Bipropellants are those in which the fuel and oxidizer are kept physically separated until they are injected into the combustion chamber. An example of a monopropellant would be the mixture of hydrogen peroxide and ethyl alcohol; an example of bipropellant would be liquid oxygen and kerosene.

While solid propellants are stored within the combustion chamber, liquid propellants are stored in tanks and injected into the combustion chamber. In general, liquid propellants provide a longer burning time than solid propellants.

They have a further advantage in that combustion can be easily stopped and started at will by controlling the propellant flow.

When oxygen or an oxygen-rich chemical is used as an oxidizer, the best liquid fuels appear to be those rich in both carbon and hydrogen.

In addition to the fuel and oxidizer, a liquid propellant may also contain a catalyst to increase the speed of the reaction. A catalyst is a substance used to promote a chemical reaction between two or more other substances.

Inert additives, which do not take part in the chemical reaction, are sometimes combined with liquid fuels. An example is water, which is often added when alcohol is used as a fuel. Although the water does not take part in the chemical reaction, the water does provide additional particles which contribute to a higher thrust by increasing the rate of mass flow through the system.

An ideal liquid propellant would:

1. Be easy to manufacture from available raw materials.
2. Yield a high heat of combustion.
3. Have a low freezing point.
4. Have a high specific gravity.
5. Have low toxicity and corrosive effects.
6. Have stability in storage.

As with the solid propellants, it is unlikely that all of these characteristics can be combined in a single fuel. One that has a high specific thrust may be very toxic and therefore dangerous and difficult to handle. Another may be very unstable and difficult to store. Liquid oxygen is an example - it must be kept in high pressure tanks until just before launching. In spite of the best care, there is a large loss by evaporation while transferring the oxygen to the missile. No "best" propellant has been discovered.

ATMOSPHERIC JETS

As mentioned previously, the atmospheric jet relies on the surrounding atmosphere for oxygen to support combustion. Ramjets fall under the category of atmospheric jets. The first successful application of atmospheric jets to missile propulsion was the pulsejet engine used in the German V-I missile, the "buzz bomb" of World War II. It was so called because of the intermittent or pulsating combustion process. An early U. S. Navy missile used a pulsejet engine, but it is now considered obsolete.

Another form of atmospheric jet is the turbojet. It is not used in any Navy missiles at present but is used in some aircraft. Three Air Force missiles are turbojets - Matador, Mace, and Hound Dog. Future inventions may make the turbojet principle applicable to high speed missiles as well as to aircraft.

Ramjet Engine

The ramjet shown in figure 3-21 is an atmospheric jet which is essentially a pipe open at both ends. From this the term "flying stove pipe" originated. The principal parts of this engine are the diffuser, the combustion chamber and associated fuel-feed system, and the exhaust nozzle. The combustion process in the ramjet is continuous rather than intermittent as in the, pulsejet. The ramjet has no bank of valve, to restrict the flow of gases to one direction For this reason, the ramjet must be boosted to a speed very near its operating speed before. it takes over on its own. To attain this speed a rocket or other type of booster is used, an. it is generally larger and heavier than the ramjet itself. The Talos missile for example has a ramjet sustainer.

This engine is ideally suited to long range high-speed missiles, since the thrust increase: with speed, and the rate of fuel consumption per unit of thrust decreases with speed. In other words, the faster a ramjet flies, the greater it efficiency. The ram action of the air increases with the speed of the missile.

OPERATING CYCLE. - The cycle of subsonic ramjet operation is as follows (fig. 3-22A)

1. The ramjet is boosted by a separate propulsion unit to the required velocity. Ail enters the diffuser inlet and, due to the increasing cross section, decreases in velocity as it approaches the after end of the diffuser (an application of Bernoulli's principle).
2. This decrease in velocity is accompanied by an increase in pressure, with the result that a relatively high pressure barrier exists at the after end of the diffuser.
3. Fuel, usually kerosene, is sprayed into the combustion chamber through injection nozzles.
4. This fuel, thoroughly mixed with the incoming air, is ignited by a spark plug.
5. The combustion gases tend to expand in all directions.

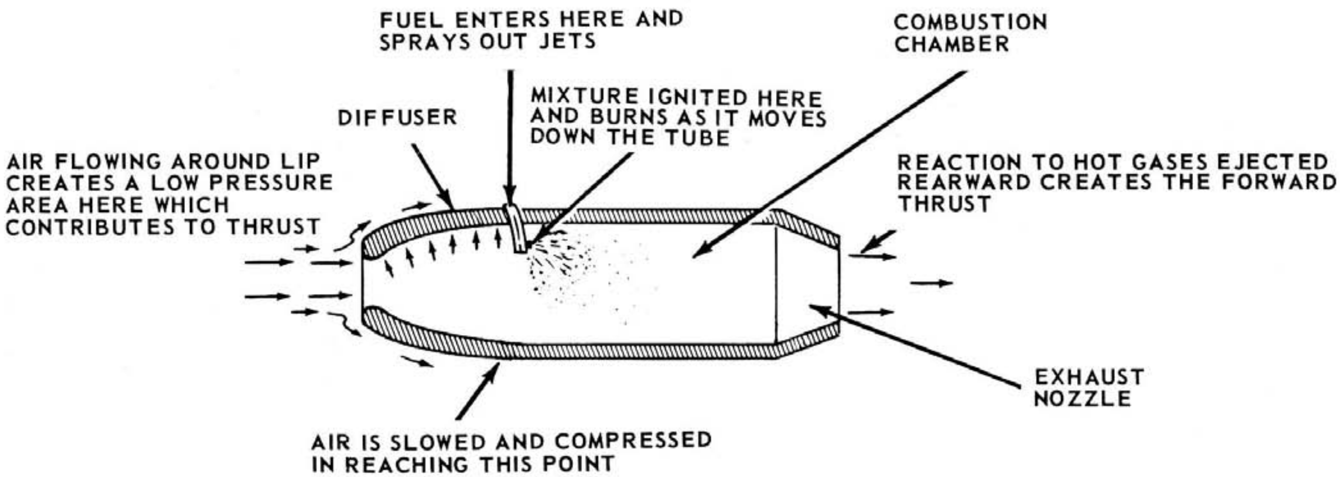

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Figure 3-21. — Ramjet engine.

6. Expansion in the forward direction is restricted by the pressure barrier existing at the after end of the diffuser; consequently, the gases must expand down the tailpipe and leave the exhaust nozzle with a greater velocity than that of the air at the intake.

Once ignition takes place, there is no further need for an electric spark because combustion is continuous as long as the air-fuel mixture is maintained with proper limits. The flame holder (figs. 3-22A, B, C), prevents the flame from being blown too far to the rear of the engine. Without it, the flame could be blown out by the high speed air stream.

The diffuser design is very important since a higher pressure barrier results in greater thrust.

The operation of a supersonic ramjet (figs. 3-22B and C) is the same as that of a subsonic ramjet, with the following exceptions. First, the supersonic jet must be boosted to a supersonic speed. Second, a higher pressure barrier exists in the supersonic engine, resulting in greater thrust. Talos missiles have supersonic ramjet propulsion systems.

Note the differences in the shape of the diffuser section and the throat in figure 3-22. They must be designed for a predetermined missile speed, according to Bernoulli's principle. Note, too, that the fuel injection systems can be varied. The effect of the shape of the exit nozzle on the speed of the exhaust gases is also illustrated. Compare the nozzles in figure 3-22 with those in figure 3-20.

ROCKETS

Present day operational rockets may be divided into two classes - solid propellant and liquid propellant.

The more important characteristics of all rocket engines are:

1. The thrust of a rocket is nearly constant, and is independent of speed.
2. Rockets will operate in a vacuum.
3. Rockets have relatively few moving parts.
4. Rockets have a very high rate of propellant consumption.
5. Burning time of the propellant in a rocket is short.
6. Rockets need no booster. They have full thrust at take off; therefore, when rockets do employ boosters it is for the purpose of reaching a high velocity in minimum time.

Solid Propellant Engines

The combustion chamber of a solid propellant rocket contains the charge of solid propellant. Solid propellant charges are of two basic types: restricted burning and unrestricted burning (fig. 3-23). The restricted burning charge is designed so that burning is permitted on only one surface at a time. A common example of restricted burning is a lighted cigarette. The restricted burning charge provides relatively low thrust and long burning time. Uses of this type of charge include JATO (jet-assisted take off) units, barrage rockets, and sustaining rockets for guided missiles.

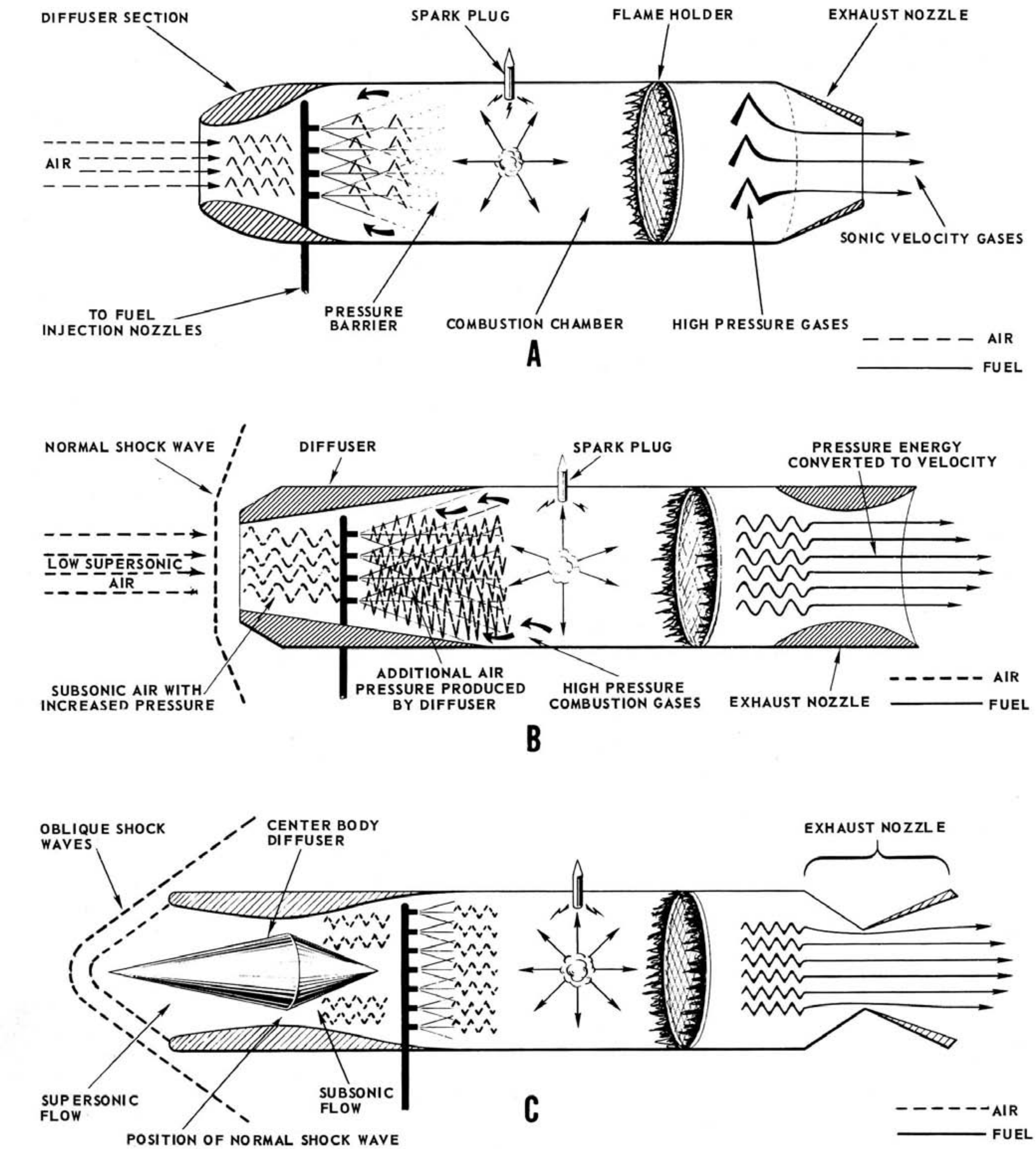

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Figure 3-22.—Structure of ramjets and combustion processes in them: A. Subsonic ramjet; B. Low supersonic ramjet. C. High supersonic ramjet.

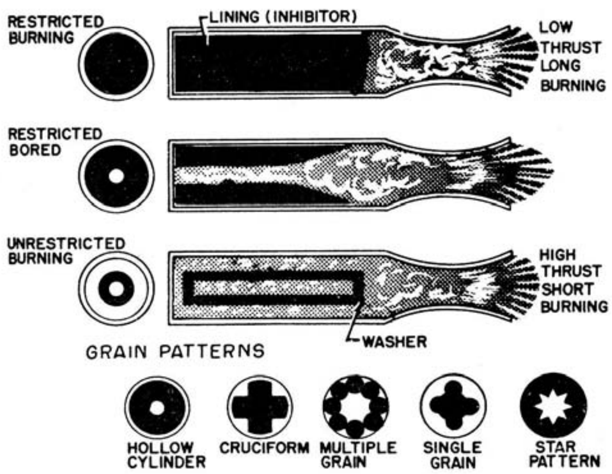


Figure 3-23.—Solid propellant grains used in rockets.

A modification of the restricted burning charge is the bored restricted charge. The main difference is that the longitudinal hole in the charge provides somewhat more burning surface and thus a higher thrust and shorter burning time.

In the unrestricted burning charge, burning takes place on several surfaces at one time. This results in a very high thrust during a short burning time. This type of charge is commonly used in booster rockets.

It should be clearly understood that in both the restricted and unrestricted burning charges, the burning rate is controlled - there is no explosion. Controlling the burning rate of a solid propellant has always presented a problem to rocket designers. You will recall that one of the properties of an ideal solid propellant would be that it ignite and burn evenly. The burning rate may be controlled in several ways. One is by means of inhibitors. An inhibitor is any substance which interferes with or retards combustion. The lining and washer shown in figure 3-23 are examples of inhibitors. Another way that burning is controlled is by use of various grain shapes. Examples are the shapes shown in the lower part of figure 3-23. Resonant burning or "chugging" may be offset by the use of resonance rods. There metal or plastic rods are sometimes included in the combustion chamber to break up regular fluctuations in the burning rate and their accompanying pressure variations. The purpose of the various designs is to maintain a constant burning area while the surface of the grain is being consumed.

To start the combustion process, some form of electrically detonated squib is ordinarily used to ignite a smokeless or black powder charge. Upon igniting, the black powder charge provides sufficient heat and pressure to raise the exposed surface of the propellant grain to a point where combustion will take place.

Until fairly recently, a serious disadvantage of the solid propellant had to do with the problem of dissipating the extreme heat of combustion. One way this has been overcome to a considerable extent is by use of the internal burning grain. Since the burning process actually takes place within the grain, the outer portion of the grain provides a shield between the intense heat and the combustion chamber wall until the grain is almost completely consumed.

Solid propellant rockets are particularly adaptable to shipboard use. They are easily stored and ready for immediate use. So great have been the improvements in solid propellants in the past few years that they are now used in such missiles as the Navy's Polaris, Tartar, Standard, and Terrier, and the Air Force's Minuteman.

Liquid Propellant Rockets

You know from your reading of the newspapers that liquid fuel is used in space vehicles and satellites and that this fuel is put into the tanks of the space vehicles immediately before launching. A missile cannot wait to be fueled when it is needed for defense or offense-it must be ready. That is one of the reasons why solid propellants have replaced liquid propellants in most of our missiles.

COMPONENTS OF LIQUID-FUEL ROCKETS. - The major components of a liquid-rocket system are the propellant, propellant-feed system, combustion chamber, igniter, and exhaust nozzle. The feed systems may be of the pressure-feed type or the pump-feed system, in which air or some other gas (preferably inert) is stored under pressure in the accumulator of the missile and is used to force the proper amounts of propellant and oxidizer into the combustion chamber when the rocket is fired. Generated-pressure feed systems contain substances, carried in the missile that generate high-pressure gas as needed. An example is hydrogen peroxide, which, when passed through a catalyst, decomposes to form a high pressure vapor. This vapor is then injected into the storage tanks to force the propellant into the combustion chamber.

Many other devices, such as valves, regulators, deli very tubes, and injectors, are necessary for the operation of either system.

Pump-feed systems are used in those missile rocket motors which are designed to burn large volumes of propellants and in power plants requiring a high rate of flow. A pump-feed system consists of a fuel pump and an oxidizer pump. Each pump is driven by a turbine wheel. Power for, the wheel may be developed by chemical gas or by the rocket's exhaust gases. The auxiliary devices and controls required by a pump-feed system are far more complicated than for a stored-pressure system and a complicated checkout is required.

PREPACKAGED LIQUID-FUEL ENGINES. - The Bullpup missile can use a prepackaged liquid-fuel engine. The first trials were made with the prepackaged version used in place of the regular solid propellant in Bullpup A, and can still be so used. It is the standard fuel package for the Bullpup B. The propellant and the oxidizer are in separate containers until the missile is fired, when the two liquids are mixed in controlled quantities and combustion occurs upon contact. The containers are designed so accidental mixing cannot occur.

The success of the prepackaged method in the Bullpup missile gives the advantages of a liquid propellant without its disadvantages. Research is continuing in the development of high power fuels that meet the requirements for storability, safety, and cost.

HYBRID PROPULSION

A hybrid engine combines the use of liquid and solid propellants. The liquid is the oxidizer and the solid is the propellant. Neither will support combustion by itself in the hybrid engine. Ignition is usually hypergolic, that is, spontaneous ignition takes place upon contact of the oxidizer with the propellant. The combustion chamber is within the solid grain, as in a solid-fuel rocket; the liquid portion is in a tank with pumping equipment as in a liquid-fuel rocket. This type is sometimes called a forward hybrid to distinguish it from a reverse hybrid, in which the oxidizer is solid and the fuel is liquid. Combustion takes place on the inside surface of the solid fuel, after the liquid fuel is injected, and the combustion products are exhausted through the nozzle to produce the thrust as in other rockets (fig. 3-24). Nozzle systems and control methods are the same as in other reaction engines. It is possible to start, stop, and restart the system as in a liquid fuel system by shutting down or I' reopening the liquid oxidizer flow system.

Missiles such as the Talos, which has a solid-fuel booster and a liquid-fuel sustainer, are not hybrid systems; the liquid and the solid propellants do not interact.

The hybrid system has several advantages on either solid or liquid systems by combining the advantages of both. At present we do not have an operational hybrid propulsion missile, but research and development are continuing.

FEATURES OF SURFACE-TO-AIR MISSILES

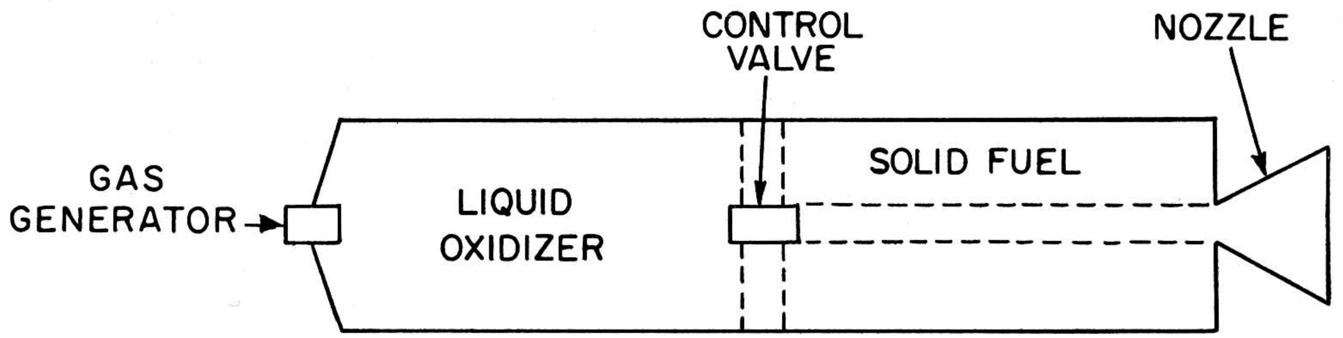
Now that you have a little background in missile flight and propulsion principles, we will relate what you have studied to specific Navy surface-to-air missiles (RIMs: see chapter 4). At this writing there are four types of operational missiles: Talos, Terrier, Tartar and Standard. As a GMM you will maintain launching system equipment that stows, handles, and launches Talos, Terrier, Tartar and Standard missiles. Therefore, we will cover briefly some of the characteristics and features of these missiles.

Coupled with your launching system maintenance duties, you will help handle and maintain missiles. The more you know about the missile you are working with, the better you can do your job.

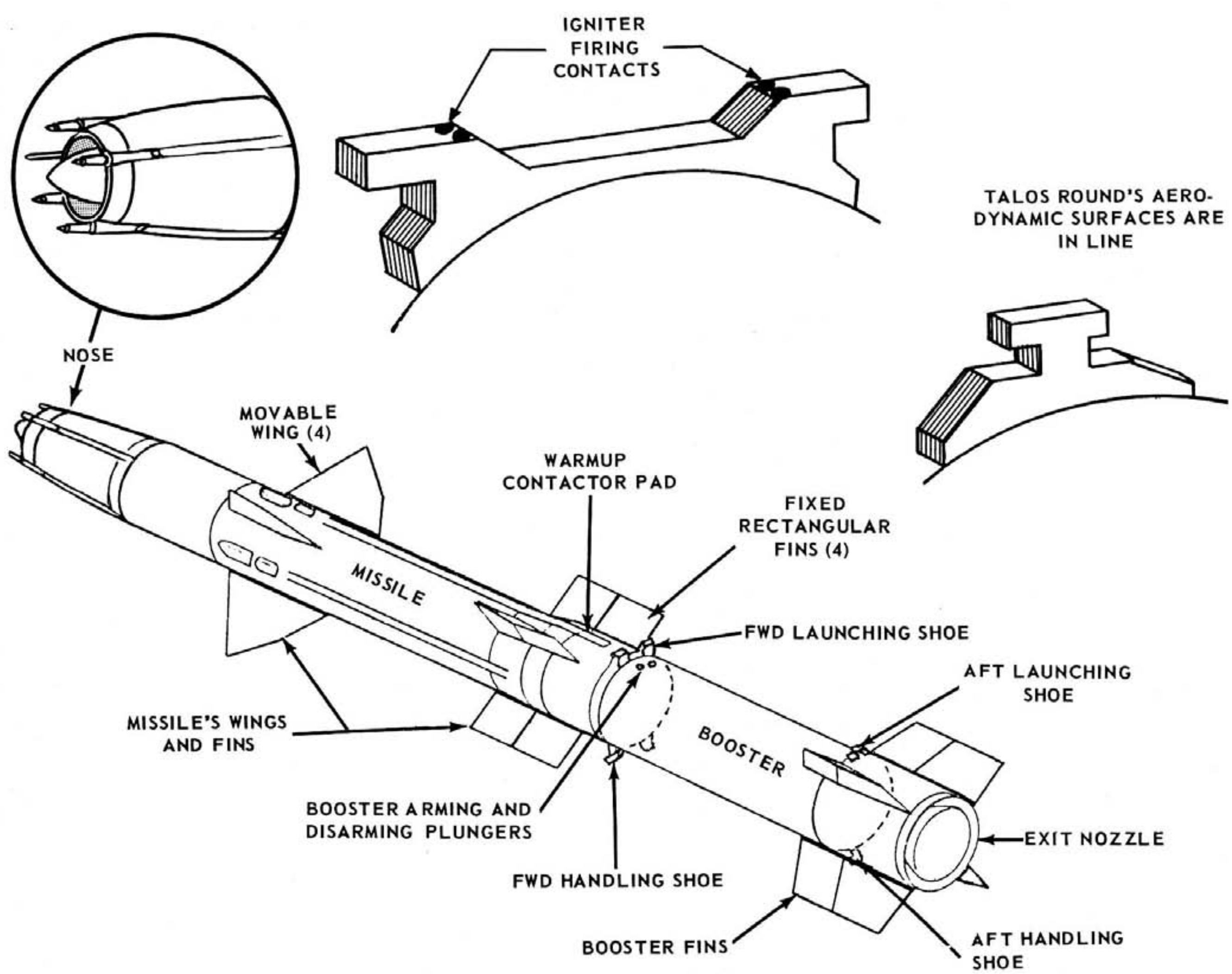
TALOS MISSILE ROUND

Figure 3-25 shows you what a Talos missile looks like. It is the largest of the RIMs. Notice that it is made up of two sections or stages. The first stage is the booster; the second stage is the missile proper. These two sections, when they are connected, form what is called a complete round, weapon, or missile booster combination. You will see the terms used interchangeably.

First, consider the missile section. It only takes a quick glance at figure 3-25 to see that Talos is a ramjet propelled missile. The clue to recognizing it as a ramjet is the diffuser opening in its nose (fig. 3-14). Four raked-tip biconvex (figs. 3-10, 3-11) wings steer the missile. The wings are located near the missile's center of gravity. Four fixed rectangular fins are attached near the end of the missile. Like the wings, they are biconvex. Both wings



144.26
Figure 3-24.—Sketch of a hybrid propulsion engine.



83.10
Figure 3-25.—Talos missile round configuration.

and fins are arranged in a cruciform pattern about the missile body (fig. 3-12). The wings and fins are in line with each other. Now. look at the booster. You learned earlier that the purpose of a booster is to propel the missile to flight speed. Talos has a ramjet sustainer, and it operates most efficiently in the supersonic range.

The Talos booster is a solid propellant rocket unit. Basically, it consists of the propellant, combustion chamber (called the case), igniter assembly (includes arming and disarming mechanisms), and exit nozzle.

The booster case is a long, round, metal tube. It serves two purposes. First, it acts as a storage place for the propellant, and second, it serves as a chamber in which solid propellant burning takes place. The propellant consists of nitrocellulose explosive and a metal compound. These materials are mixed together to make an even burning grain. The grain is star shaped. When propellant grains are shaped in this fashion, many constant burning surfaces are provided. The booster produces a large amount of thrust for a short time - in the order of 4 or 5 seconds. To reduce chugging, resonance rods are placed along the length of the grain. The rods absorb vibrations set up in the combustion chamber.

The front end of the booster is enclosed by a metal cap. The cap supports the igniter assembly. The igniter consists of a small charge of pyrotechnic material and several electrical squibs. When current flows through the squibs the pyrotechnic material starts burning. The material generates enough heat and flame to ignite the main rocket propellant.

Another unit attached to the head cap is the booster arming-disarming device. Its purpose is to mechanically open and close that portion of the booster firing circuit that is in the booster igniter. The rest of the firing circuit is in the launching system. (We'll cover firing circuits in detail in chapter 9 of this manual.) Boosters are in the disarm (safe) condition while they are in stowage. They are not armed until they are ready to be launched. Then they are armed by a mechanical device (called an arming tool) on the launcher.

A clamping arrangement on the head cap connects the missile and its booster. When the booster burns out, the clamp is released and the booster falls away from the missile. Then the missile continues on its way under its own sustainer power.

An exit nozzle is at the after end of the booster case. It compresses the propellant gases as they escape through the opening in the nozzle. The nozzle is a convergent-divergent (fig. 3-20) type. The nozzle also provides a foundation for the four fixed fins.

The only continuous physical contact the Talos round has with its launcher is through the top set of shoes. These hooklike metal lugs are solidly attached to the booster case. And they fit into slots cut into the launcher's guide rails. Igniter firing contacts are located on the forward top shoe. The bottom set of shoes are used to handle the weapon. By handling we mean the operations and steps involved in stowing the weapon and loading it on the launcher.

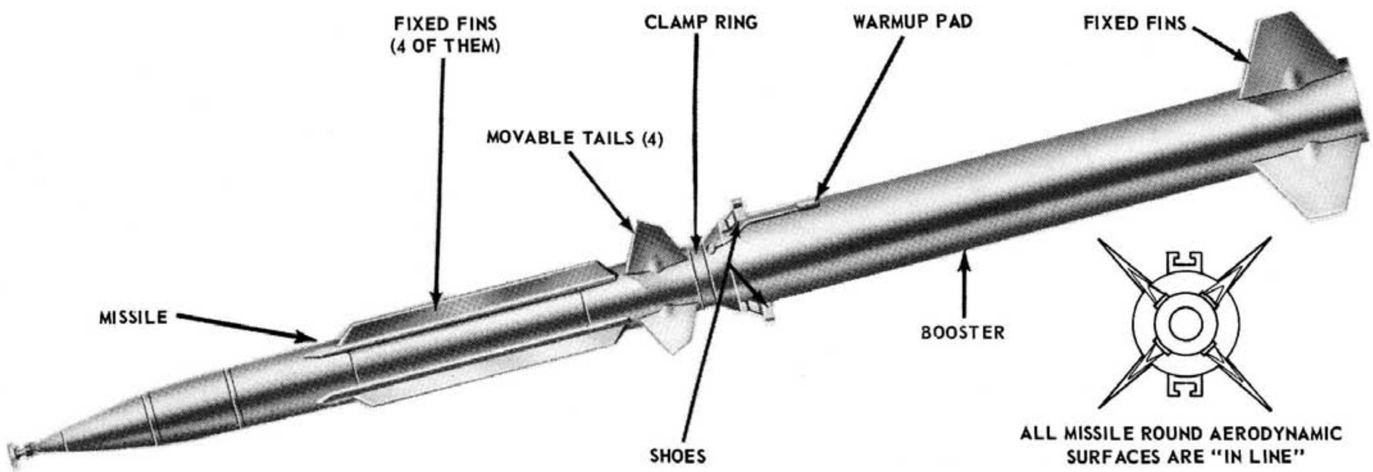
TERRIER GUIDED MISSILE ROUND

Terrier is the name applied to a large family of missiles. The most obvious common feature of Terrier missiles is that each type has a separate booster. Some Terriers have movable tails; others have movable wings near the missile center of gravity to do the steering job. The tail controlled missiles have fixed fins that resemble the dorsal fins of a sail fish or marlin. The earliest Terriers put aboard ship were the wing-controlled BW-O and BW-l. They are now obsolete as weapons but may be used as target drones.

The beam-riding, tail-controlled missile, designated the BT-3 (B for beam-riding the T for tail-controlled) was next to be tested and improved. The improvements included the BT-3A and the BT-3B, each of which had a choice of warheads. These, too, are no longer being produced, but there are some around.

In the next chapter we will briefly cover the rest of the Terrier family and point out the similarities and differences between members. Now then, look closely at figure 3-26. It shows the general outline of the BT-3 and its booster. Variations in the mods of the BT-3 will not be discussed here.

Let's start at the nose of the BT-3 and work aft. The nose has an ogival shape, which is a characteristic of most supersonic missiles. Four fixed dorsal fins are attached to the missile in cruciform arrangement. They stabilize the missile and provide some lift. Four control surfaces, called tails, steer the missile and keep it from rolling. Another feature of the tails is that they can be folded. This cuts down on the space needed for stowage, and makes handling



83.11
Figure 3-26.—BT-3 Terrier round.

easier. Before a missile is put on its launcher, the tails are manually unfolded.

Notice the clamp ring between the end of the missile and the head of the booster. The clamp holds them together. For the present, we'll leave the missile, and return to it in chapter 4.

Now consider figure 3-27. It shows a cutaway drawing of the BT-3 booster. The drawing is simplified but shows all the booster's essential parts. The booster is basically a round steel shell, closed at the forward end and open at the after end. Four fixed fins (not shown in fig. 3-27) are attached to the after end of the booster. The fins simply help stabilize the complete round during the boosted part of the missile's flight. Notice the shoes at both ends of the booster. The top set is used to hang the missile from the launcher. The bottom set is used for handling the missile. The booster and missile are held together by a mechanical clamping device attached to the forward end of the booster. An electrical connection is also made between missile and booster. The booster igniter is in the forward end of the booster, and is wired to contacts on the upper forward shoe. Booster ignition current is applied from the launcher to the pair of shoe contacts and then to the igniter squibs.

On the top forward part of the booster you can see an electrical receptacle (pad). It receives a hydraulically operated contactor which extends from the launcher and jabs into the pad. It can also be retracted. (More about this in chapter 6.)

The separation action of booster from missile is extremely crucial. It must take place very quickly and smoothly so as not to disturb the flight of the missile. Many other factors must be calculated by the designers to/ achieve successful separation of missile and booster in flight.

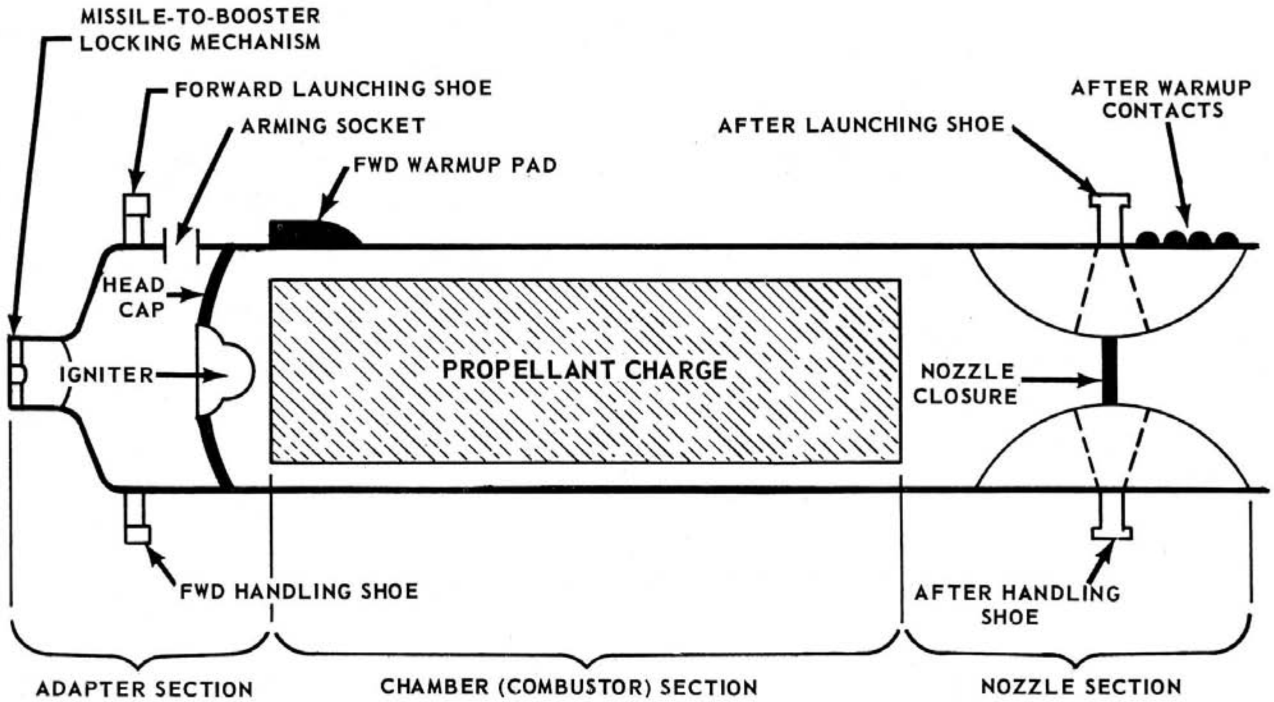
The HT-3 Terrier Missile

In outward appearance, the HT-3 missile is much like the BT-3. Figure 3-28 shows the exterior of the HT-3 and the BT-3 for comparison, and indicates the location of the main components of each. The booster is not shown; all mods of the BT-3 and the HT-3 can use the same booster.

Much of the actual hardware is the same in the BT-3 and the HT-3. The booster (mentioned above), the sustainer, and the aft section are identical.

The big difference is in the method of guidance used. All mods of the BT-3 missile are beam-riders, while the HT-3s are homing missiles. Semi active homing is the type usually used, but some mods have the capability of switching to passive type of homing. Guidance methods are discussed in the next chapter.

With a homing missile, its target seeker is in the nose, or forward end of the missile. A radome encloses the instruments to provide a streamline shape to the missile; it is transparent to radar waves, which the missile must receive and interpret in order to locate the target.



83.12
Figure 3-27.—Cut away of BT-3 Terrier booster.

Additional differences and similarities are pointed out in chapter 4.

TARTAR MISSILE ROUND

Tartar does not have a separate booster. The missile comes all in one piece as you can see in figure 3-29. Instead of a separate booster, it has what is called a dual thrust rocket motor (DTRM). The DTRM has two propellant grains: one to boost the missile to flight speed, and one to keep it flying at this speed.

The Tartar missile looks just like the HT-3 Terrier, though it is considerably longer, so we won't dwell on Tartar's physical appearance. Briefly, it is round, with an ogival nose. Four fixed dorsal fins are in line with four independently movable tails. Unlike the other two missiles you must read about, Tartar is designed to fly in either of two flight positions.

Figure 3-30 shows a cutaway view of the DTRM. You will notice that it has all the parts that Terrier and Talos boosters have. There

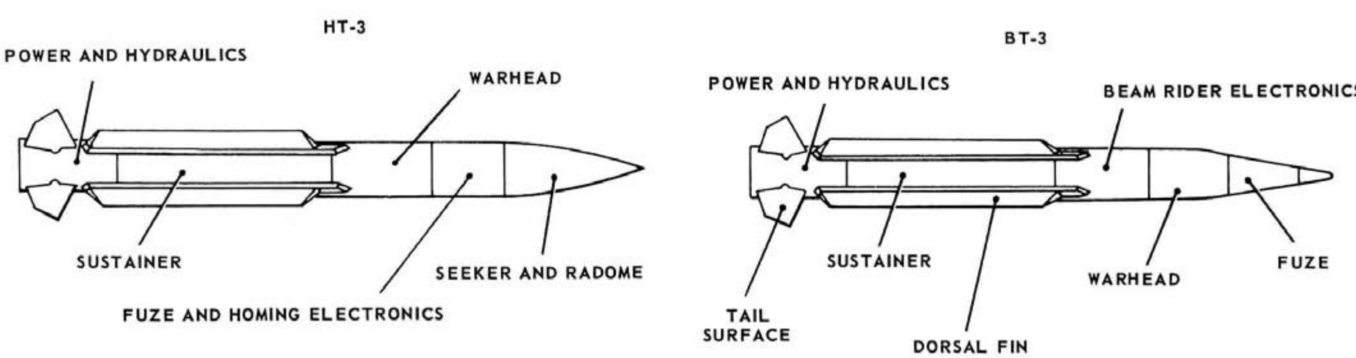


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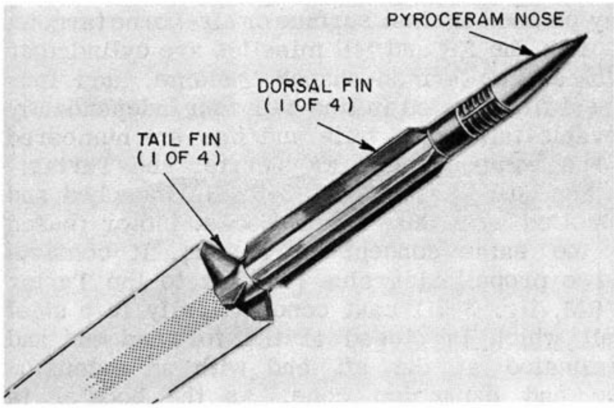
Figure 3-28.—Terrier HT-3 and BT-3 exterior configuration.



83.13
Figure 3-29.—Tartar missile.

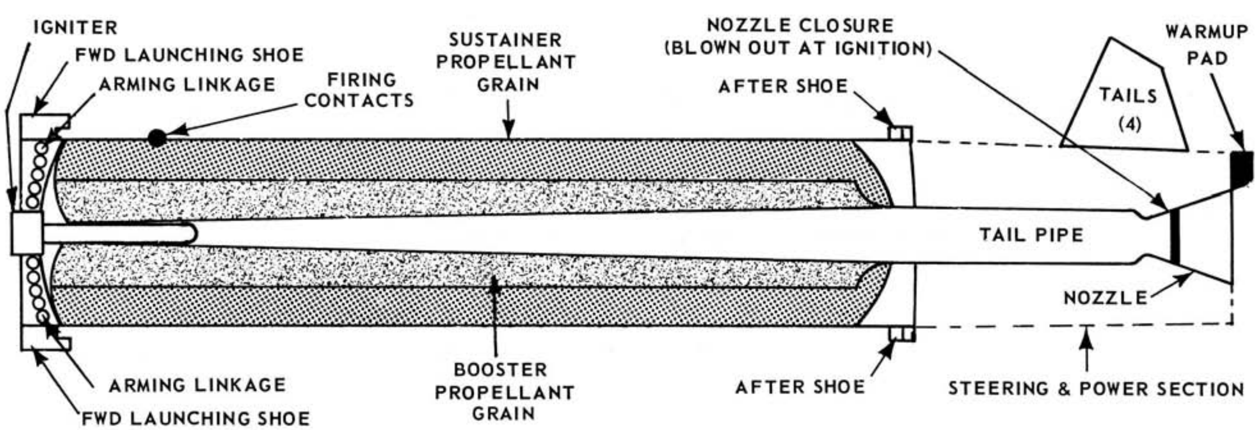
is a booster igniter, and an igniter arming-disarming device. An arming tool on the Tartar launcher mechanically arms or disarms the igniter circuit. Firing contacts on the missile skin scrape contacts on the launcher to complete the missile-to-launcher part of the firing circuit. The warmup pad is not located in the same place as on Terrier and Talos, but on the after face of the steering and power section. This section fits around the tail pipe and is indicated by the broken lines in figure 3-30. The warmup pad has the same function, of course, as the pads on Talos and Terrier - to provide an external warmup power connection.

The Tartar propulsion unit is unique because it has two separate grains in its propulsion system. Figure 3-31 shows a cross- sectional view of the DTRM as seen from the end of the missile. The steering and control section have been removed. You can see that the two grains are cast in a concentric grain design-the sustainer grain encloses the inner booster grain. There are no resonance rods because the grains burn so smoothly that chugging does not happen. The inner, or booster part of the DTRM is a fast-burning type of propellant and burns first and then the slower burning propellant in the sustainer portion takes over to furnish the thrust during the main part of the missile's flight.

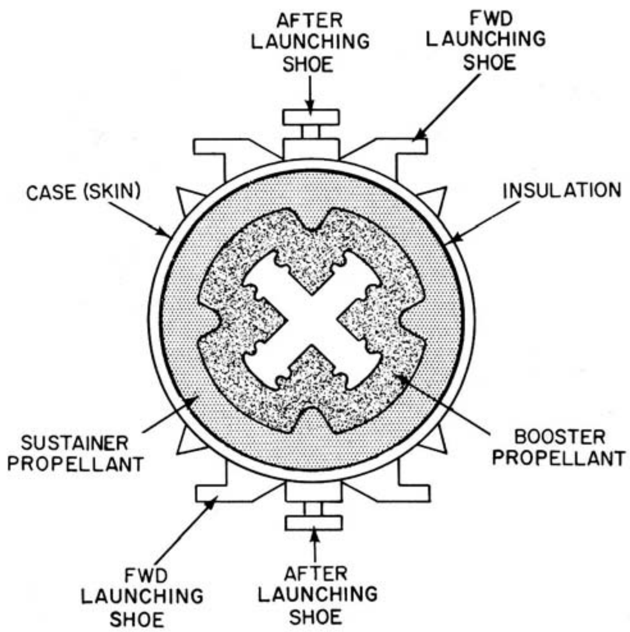
Several advantages of dual-thrust rocket motors over separate boosters are:

1. There is no empty booster case to get rid of. Sometimes booster cases fail to separate from the missile, clamping devices fail to operate, or, during handling the booster and missile are tightly jammed together. Another problem caused by empty boosters is related to safety. Care must be taken to keep a booster from falling on another ship. The booster splash point (the area in the sea where the empty case will hit at the end of its fall) must be predicted. This requires extra computing equipment on board ship.

2. Heavy power-driven equipment is needed to hold and to move the missile and separate booster during the mating operation. These equipments are not required for single-stage missiles.



83.14
Figure 3-30.—Cutaway of Tartar DTRM.



83.15
Figure 3-31.—Cross section of Tartar DTRM, showing booster propellant and sustainer propellant grain conformation.

STANDARD MISSILE ROUND

Figures 3-32 and 3-33 show the configuration of the Standard missiles. There are two versions of the Standard missiles: RIM-66A is a Medium Range (MR) missile and RIM-67A is an Extended Range (ER) missile. Both configurations are surface-launched, supersonic guided missiles that may be used against surface or air-borne targets.

Both the ER and MR missiles are cylindrical with a VonKarman-shaped radome, and four dorsal fins located in line with four independently movable tails. The tails and fins are numbered in the same manner as Terrier and Tartar.

The MR version, fig. 3-32. is launched and propelled by a dual thrust rocket motor (based on the same concept as Tartar). It consists of two propellant grains (similar to the Tartar DTRM, fig. 3-31) cast concentrically in a steel shell which is closed at the forward end and terminated at the aft end with an extension tube and expansion cone. As the booster is consumed, the sustainer (outer) grain is ignited and provides the thrust necessary to maintain velocity acquired during the boost phase.

The ER version, fig. 3-33, is launched and propelled in two stages by a solid fuel rocket motor (booster and sustainer). The booster is a cylindrical rocket motor consisting of a dual- propellant grain housed in a steel shell which is terminated at the aft end in a nozzle and closed at the forward end by an adapter assembly. When ignited, the booster grain provides the initial thrust necessary to accelerate the ER missile to supersonic velocities. The sustainer is a cylindrical rocket motor consisting of a propellant grain housed within a steel shell which is closed at the forward end and terminated at the aft end with a nozzle assembly. An in-flight arming-firing device if armed by acceleration during the boost phase

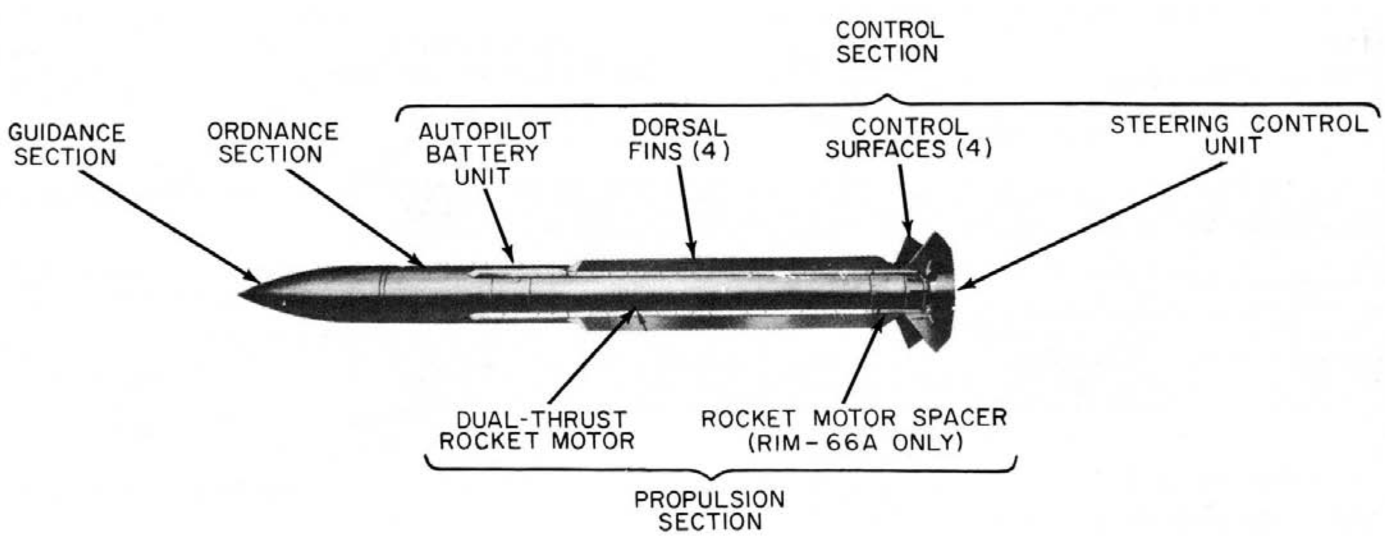


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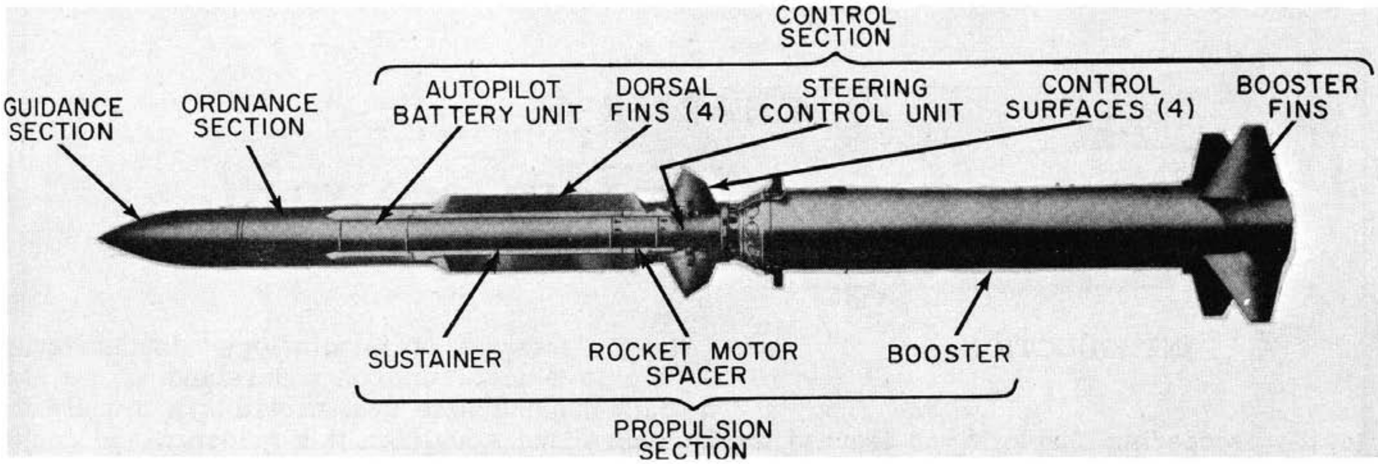
Figure 3-32.—Standard missile RIM-66A (MR), major sections and components.



141.234(141B)B

Figure 3-33.—Standard missile RIM-67A (ER), major sections and components.

and thereafter, upon receipt of firing voltage, ignites the igniter train. The sustainer provides the necessary thrust to maintain the velocity acquired during the boost phase.

The guidance system of the ER and MR missiles operates as either a semiactive or passive homing guidance system. Roll stabilization and steering are accomplished by the movement of four aerodynamic control surfaces (tails). Guidance systems are discussed more in detail in chapter 4.

Missile operating power is provided by the primary battery which consists of two electric ally separate cell packs (electronic battery and electromechanical battery) and an activator assembly. The electronic cell block supplies power to signal and low power level circuits. The electromechanical cell block supplies power to major power consumption circuits. Both cell packs are of the silver zinc type and are inactive until filled (at launch) with the electrolyte contained in the activator assembly. Battery power eliminates the need for hydraulics and for power conversion during flight.

CONCLUSION

The material in this chapter will be extremely valuable to you in your duties as a Gunner's Mate Missile. An understanding of aerodynamics, the jet propulsion theory, the gas laws, and the various basic missile propulsion systems will help you to realize why missile launching systems and missile magazine spaces are designed as they are. Much of the information covered will also relate directly to the operational aspects of missile launching systems.

The next chapter of this manual will take up missile guidance - that is, it will discuss the basic components of guided missiles which enable them to alter their trajectories and collide with moving targets. We'll also have more to say about Talos, Tartar, Terrier, and Standard missiles.

CHAPTER 4

MISSILE GUIDANCE AND CONTROL

INTRODUCTION

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

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

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

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

GUIDANCE AND CONTROL

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

SUBSYSTEMS AND COMPONENTS

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

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

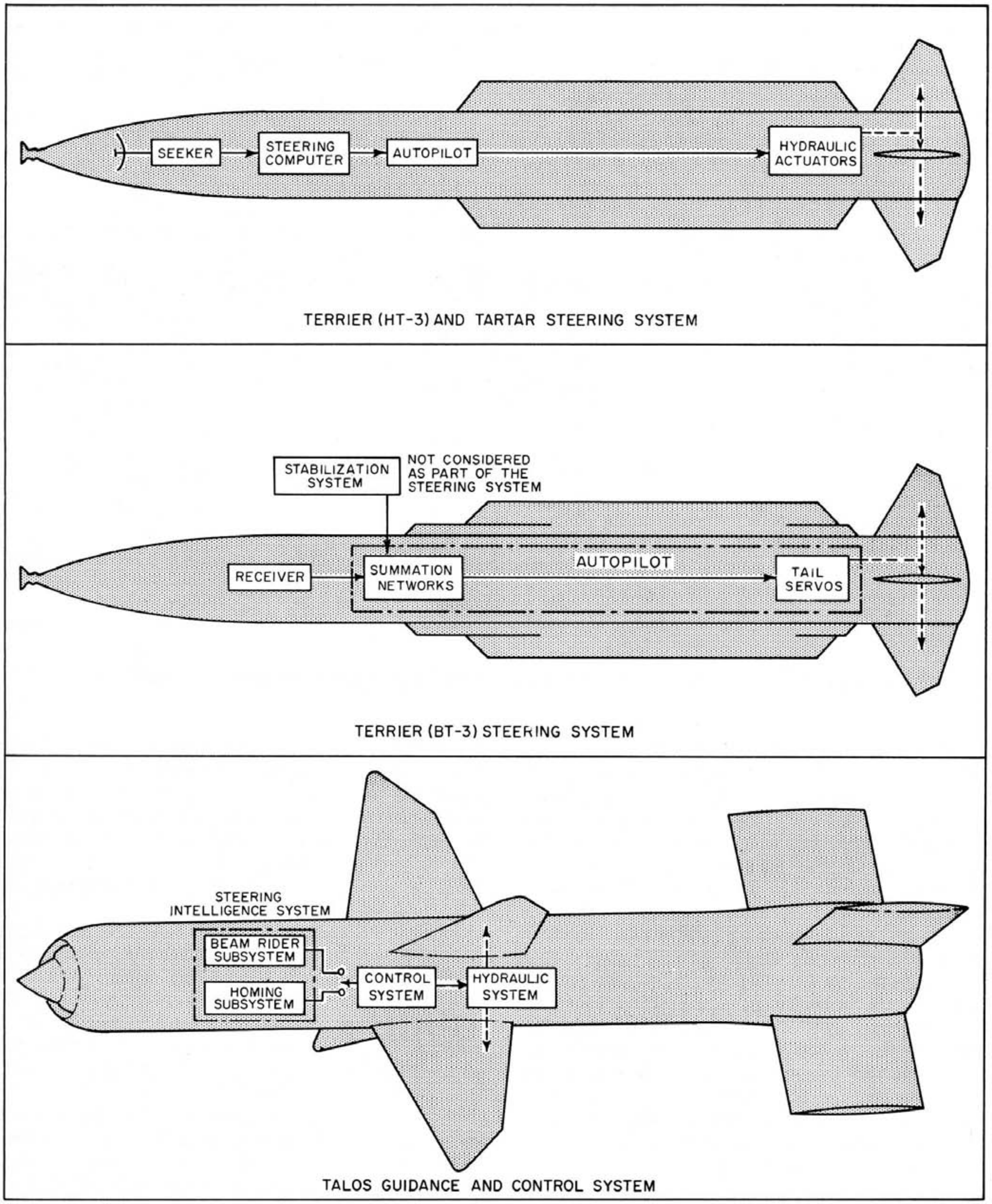


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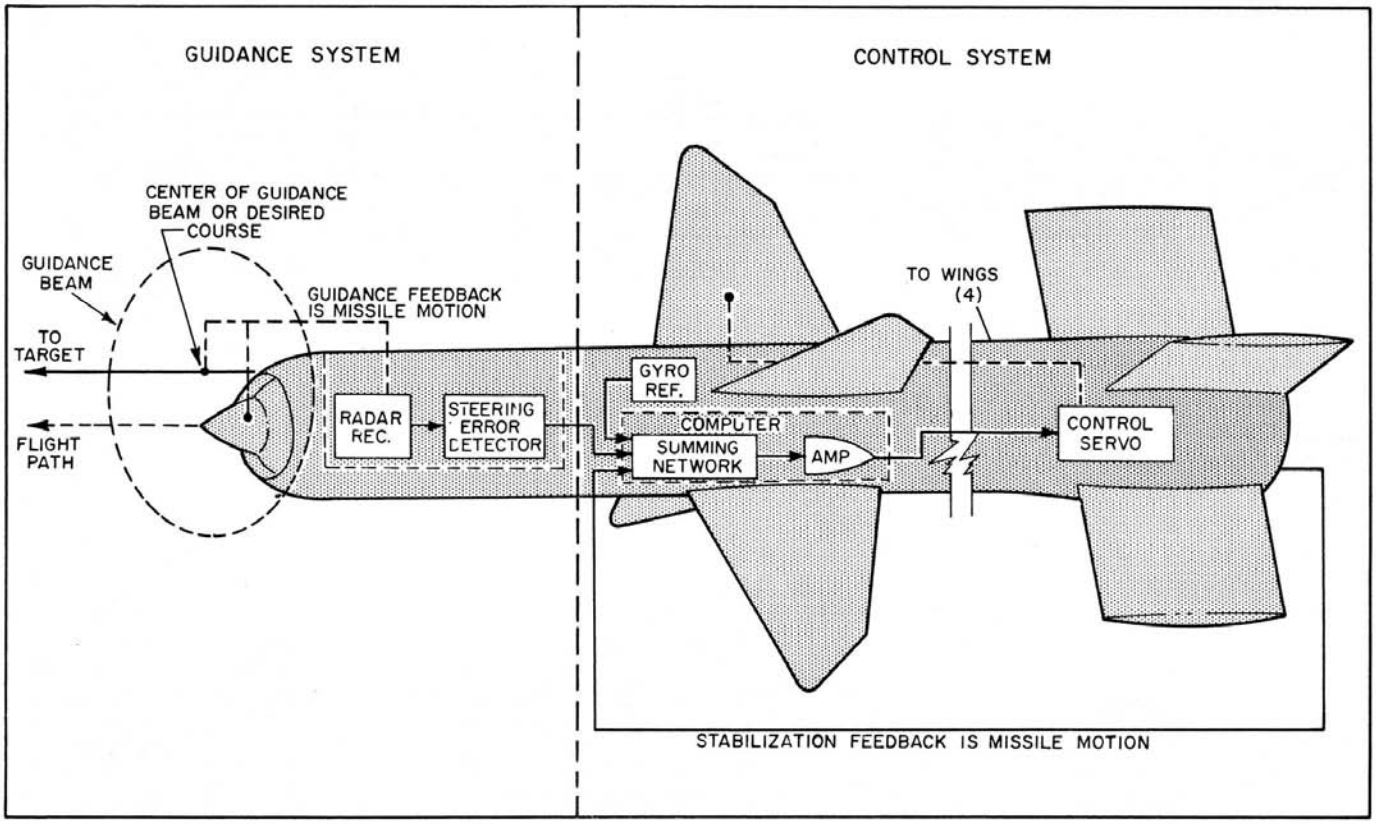
Figure 4-1.—Names for guidance and control systems and system components.



83.17
Figure 4-2.— Essential parts of a basic missile guidance and control system.

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

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

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

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

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

TYPES OF FEEDBACK LOOPS

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

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

Guidance Feedback Loop

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

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

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

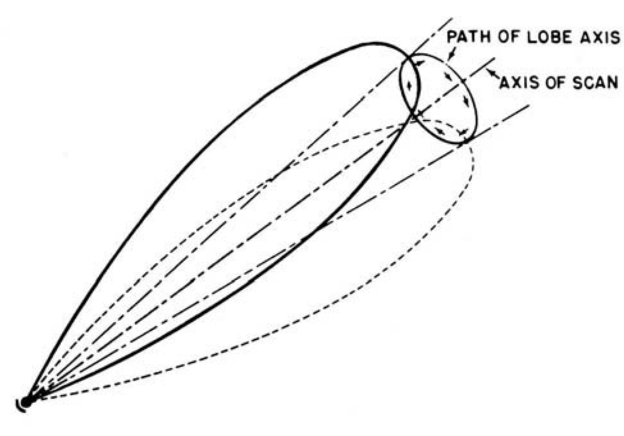


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Figure 4-3. —Nutating lobe of radar beam, conical scanning of the pencil is nutation. The pencil point corresponds to the open or transmitting end of the radar waveguide antenna. The radar beam moves in a similar manner when scanning, moving in a conical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

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

Stabilization Feedback Loop

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

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

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

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

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

COMPONENTS AND INSTRUMENTS

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

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

Gyroscopes

One of the most important instruments in a missile control system is the gyroscope, or gyro for short. Any spinning object - a top, a wheel, a planet, or a spinning projectile - is fundamentally a gyro. But strictly speaking, a gyro may be defined as a mechanical device containing a spinning mass mounted in such a manner as to have either one or two degrees (directions) or freedom.

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

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

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

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

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

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

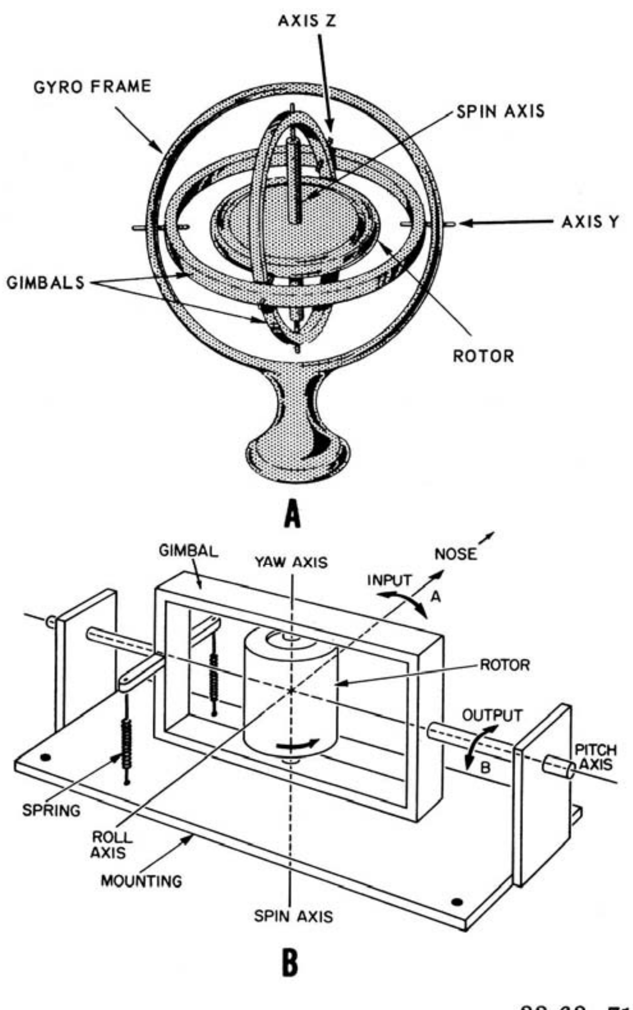

Figure 4-4.—Gyroscopes: A. Free gyro has two degrees of freedom; B. A rate gyro has one degree of freedom.

Precession

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

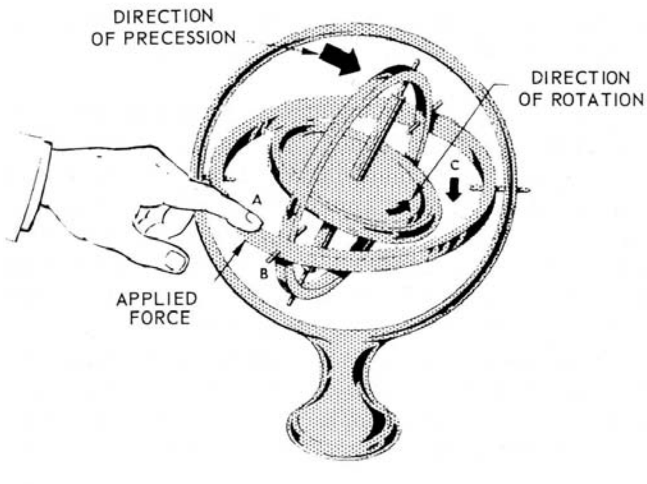

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Figure 4-5. — Precessing a gyro.

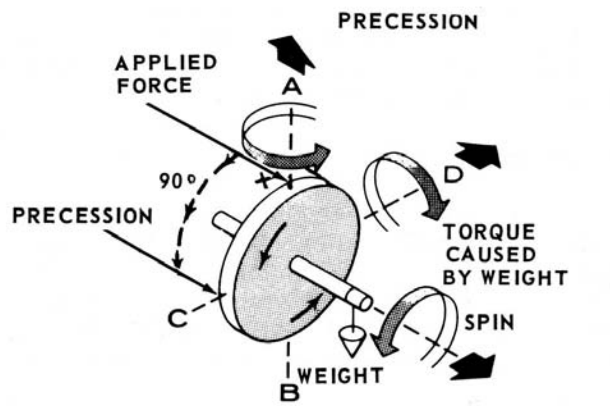

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Figure 4-6. — Direction of gyroscopic precession.

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

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

Free Gyros In Guided Missiles

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

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

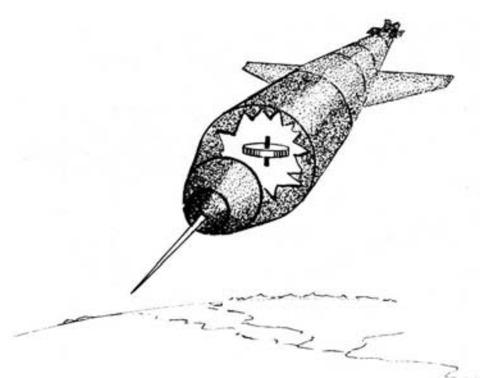

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Figure 4-7. — Missile horizontal — gyro remains fixed in space.

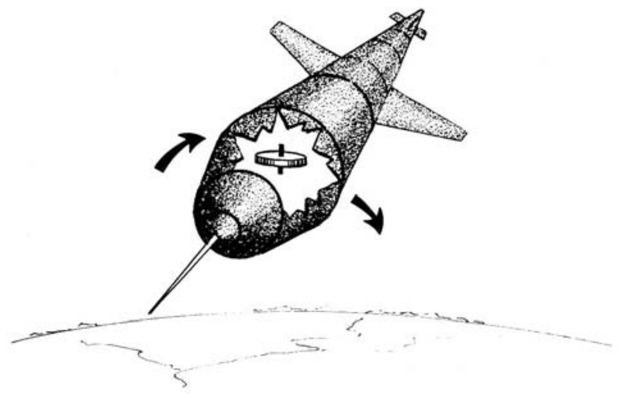

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Figure 4-8.—Missile rolls—gyro stays fixed in space.

Rate Gyros

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

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

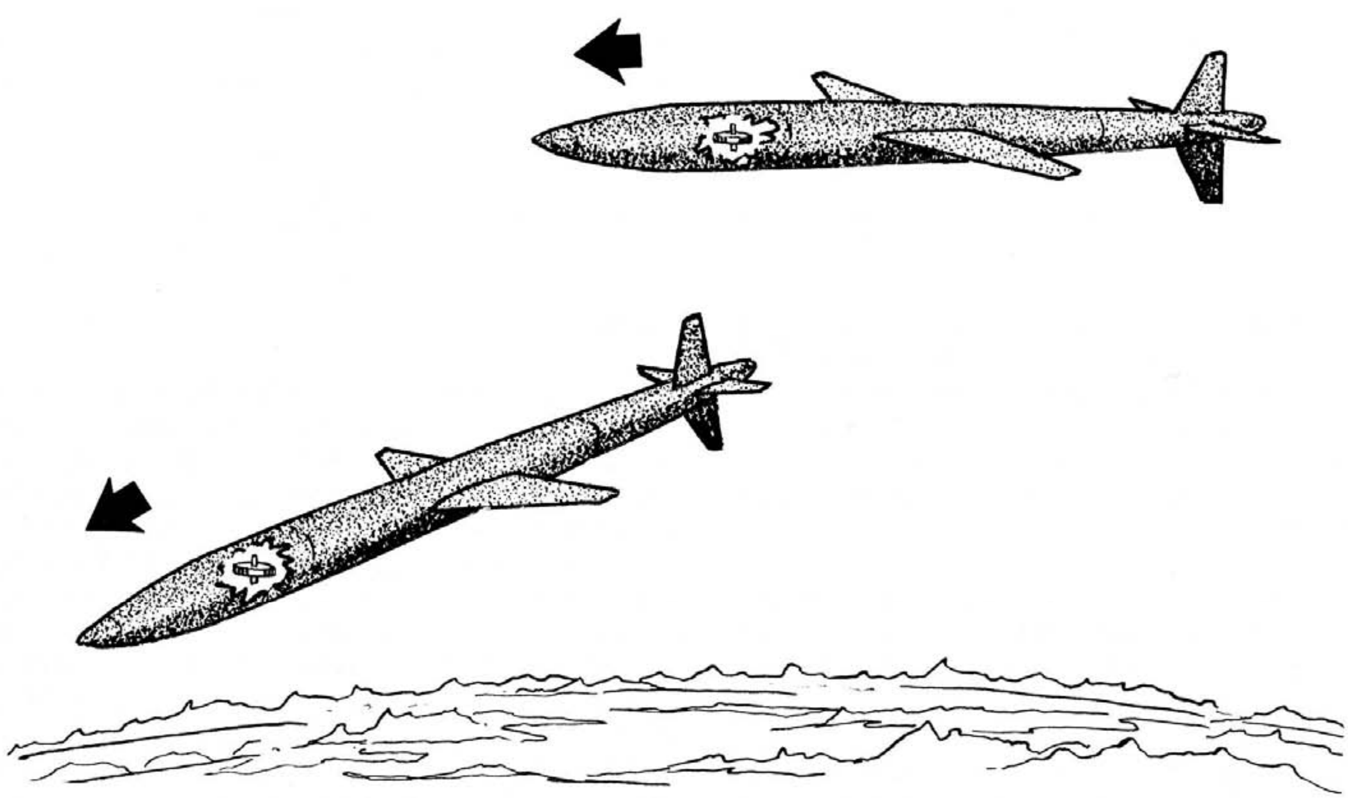

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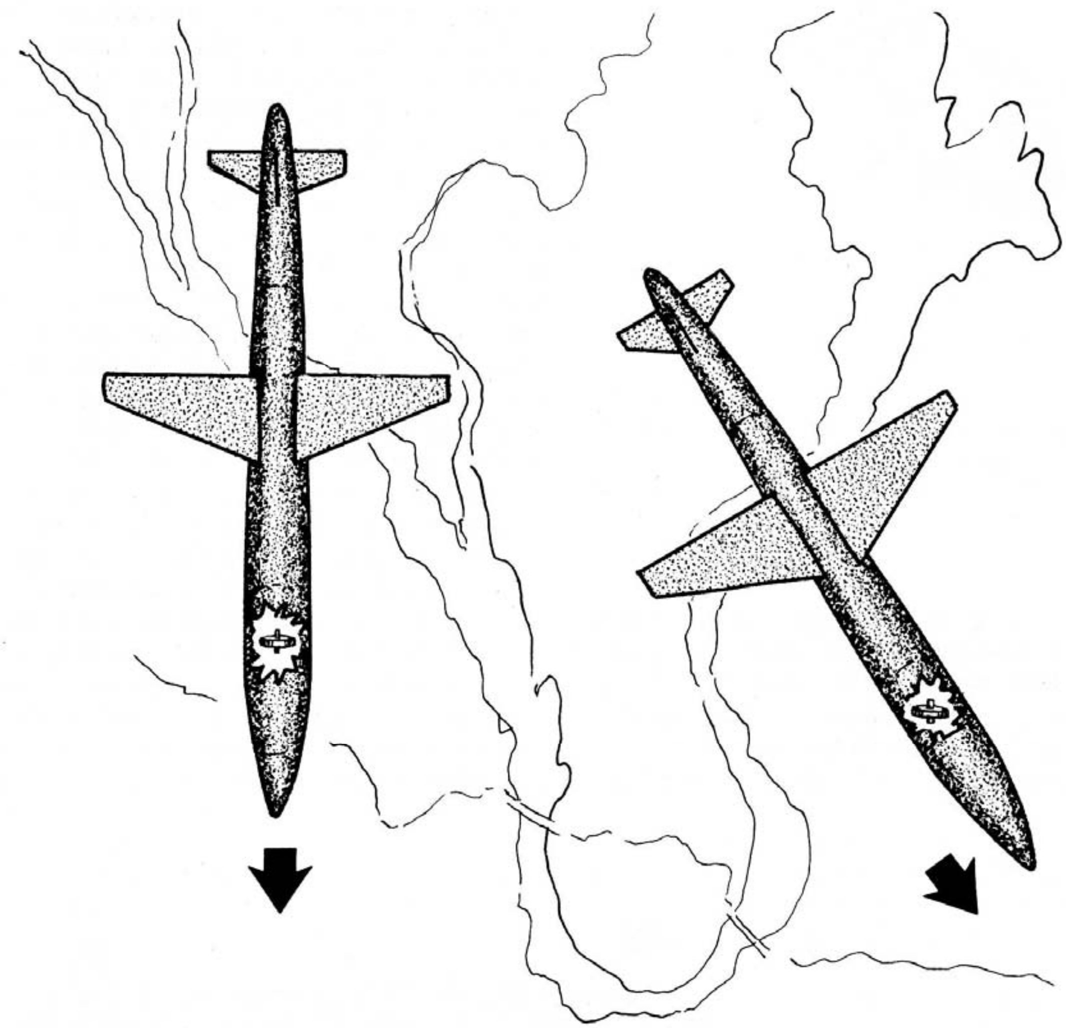
Figure 4-9.—Missile pitches—gyro stays fixed in space.



33.70
Figure 4-10.—Missile yaws—gyro remains fixed in space.

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

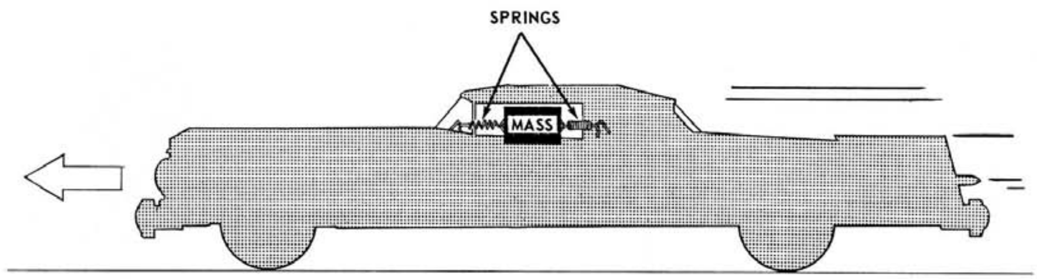
Restraining springs may be attached to the gimbals as shown. The force on the springs would then be proportional to angular acceleration about the roll axis.

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

Accelerometers

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

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



33.130
Figure 4-11.—Spring-suspended mass reacts to acceleration of car, proportional to the force and opposite in direction.

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

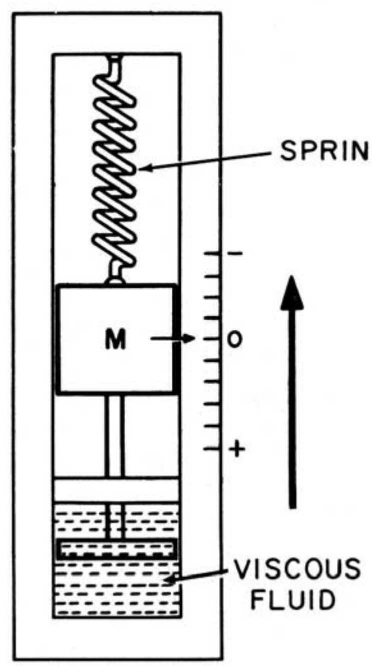
The movement of the mass is in accordance with Newton's second law of motion which states that when a body is acted on by a force, its resulting acceleration is proportional to the force and inversely proportional to the mass of the body. In mathematical terms this may be expressed as $a = F/M$, or by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

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

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

SENSORS AND PICKOFFS

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



33.131
Figure 4-12.—Liquid-damping system.

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

Types of Sensors in Missiles

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

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

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

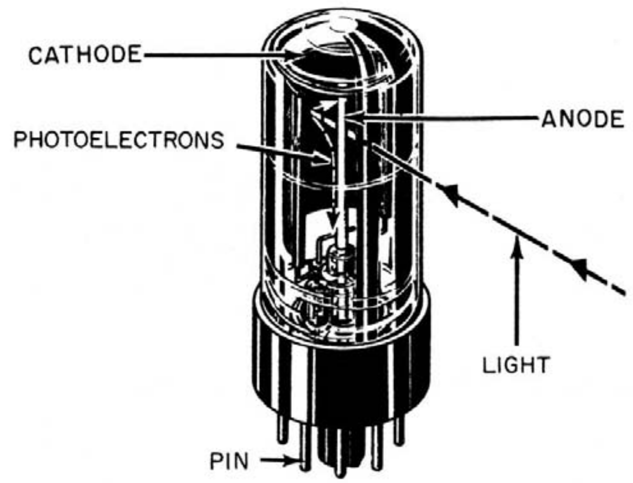


Figure 4-13.— Photoelectric cell.

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

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

Pickoffs Used In Missiles

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

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

1. Potentiometer pickoffs
2. Synchro pickoffs

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

MISSILE GUIDANCE PHASES

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

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

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

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

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

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

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

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

TYPES OF GUIDANCE SYSTEMS

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

Self-Contained Guidance Systems

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

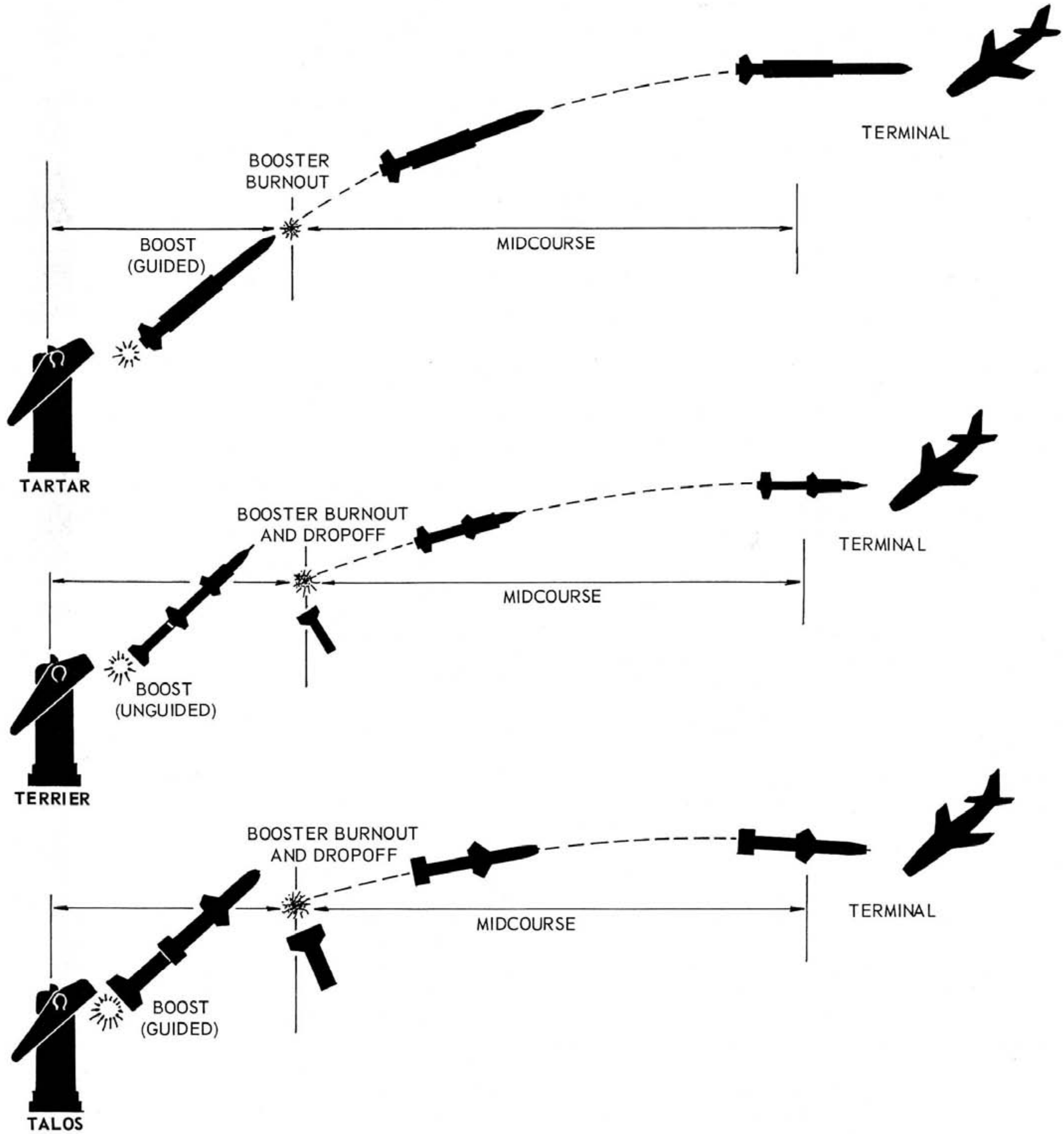


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Figure 4-14.—Guidance phases of flight for the 3 T's.

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

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

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

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

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

Development of Surface-to-Air Guidance Systems

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

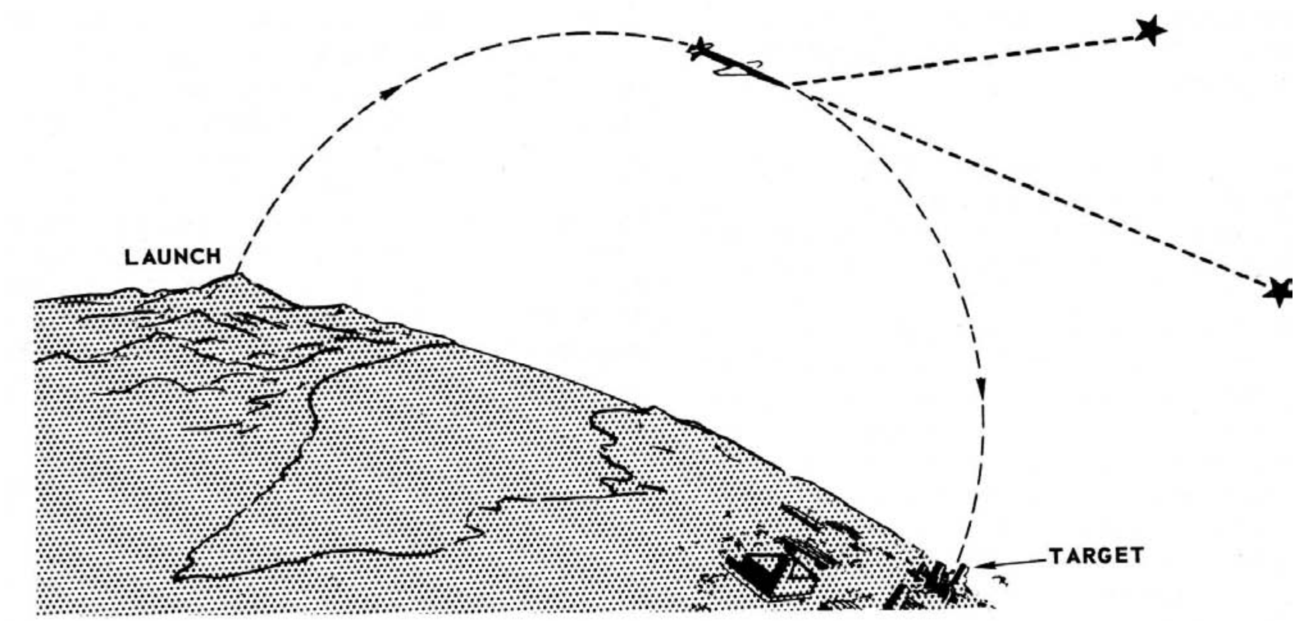

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Figure 4-15.—Celestial guidance.

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

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

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

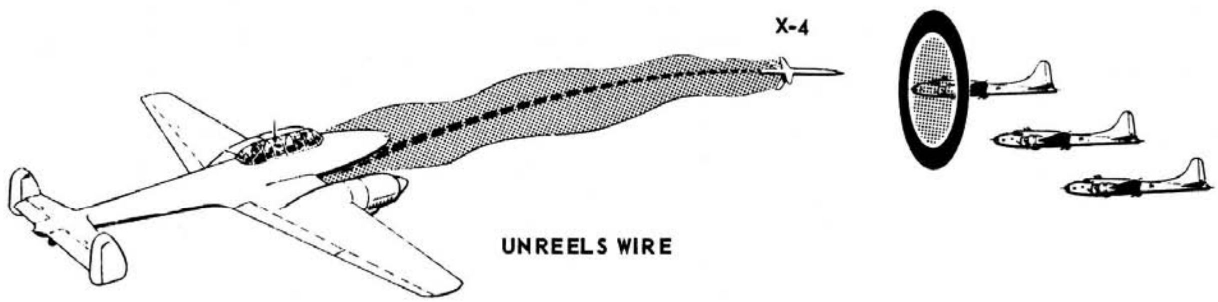

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Figure 4-16.—Wire guidance.

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

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

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

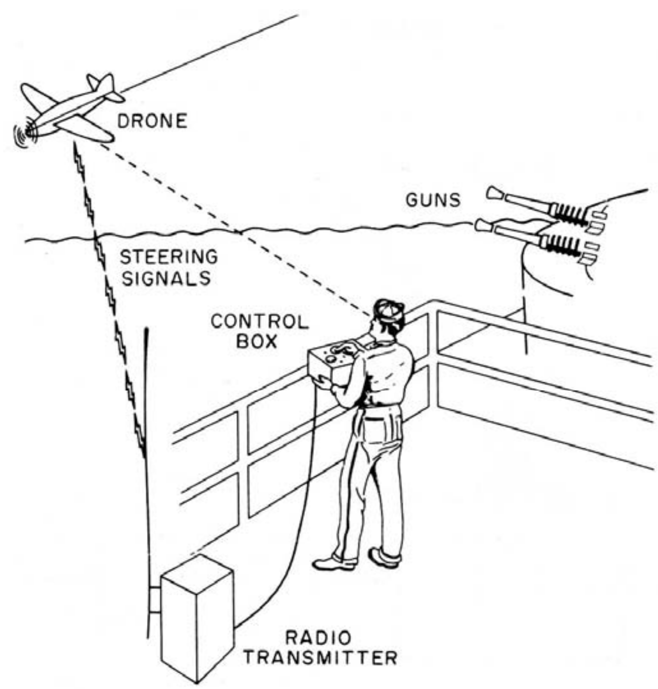
Command Guidance

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

Remote Control by Radio

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

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



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

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

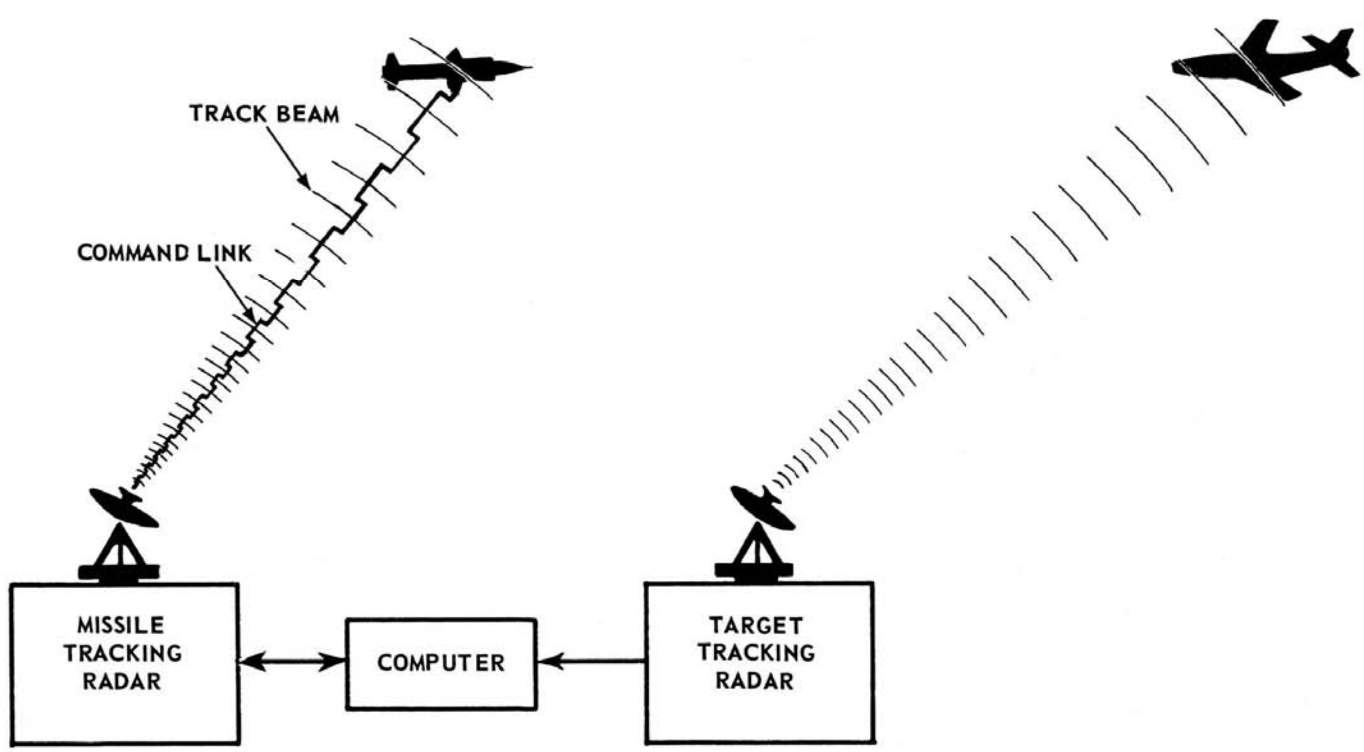
Missile Remote Control by Radar

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

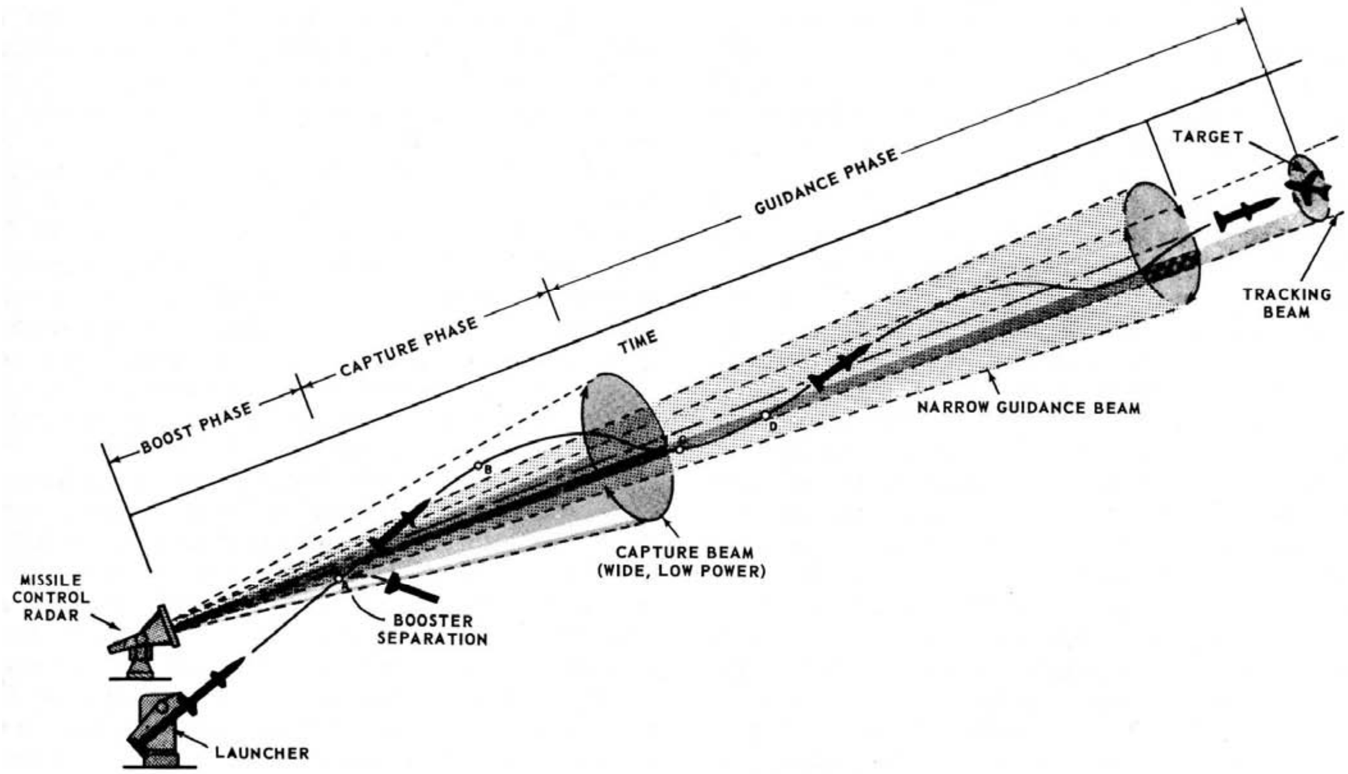
But in the systems that we will study next, only information is sent over the radar beams- not guidance signals. It is the missile's guidance system that acts on the information and develops guidance signals to direct the missile to the desired flight path.

BEAM-RIDER METHODS

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



83.22
Figure 4-18.—Radar command system.



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

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

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

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

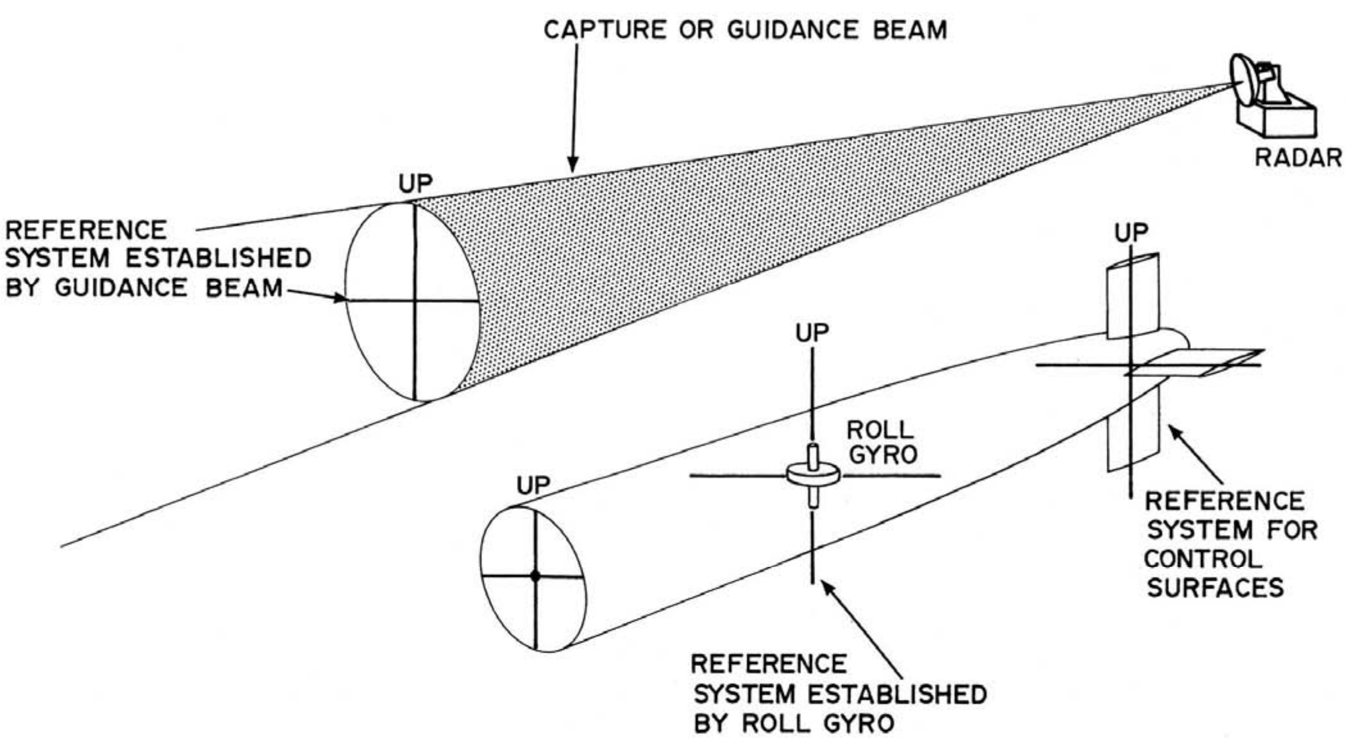
In place of selenium cells, the missile has a radar antenna-receiver system which senses the missile direction and distance from the center of the guidance beam. The missile control system then corrects the missile's flight to place the missile in the center of the guidance beam.

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

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

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

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



83.23

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

Homing Systems

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

Active Homing

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

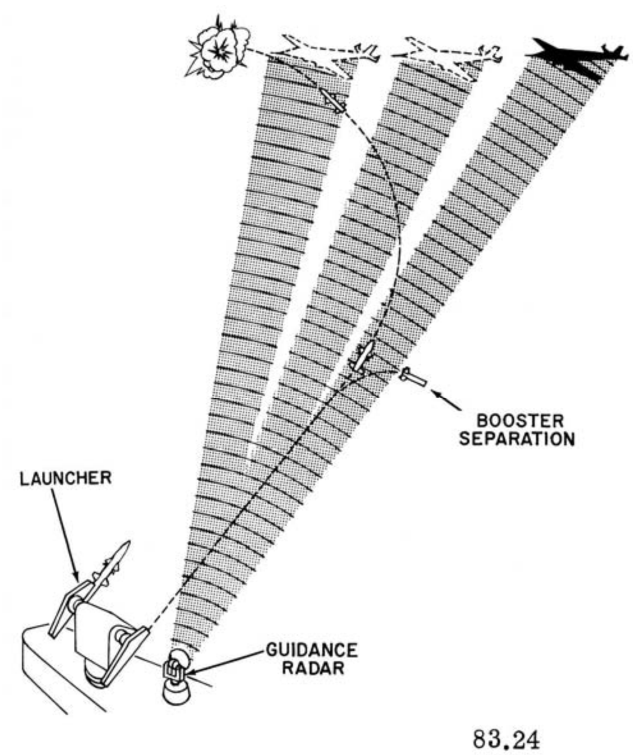


Figure 4-21.—Beam-rider track.

section, which in turn corrects the missile flight path to cause collision of the missile and target.

Passive Homing

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

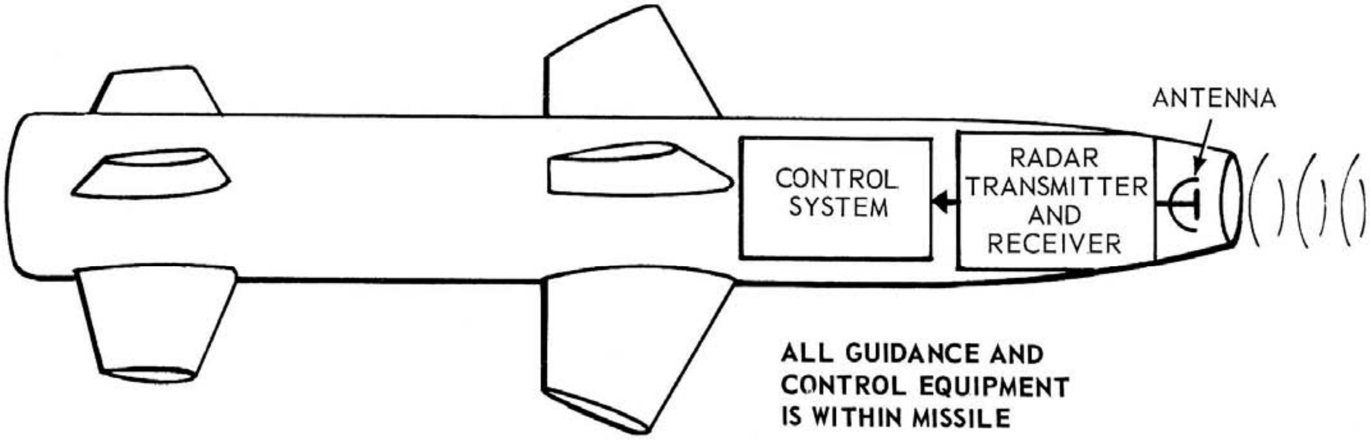
Some surface-to-air missiles use passive homing when their normal guidance system is jammed. Then the target is the source of electromagnetic energy used by the passive homing system to develop guidance signals. The energy source within the target may be an electronic jammer. The jammer is used to mix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

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

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

SEMIACTIVE LEAD HOMING GUIDANCE

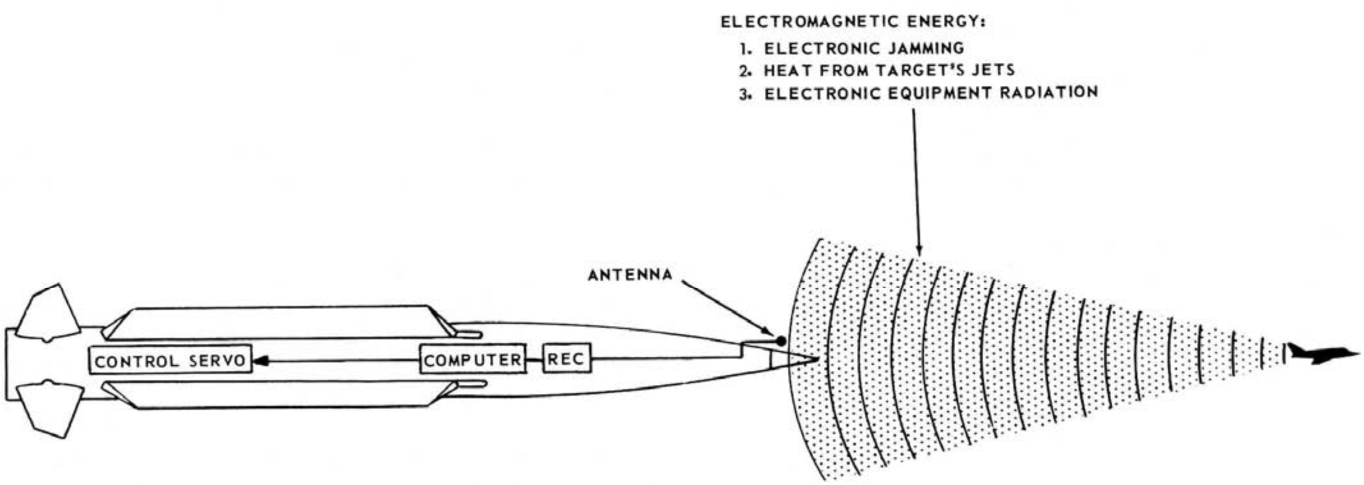
A missile using semiactive homing guidance receives radar energy along an indirect path. Radar waves are sent out from a fire control radar to a target. The transmitted waves strike the target and bounce off it. Some of the reflected waves of radar energy travel toward the semiactive homing missile sent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



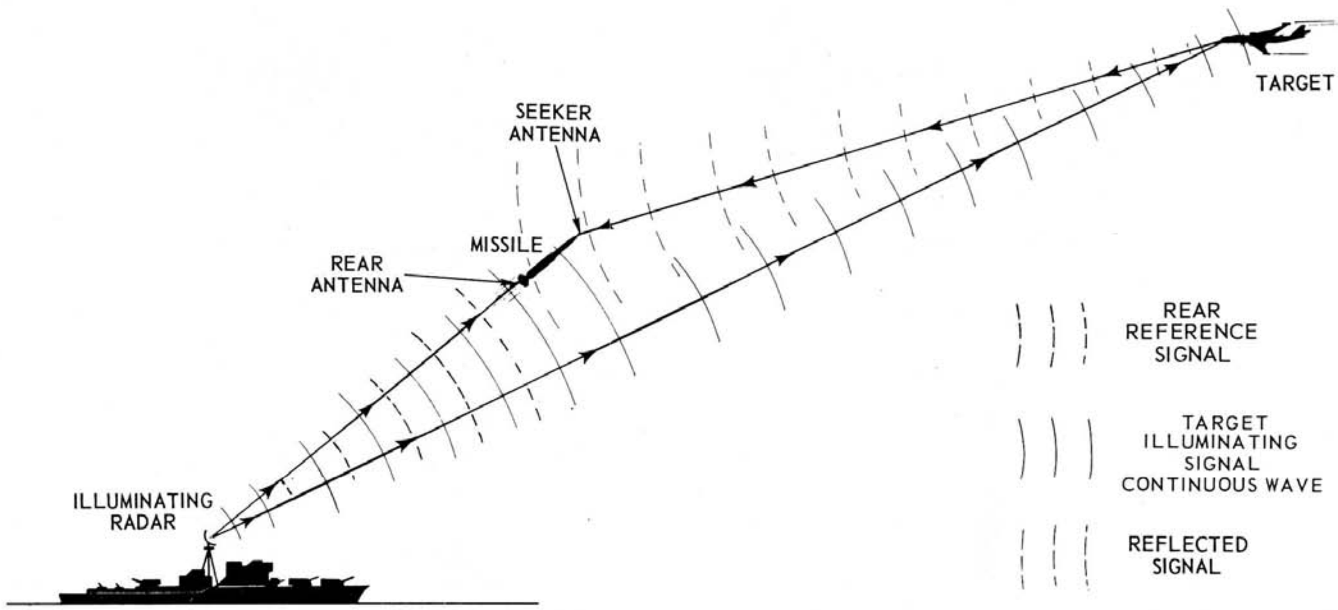
83.25
Figure 4-22.—Active homing guidance system.

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

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



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



83.27

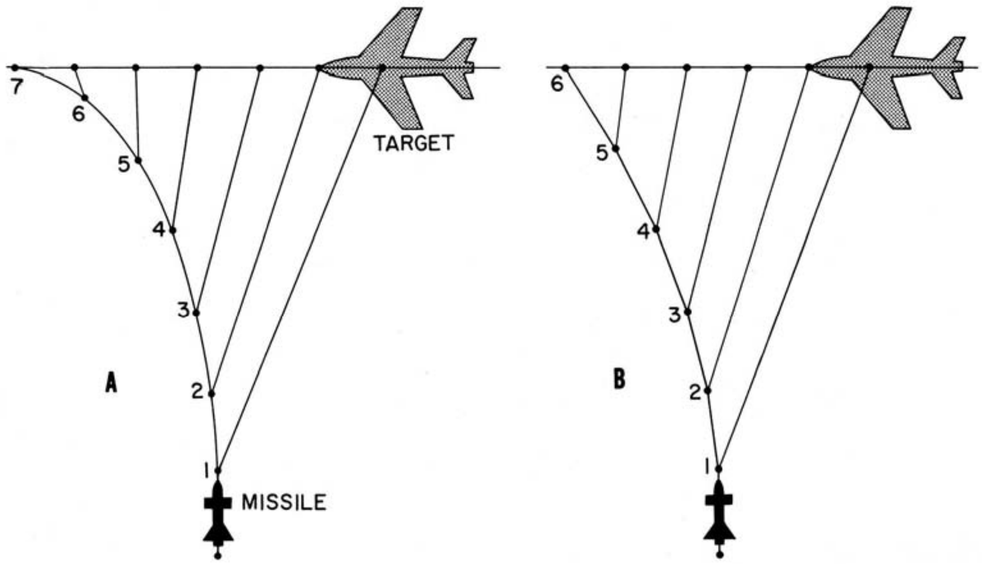
Figure 4-24.—Semiactive homing guidance system.

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

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

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

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



83.28
Figure 4-25.—Proportional navigation.

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

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

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

DOPPLER PRINCIPLE

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

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

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

Pulse Doppler Radar

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

CLASSIFICATION OF NAVY MISSILES

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

The following letters are used to indicate the launch environment:

A - air launched.

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

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

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

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

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

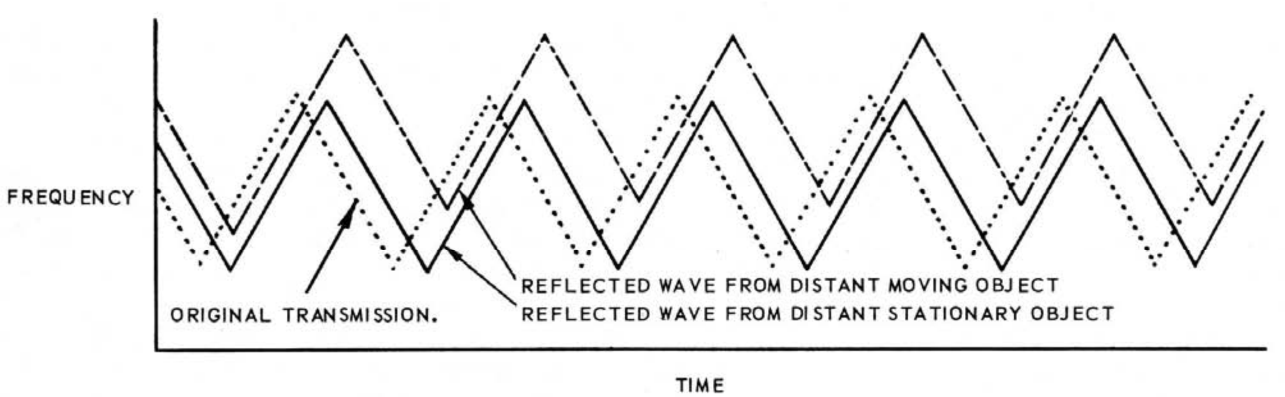


Figure 4-26.—Doppler effect on frequency modulation (sawtooth wave) of radar.

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

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

U - launched from a submarine or other underwater device.

The following letters are used to indicate the mission:

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

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

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

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

Q - drone.

T - training.

U - underwater attack.

W - weather.

The following letters are used to indicate the vehicle type:

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

N - probe.

R - rocket.

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

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

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

J - special test, temporary.

N - special test, permanent.

X - experimental.

Y -prototype.

Z - planning.

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

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

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

SURFACE-TO-AIR MISSILES

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

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

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

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

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

TERRIER MISSILE CHARACTERISTICS

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

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

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

BT Terrier Missiles

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

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

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

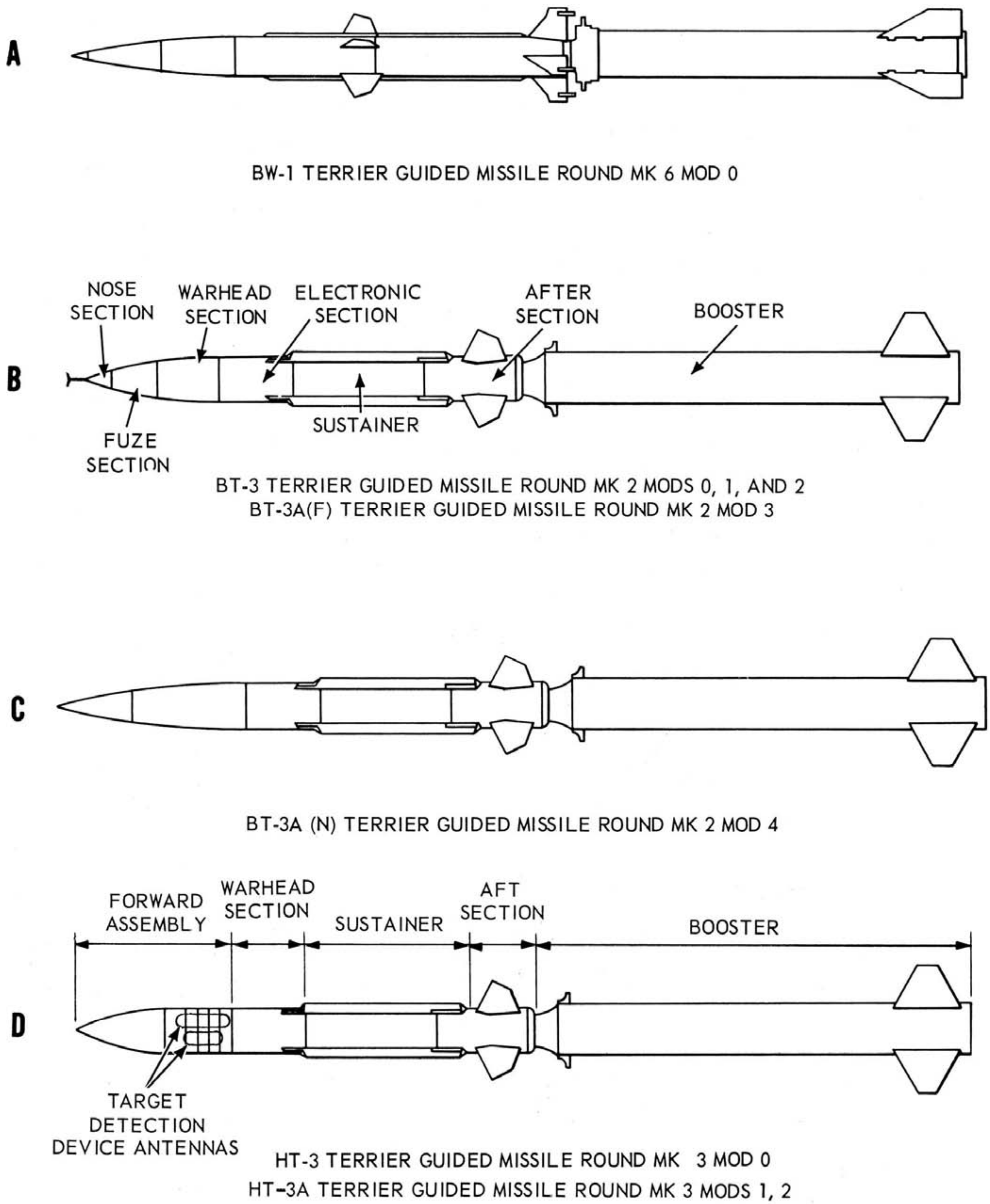
2. Just aft of the nose section is the fuze section. It contains the target detection device (TDD) and the warhead safety and arming device (S&A). The TDD senses the presence of a target and sends a signal through the S&A device to detonate the fragmentation warhead. The primary purpose of the S&A device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

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

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

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

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



83.29
Figure 4-27.—Terrier missile family.

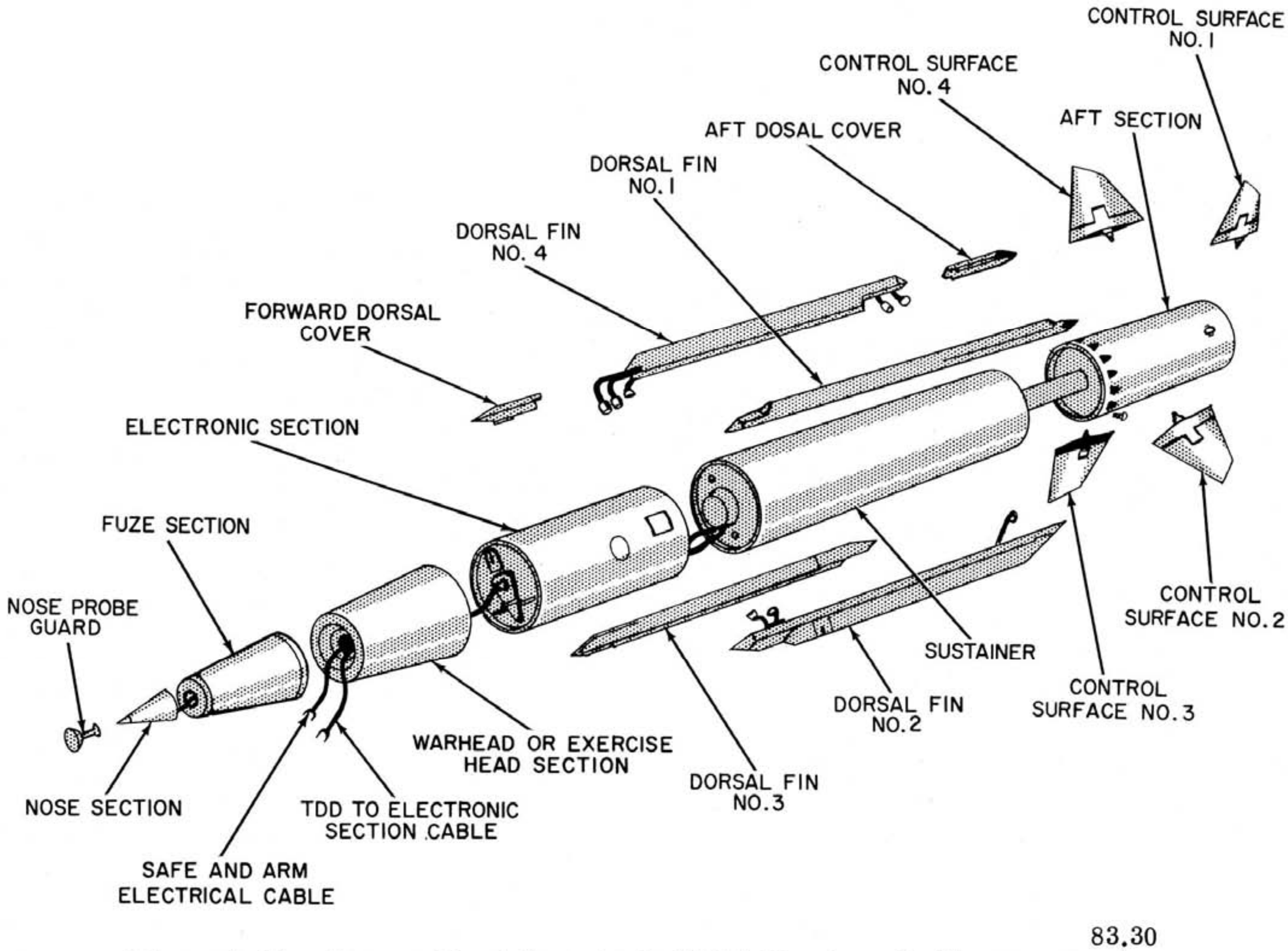


Figure 4-28.—Beam-rider tail-controlled (BT) Terrier missile; components.

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

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

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

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

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

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

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

HT TERRIER MISSILES

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

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

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

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

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

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

TARTAR MISSILES

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

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

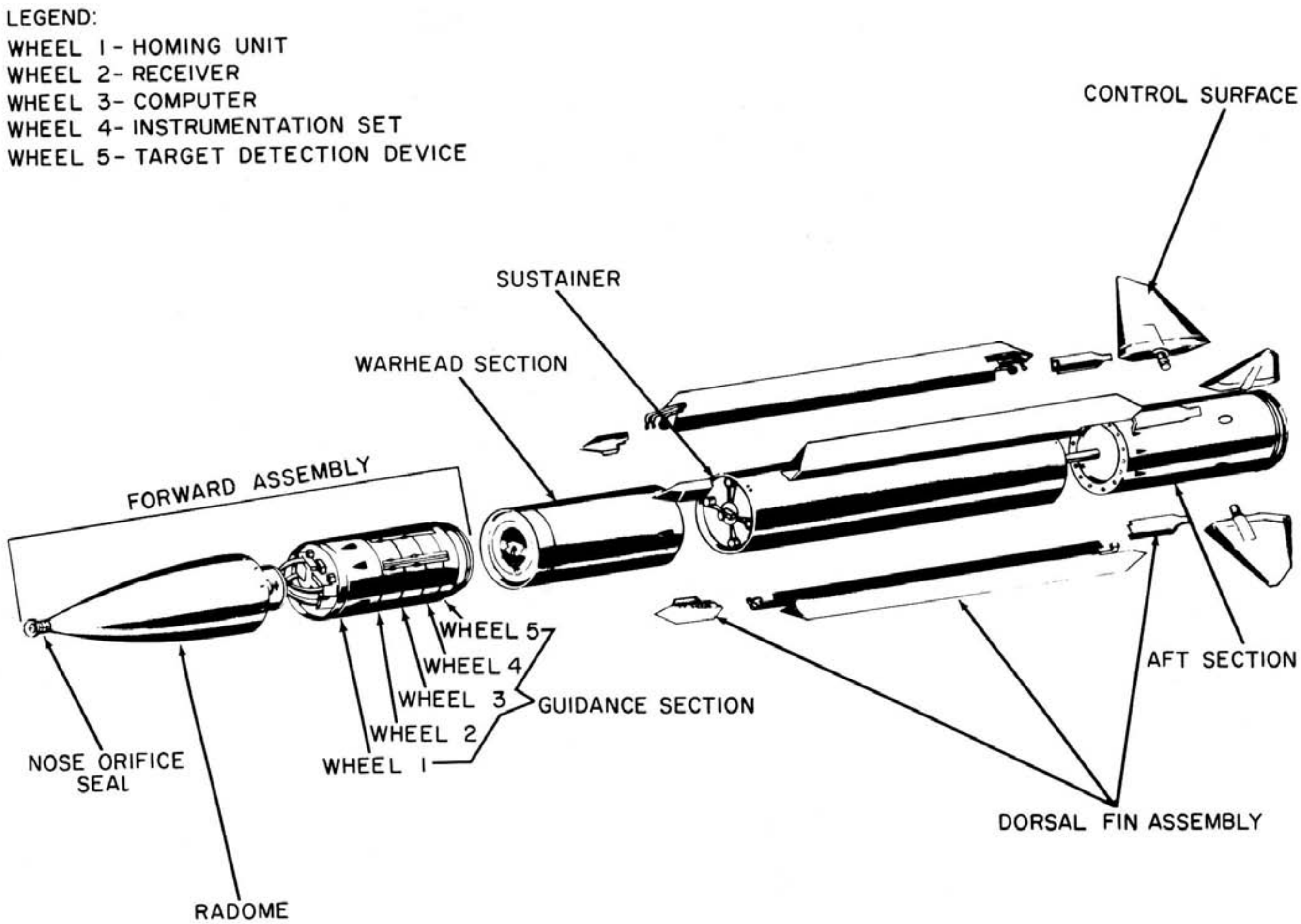


Figure 4-29.—Homing tail-controlled (HT) Terrier missile; components.

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

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

Forward Assembly

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

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

1. Homing Unit (Wheel 1). The first wheel contains the seeker head antenna, reference antennas, and passive homing circuitry.
2. Homing Receiver (Wheel 2). This package contains most of the seeker head guidance circuits and the self-destruct circuits.
3. Guidance Computer (Wheel 3). The computer uses output signals from the homing system to produce missile steering orders that keep

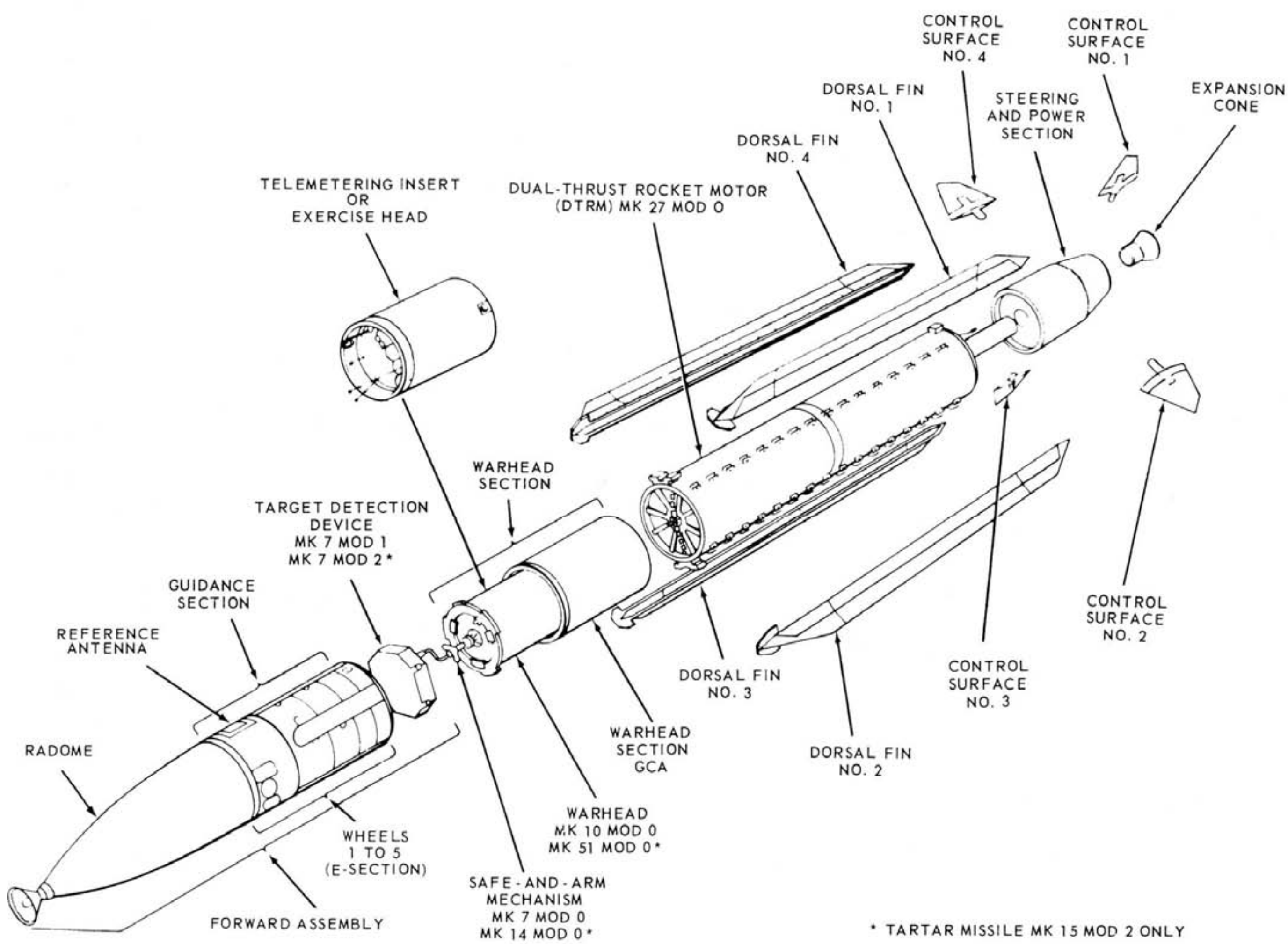


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Figure 4-30.—Improved Tartar round; exploded view.

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

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

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

Warhead Section

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

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

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

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

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

Dual-Thrust Rocket Motor (DTRM)

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

Steering and Power Section

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

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

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

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

STANDARD MISSILES

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

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

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

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

Guidance Section

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

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

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

Ordnance Section

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

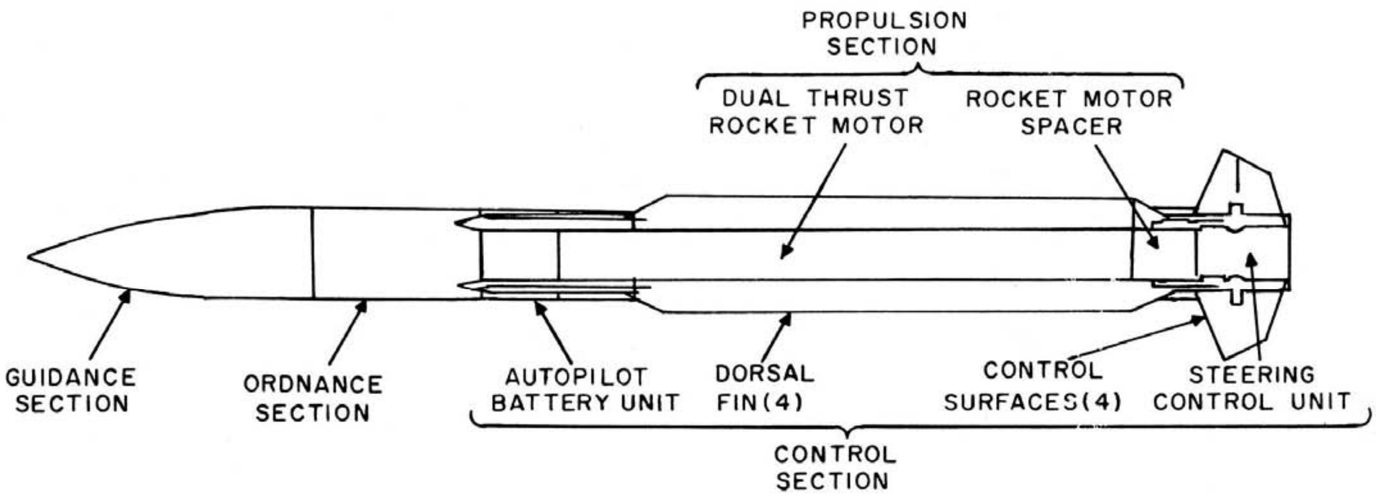

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Figure 4-31.—Standard missile RIM-66A, major sections and components.

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

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

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

Control Section

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

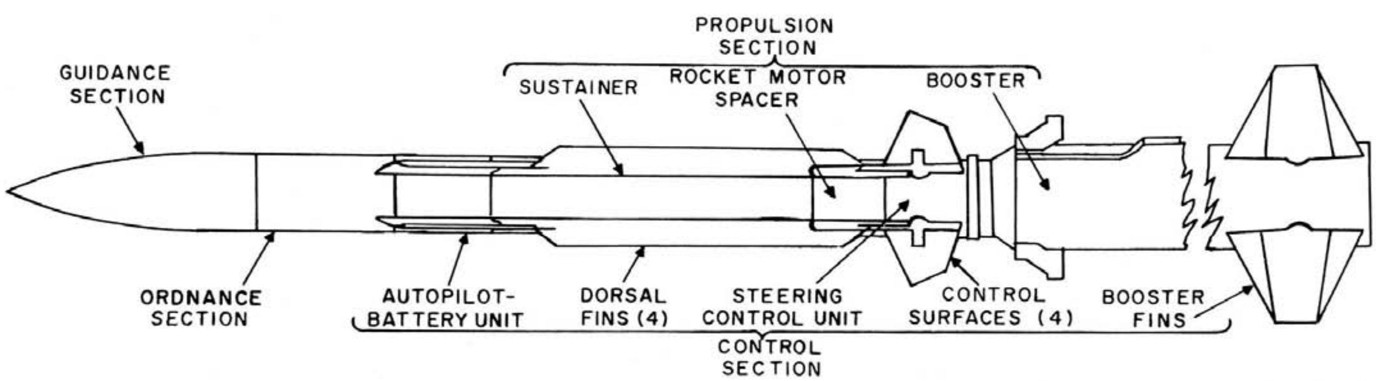

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Figure 4-32.—Standard missile RIM-67A, major sections and components.

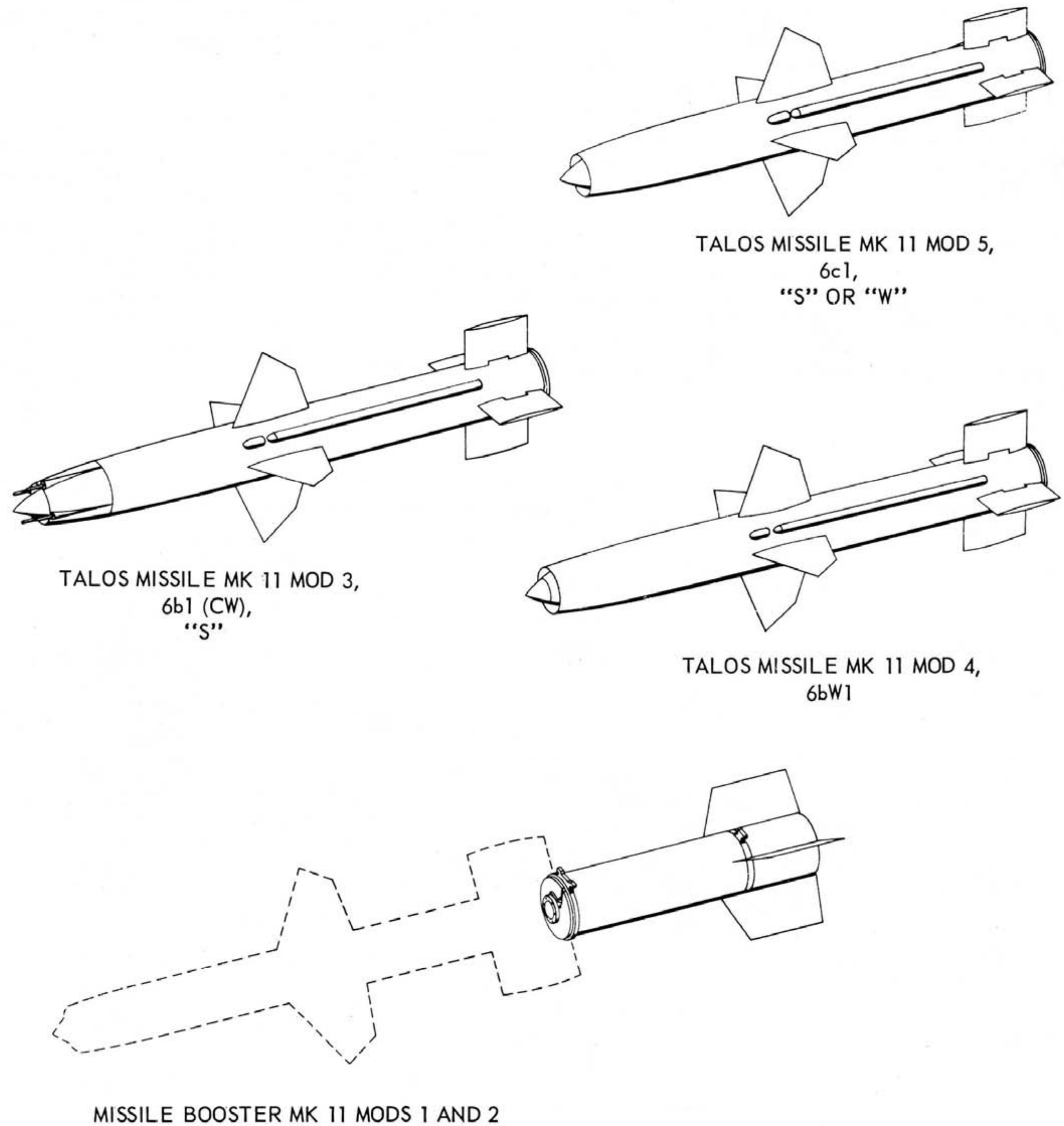

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Figure 4-33. — Talos missile types, and booster.

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

Power Supply

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

Propulsion System

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

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

TALOS

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

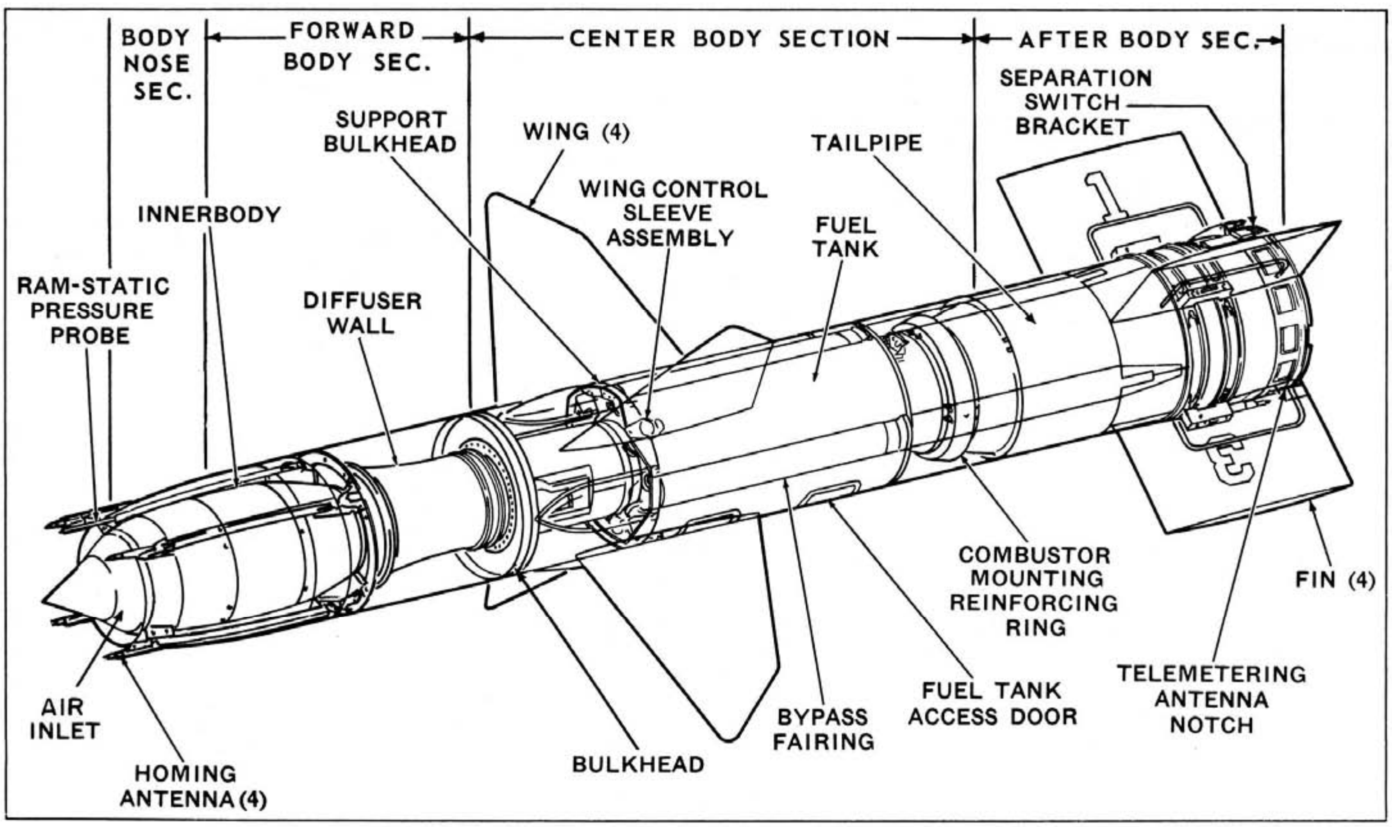

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Figure 4-34.—Major sections and some components of Talos missile.

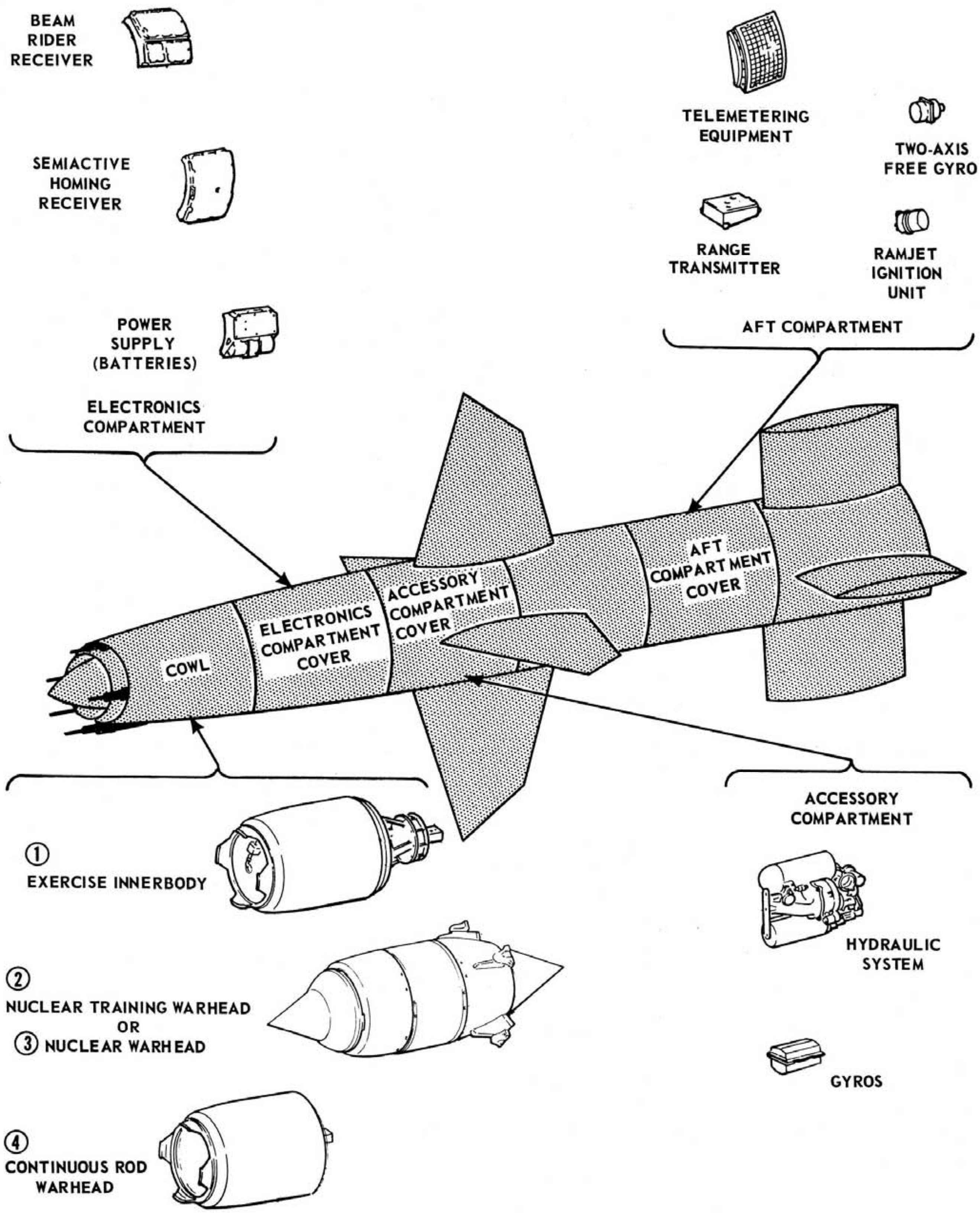

Figure 4-35.—Talos compartment and compartment covers.

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

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

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

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

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

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

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

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

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

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

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

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

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

CHAPTER 5

GUIDED MISSILE LAUNCHING SYSTEMS

INTRODUCTION

The guided missile launching system (GMLS) on a ship is that part of a ship's installation designed to stow and launch the missiles. Its purpose is to deliver a missile, ready for firing, from the missile magazine to the launcher guide arm. It must also return a missile from the launcher to the magazine for stowage. The launching system includes the feeder system, the launcher, and the launching system control. The feeder system stores the missiles and delivers them to the launcher. A typical feeder system consists of the missile magazine, loader, assembler, and strikedown and checkout equipment. Figure 5-1 shows these components for the Mk 12 GMLS (Talos). Not all launching systems have all these major components. The Tartar system, for example, does not have an assembler. For launchers with two arms, there are also duplicate components of the other parts of the system, one for the A-side and the other to supply the B-side, either simultaneously or independently.

Although the ship's fire control system is essential for successful missile action, it is not considered part of the launching system.

In your work around missiles and launchers you have undoubtedly heard the term "launching groups." The term "group" means the same thing as system - a group of inter-related equipments. The launching system for the ASROC, which is the responsibility of the Gunner's Mate (T), is called "launching group."

GENERAL DESCRIPTION

The discussion here, because it is limited to but one chapter in a course that must take up many topics other than this, will unavoidably omit a good many details.

The overall configuration of a missile launching system is determined by the type of missile used and the class of ship on which it is installed. The missile type is the most important factor to be considered.

The types of launching systems, however, are designed for specific ships, or rather, classes of ships. Many changes have evolved since the USS Gyatt was converted from a conventional DD to the first guided missile ship.

The arrangement of the major components of a launching system that handles the same type missile will vary with the Mk and Mod of the launching system, and the ship on which it is installed. This is especially the case with the location of the stowage area or magazine.

The Talos system, being large, is placed only on CGs, CLGs, and CGNs. The much smaller Tartar system is placed on smaller ships, such as DDGs, although CGs may have Tartar as well as Talos systems aboard.

LAUNCHERS

The main purpose of a launcher is to provide a launching platform or pad for missiles. But launchers have secondary purposes too: they must support missiles, aim them, prepare them for firing and, finally, launch them in the direction of the target. All missile launchers you will work with do these fundamental jobs.

The modern missile launcher is characterized by:

1. Its ability to position itself in train and elevation.
2. A structure that can support missiles singly or in pairs.
3. Devices that provide a method of inserting information into the missile before it is fired.
4. Devices that fire the missile.
5. Systems that provide for the safety of the ship, missile, and personnel.

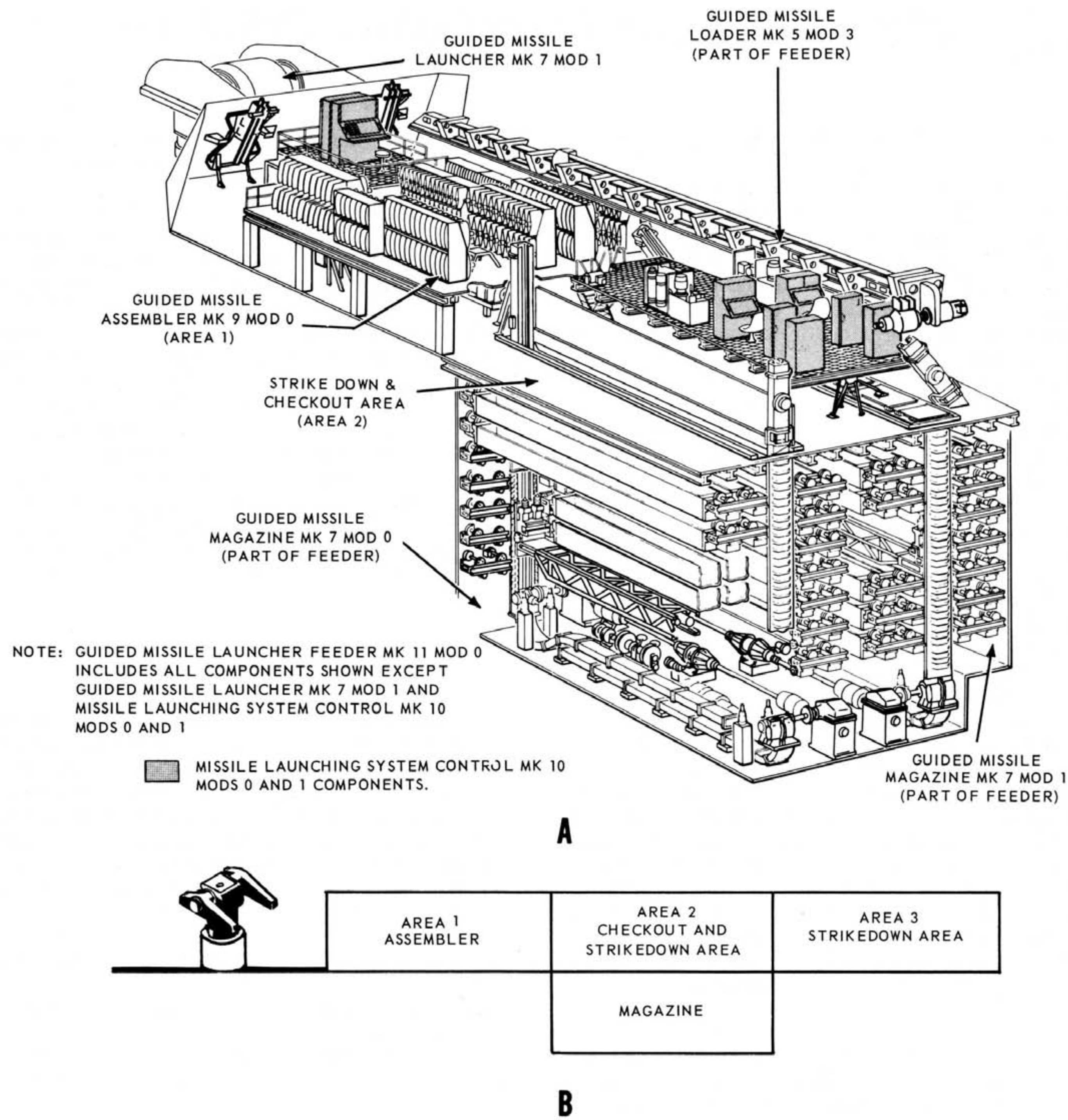

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Figure 5-1.—Guided Missile Launching System Mk 12. (Talos)

Every missile launcher has these general characteristics. In this section we will take up the more significant and common features of launchers.

Types of Launchers

Missile launchers may be classified in many ways:

1. By the common name of the missile it launches. Thus, you can call a launcher a Talos, Tartar, or Terrier launcher.
2. By the number of rails or guide arms. This method of classification is illustrated in figure 5-2. Notice that Terrier and Talos launchers are dual-arm ones, while Tartar launchers come in two varieties - single- or dual-arm types.
3. By the elevation position of the guide or missile-supporting structure when loading missiles. All Tartar launchers are vertical-load types. Early Terrier launchers are also vertical- load launchers. But the more modern Terrier launchers load missiles with the guide arms horizontal to the deck plane, or nearly so (at an angle on forward installations). Talos launchers receive missiles with the guide arms horizontal to the deck.
4. By the distance the missile travels on the launcher during firing. If the first motion of the missile during the launching process releases it from the launcher, the launcher is called a zero-length type. But, if the missile travels any distance along its supporting rail, the launcher is designated a rail-type launcher. Terrier and Talos launchers are sometimes loosely called zero-length launchers, but their missiles during launch do travel several inches before they detach themselves from the launcher.

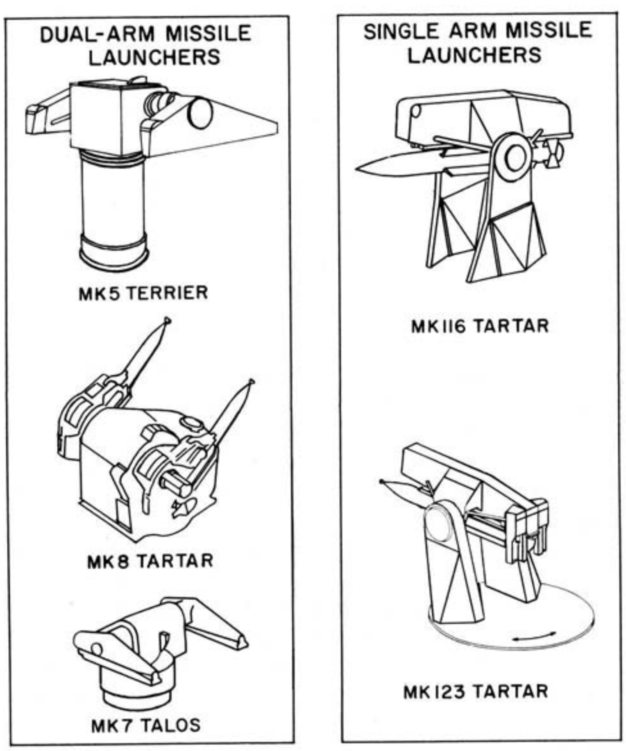


Figure 5-2.—Launchers classified according to the number of arms. 83.37

Various proposals have been made to use guns for launching missiles, but at present this method has not been used on ships, although successful test firings have been made. The Tartar Mk 22 launching system was designed to use the training circle of a 5"/54 caliber gun.

FEEDER SYSTEMS

Some of the most noticeable differences are in the components of the feeder system.

Magazines

The three Terrier systems use magazines of entirely different designs. The Mk 4 system, which is installed on the USS Boston and USS Canberra, has the missiles stored in a vertical position and the launcher is located directly over the magazine, so the missiles are loaded vertically. The Mk 10 system, now used on most Terrier ships, stows the missiles in a horizontal position; but there are differences in the details of loading and unloading. The Mk 10 system has the missiles stowed in a ready service ring that rotates to the position directed when a missile is to be transferred. The Mk 9 system also had the missile stowed in a horizontal position, but in cells, and the hoist (a transfer car on rails) has to go to the missile to bring it up, instead of the missile being brought up to the hoist for moving to the loader, as in the Mk 10 system. The missile is extracted from the cell, and placed on the transfer car, which moves it to the loader.

The Mk 7 Talos system stows the missiles in a ready service compartment which contains trays that index to bring the selected missile to the hoist for loading. In addition, there is a replenishing magazine for additional missiles.

The Mk 12 Talos system (fig. 5-1) stows its missiles in trays, positioned like the cells in the Mk 9 Terrier system, but movable.

The missiles in all of the Tartar systems are stored in a vertical position in ready service rings directly below the launcher. Since Tartar missiles are complete, no assembly area is needed. The missile fins, which are on the missile in a folded position, unfold automatically after the missile is on the launcher.

Loader

In figure 5-1, locate the loader, sometimes called the rammer. It picks up the missile after it has been brought up from the magazine, moves it to the assembly area, where the wings and fins are attached, and then moves it to the launcher. Of course there are many more steps in this sequence, which we will not detail here. In systems where the launcher is directly above the magazine, there is no need for this lengthy transfer, and the loading sequence is shortened.

Assembler

The assembly area is in the missile house, near the launcher. The wings and fins that are to be attached to the missiles are stored in racks in this area. Men are stationed here (the number varies with the type of missile and its Mk and Mod) and they attach a wing or fin to the missile as it rests on the loader. It must be done very quickly to maintain the timing sequence of the launcher, and the men must have had precision- timed training before they are assigned to the task.

Strikedown and Checkout Equipment

By strikedown we mean the loading of the ship's magazines with missiles, boosters, and other missile components. Checkout means the preflight checks on missiles by the use of special test equipment. The tests are conducted by men of other ratings; your part of the job is to position and prepare the missiles for testing. Mating and unmating of missiles is performed in the checkout area; this, too, is part of your job. The layout and the location of the checkout area varies with the missile and the ship. See chapter 14 for illustrations and detailed discussion.

LAUNCHING SYSTEM CONTROL

The third major component of the launching system is the control equipment. The control panels for components are located as close to the component as possible. The large control panel offers pushbutton control of most if not all parts of the system. The large control panel offers automatic control, but local control is necessary for testing, checking, repairing, or replacing individual units of components. The local control panels are necessary for those procedures. A "typical location" diagram is shown later in this chapter.

TERRIER LAUNCHING SYSTEMS

As we have mentioned before, Terrier systems have been under development for a number of years and many changes have resulted. The Mk 10 launching system is the one found on the largest number of Terrier missile ships, but there are variations in the mods of this, ranging from Mod 0 to Mod 8. The Terrier Launching System Mk 9 is installed on three CLGs: USS Providence, USS Topeka, and USS Springfield.

We will describe the Mk 10 launching system, pointing out the important differences in mods and showing where the Mk 4 and the Mk 9 systems are different.

LOCATION AND ARRANGEMENT ABOARD SHIP

The location of the components of the Terrier launching system varies with the type of ship and the Mk and Mod of the system.

Mark 10 and Mods

On a DLG-26 class destroyer, the launcher of the Mk 10 Mod 7 system is mounted at the ship centerline of the 01 level and the feeder system (magazines, loaders, strike-down equipment) is located below and aft of the launcher. As shown in figure 5-3, the Mk 10 Mod 7 Terrier system has three magazines (ready service rings), two of them at the upper level and one at a lower level. The one at the lower level is for auxiliary stowage purposes, and only Terrier missiles are stowed in it. The other two magazines can hold Terrier or a mixture of Terrier and Asroc (fig. 5-3). Each ready service ring has trays to hold twenty weapons. Because the Asroc is considerably shorter than the Terrier, it must be stored with an adapter attached to it. When an

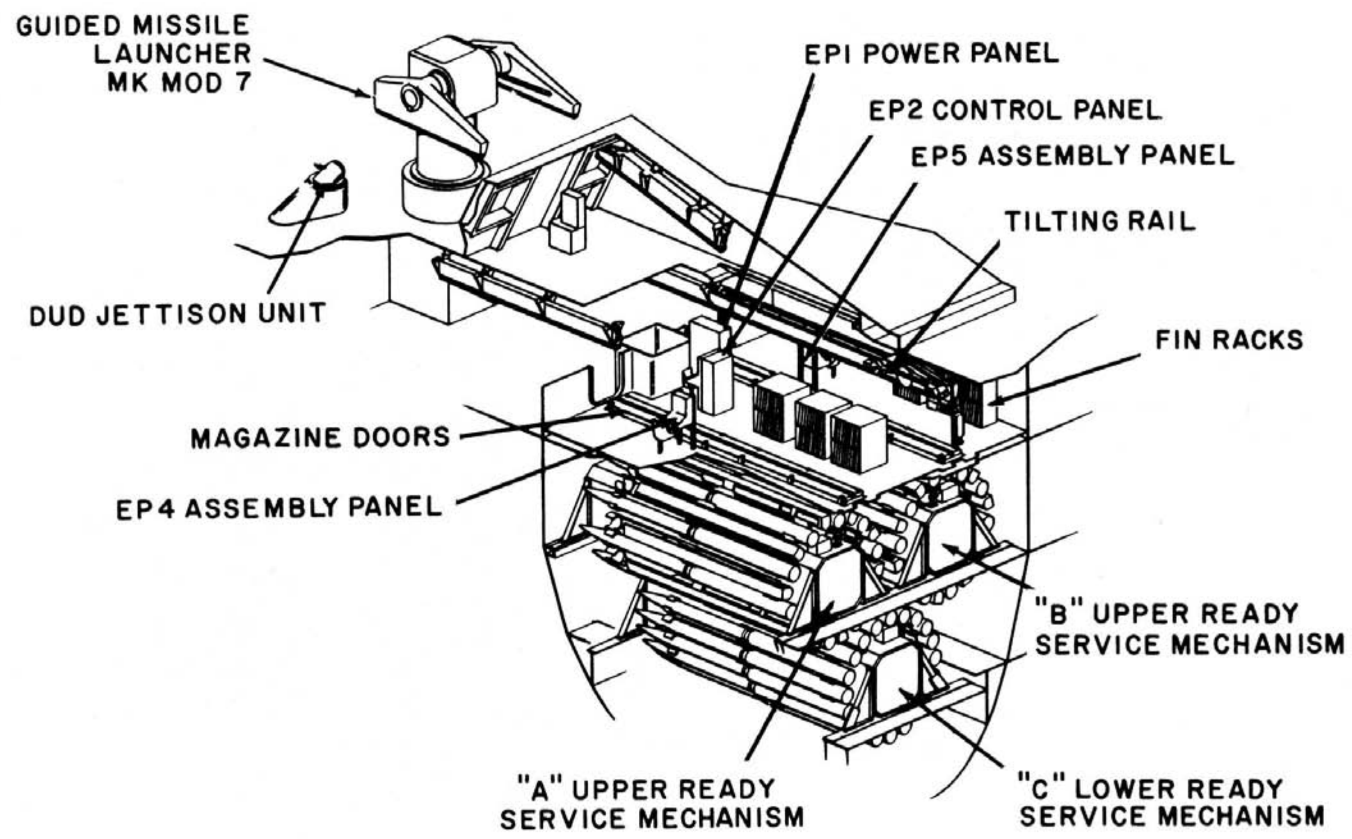


Figure 5-3.—Guided Missile Launching System Mk 10 Mod 7 With Complement of Asroc.

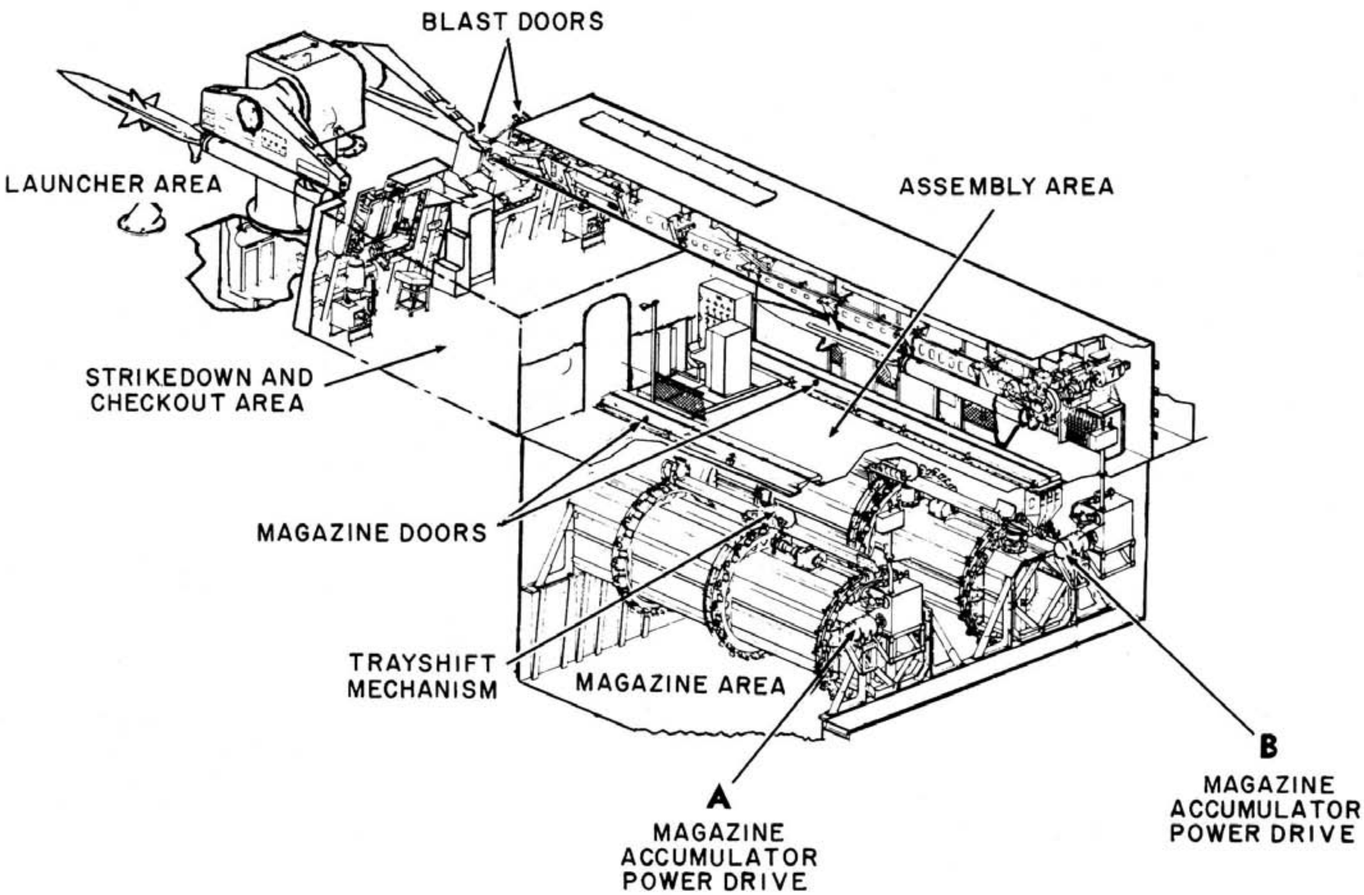
Asroc is fired, the adapter rail is left behind and must be returned to the ready service ring.

GMLS Mk 10 Mods 0, 5, and 6, has two ready service rings instead of three, and it does not accept Asroc missiles. Figure 5-4 shows a Mk 10 Mod 0 system. The launcher is near the aft end of the ship. Part of the launching system is in the aft deckhouse (missile house); the magazine area, containing the ready service rings, is below decks.

The aft deckhouse is divided into two compartments. The part nearest the launcher is the strikedown and checkout area, and the other compartment is the assembly area, with the missile magazine area directly beneath it. The missiles are transferred from the magazine area to the assembly area through the magazine doors (fig. 5-4) by the hoist. After assembly is completed, the missile is moved out of the assembly area on a loader r ail that extends from the magazine door, through the assembly area and the strikedown and checkout area, to the blast door. When the blast door is open, a rail extension connects the loader rail to the guide arm on the launcher, so the missile can move onto the launcher. The blast doors remain closed except during the moment of actual transfer of a missile to the launcher (or when unloading the launcher and moving the missile from the launcher to the magazine).

Mk 9 System

Instead of ready service rings that rotate to bring the selected missile to the hoist, the Mk 9 system stores its missiles in individual cells, and (instead of the hoist) a transfer car moves to the cell that contains the selected missile. This arrangement is shown in figure 5-5. The cells are numbered and identified on the control panel so that any missile may be selected for transfer from the cell to the launcher by pushing the correct button on the launcher control panel. A transfer car, which is part of the loader, runs athwartships on tracks to the selected cell, where an extractor beam extracts the round. As you can see in figure 5-5, there are two sets of magazines, one next to the assembly area and another for additional stowage.



83.160
Figure 5-4.—GMLS Mk 10 Mod 0, General Arrangement.

The system is divided longitudinally into two independent halves, as is the Mk 10 system. The "A" side equipment is the starboard side and the "B" side is the port equipment. The two halves operate simultaneously or separately, each to supply the launcher arm on its side.

Instead of a loader to move the missile round from the hoist to the assembly area, the Mk 9 system has a rammer system. The missile round rides on the rammer rail, which is driven by a continuous sprocket-driven chain that engages the booster shoe on the round. The first stage rammer carries the round to the assembly area and the second stage rammer takes the round from the assembly area, after the wings and fins have been assembled to it, to the launcher. The two stages have separate and independent hydraulic drives located in the overhead above the loader rails. Warmup power is applied to the missile while it is on the second stage rammer.

Mk 4 Launching System

The Mk 4 launching system is installed on two CAGs, USS Boston and USS Canberra. At this writing both ships have been placed in an inactive status in the reserve fleet so the system will not be discussed. Figure 5-6 is presented, however, to show the method of missile stowage in the magazine.

Control Equipments

Control panels for various parts of the launching system equipment are shown in figure 5-1, 5-3, 5-4, and 5-5. Most of them are in the assembly area of the system, but the power panels usually are placed as close as possible to the equipment they supply.

Power panel EP1 and Control Panel EP2 (fig. 5-4) of the launching system are manned by the launcher captain. If it is necessary to

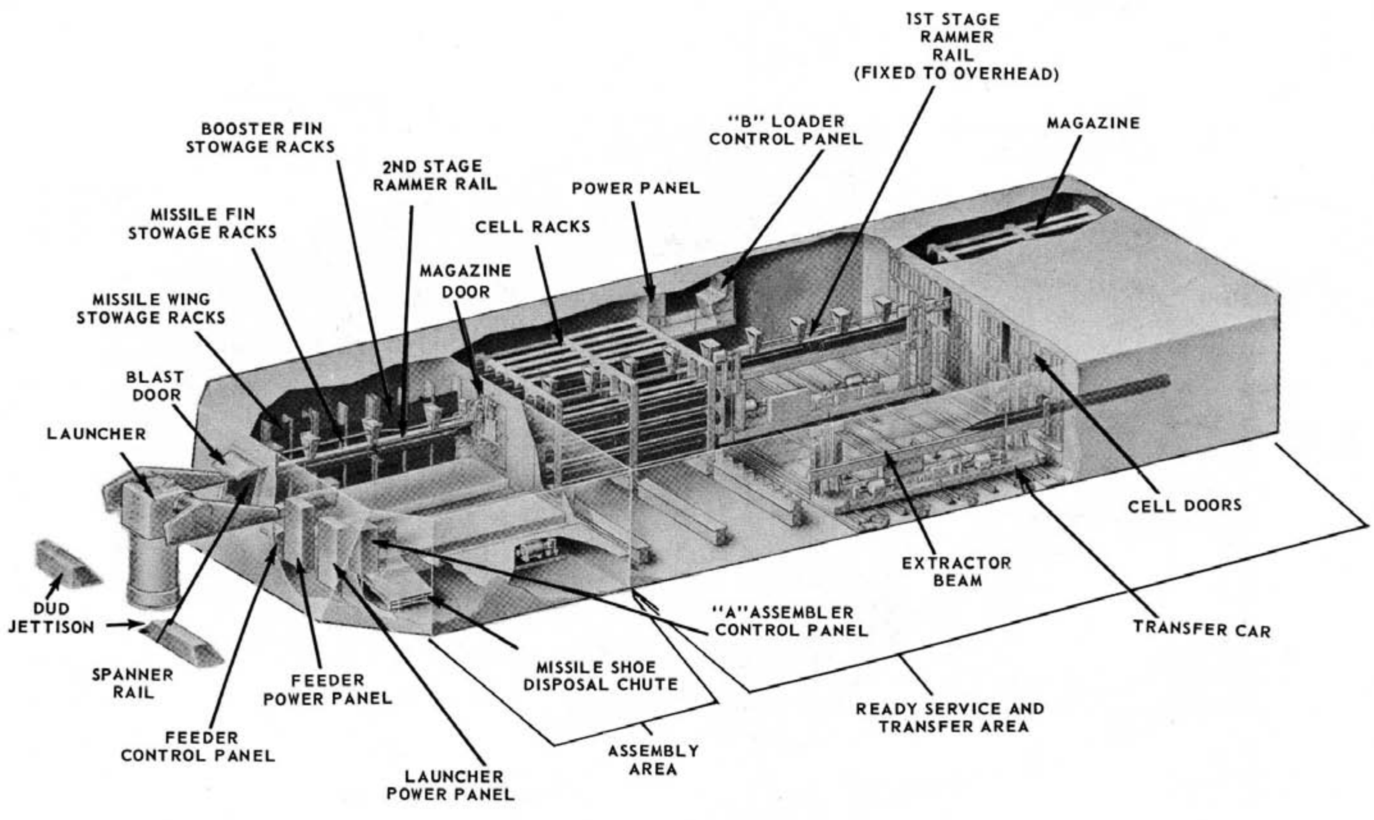


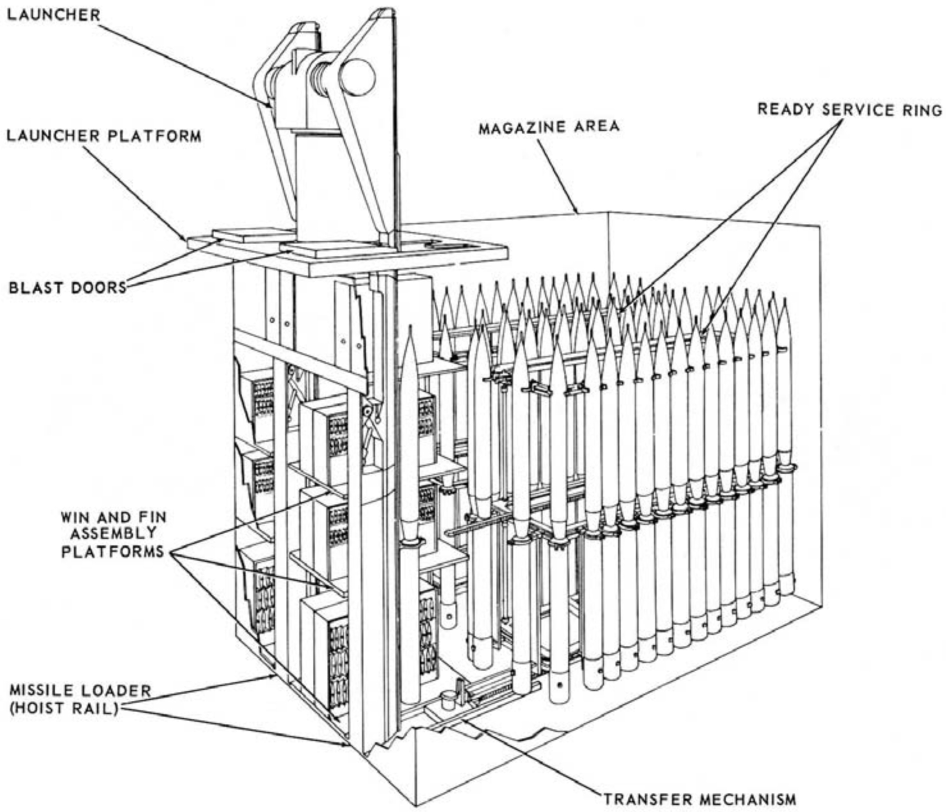
Figure 5-5.—Guided Missile Launching System Mk 9.

use EP3 and Dud Jettison panels, a crew member is assigned. The EP1 panel is the basic power distribution system for all electrical power to the launching system. It contains switches, circuit breakers, fuses, relays, and contractors for the power and control circuits. The EP2 panel is the operations control panel for the system. It contains the switches and relays to select the type of operation wanted, lights to indicate the phase or sequence of operation, the position synchros for the launcher, and the amplifier for the train and elevation movements of the launcher.

The EP3 panel is primarily a test panel, and is not manned during normal launching activities. Various test equipments can be plugged into it, and it can also be used for local control of the launching system.

The number and the functions of control panels vary with the launching system. Some systems have many more control panels than the three mentioned above.

So far we have talked only about the control panels in the launcher-feeder area. Orders for the operation of these controls must come from a higher authority. The Weapons Control System controls all the weapons on the ship, including missiles, guns, torpedoes, rockets, and depth charges. It consists of the Weapon Direction System and one or more Fire Control Systems. Figure 5-7 shows a specimen weapon control station with typical equipments. The launcher and feeder system are controlled by the operator of the Weapon Assignment Console (WAC). The WAC operator selects the missile rail to be loaded and the method of loading (single or continuous), applies warmup power to the missiles, selects the number of missiles to be fired per salvo, and assigns the launcher to a fire control system; or he can cancel the launcher assignment. These orders are not the whim of the operator, but are based on the information supplied to him by the WAC and the other equipment in the station. The men below deck can't see the target; they depend on the radars above deck to locate and track the target, the



83.161
Figure 5-6.—Missile Launching System Mk 4.

computer to figure the angle of train and elevation necessary for the launcher so the missile will intercept the target, and signals from various equipments in CIC to transmit decisions and orders.

THE FEEDER SYSTEM

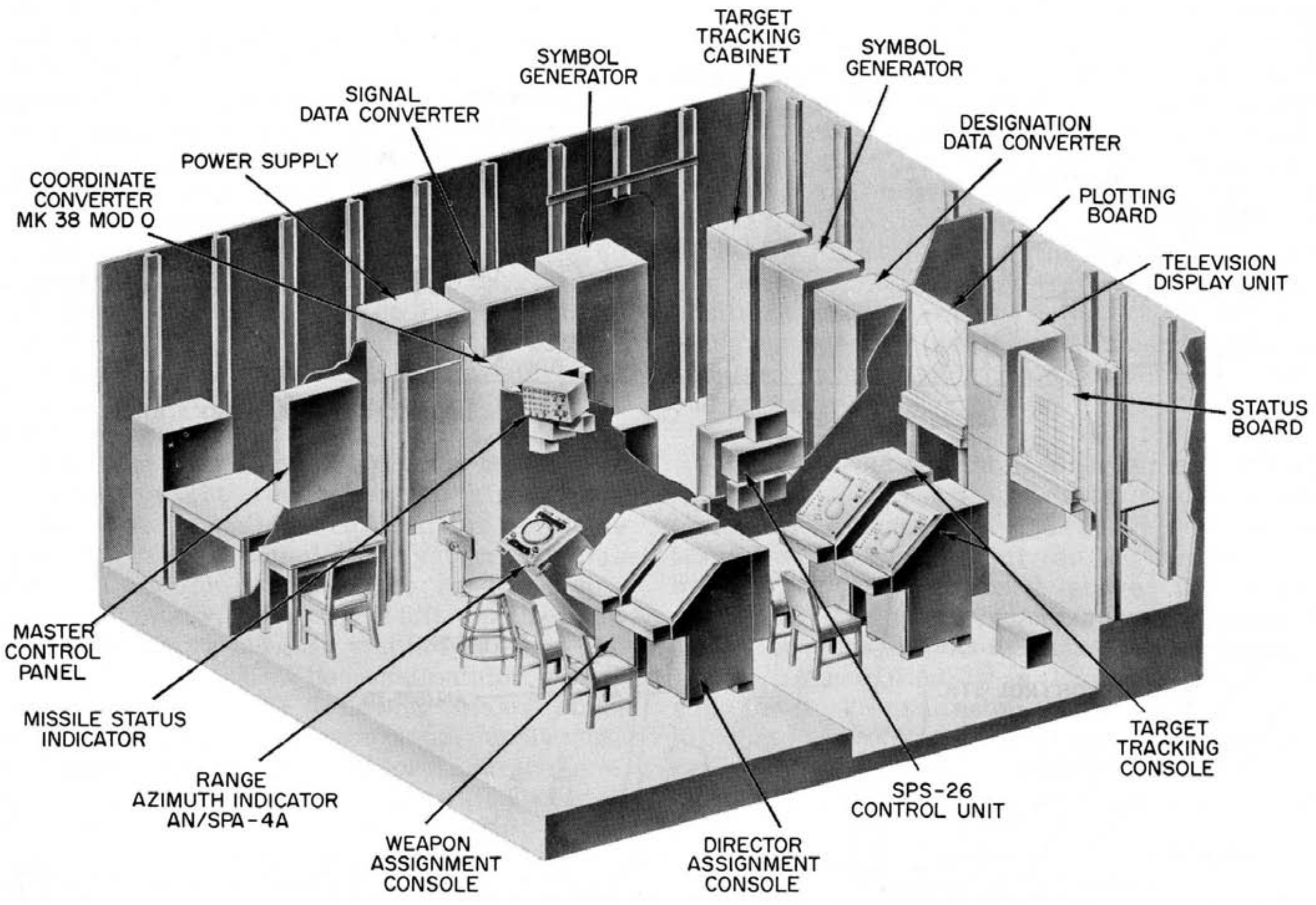
The feeder systems of the different Terrier launching systems may be seen in the illustrations of the launching systems; figures 5-3, 5-4, 5-5, and 5-6. The general arrangement of the magazines, the assembler, and the launcher may be seen in the illustrations. The placement of control panels may be seen in figures 5-3 and 5-4.

Location

When missile systems were first installed on ships, ships already in service with conventional firepower were converted for missile use. The deckhouse was made to house much of the feeder system. The magazines were placed below deck as much as possible for protection of the explosives.

New ships, designed and built to carry missile systems, provide space below deck for every thing in the system except the launcher. Figure 5-8 shows the location of launchers and feeder systems on three types of ships. Figure 5-8A shows the arrangement on the first ships converted to missile use-the USS Boston (CAG-1) and the USS Canberra (CAG-2). Each ship is equipped with twin launchers, which replace the aft 8- inch gun turrets. The two automatic vertical missile launching systems, one for each twin launcher, provide the means for stowing, handling, and loading 144 Terrier rounds. Originally designed for BW missiles, the equipments have been modified to take BW1 Terriers.

Figure 5-8B shows the arrangement on the converted light cruisers, the USS Providence (CLG-6), USS Springfield (CLG- 7), and USS Topeka (CLG-8). On these ships, much of the launching equipment is in the deckhouse, mounted aft,



83.162
Figure 5-7.—Weapon Control Station (WCS).

with one twin launcher on the main deck. All of them have the missiles stowed in horizontal position.

Most of the ships carrying Terrier missiles are guided missile destroyers. The first of these, a converted DD, was the USS Gyatt (DDG-1), from which many lessons were learned in designing missile ships. Everything except the launcher is below deck. The dud jettison unit is mounted to the deck, but its control panel is below deck, as is the power supply. Figure 5-8C shows the location of missile system major components on a destroyer class ship. All of them use the Mk 10 launching system, varying in the mods used.

The Navy also has some missile frigates and these, too, carry the Mk 10 launching system installation. Carriers, too, have the Mk 10 Terrier system as part of their missile armament.

Components of Missile Magazine

Of the four major components of the feeder system, we've already given most attention to the missile magazine, its type (ready service ring or cell; vertical or horizontal stowage), and its location with regard to the launcher on different ships. Let's turn our attention now to other components.

POWER SUPPLIES. - You realize that considerable power is necessary to turn the ready service ring loaded with large, heavy missiles. We've mentioned a power panel that supplies electric power. In figure 5-3, locate the EP1 panel in the assembly area. In figure 5-4, locate the A magazine accumulator power drive and the B magazine accumulator power drive. Where there is an accumulator, there is hydraulic power. Figure 5-5 points out the power panels

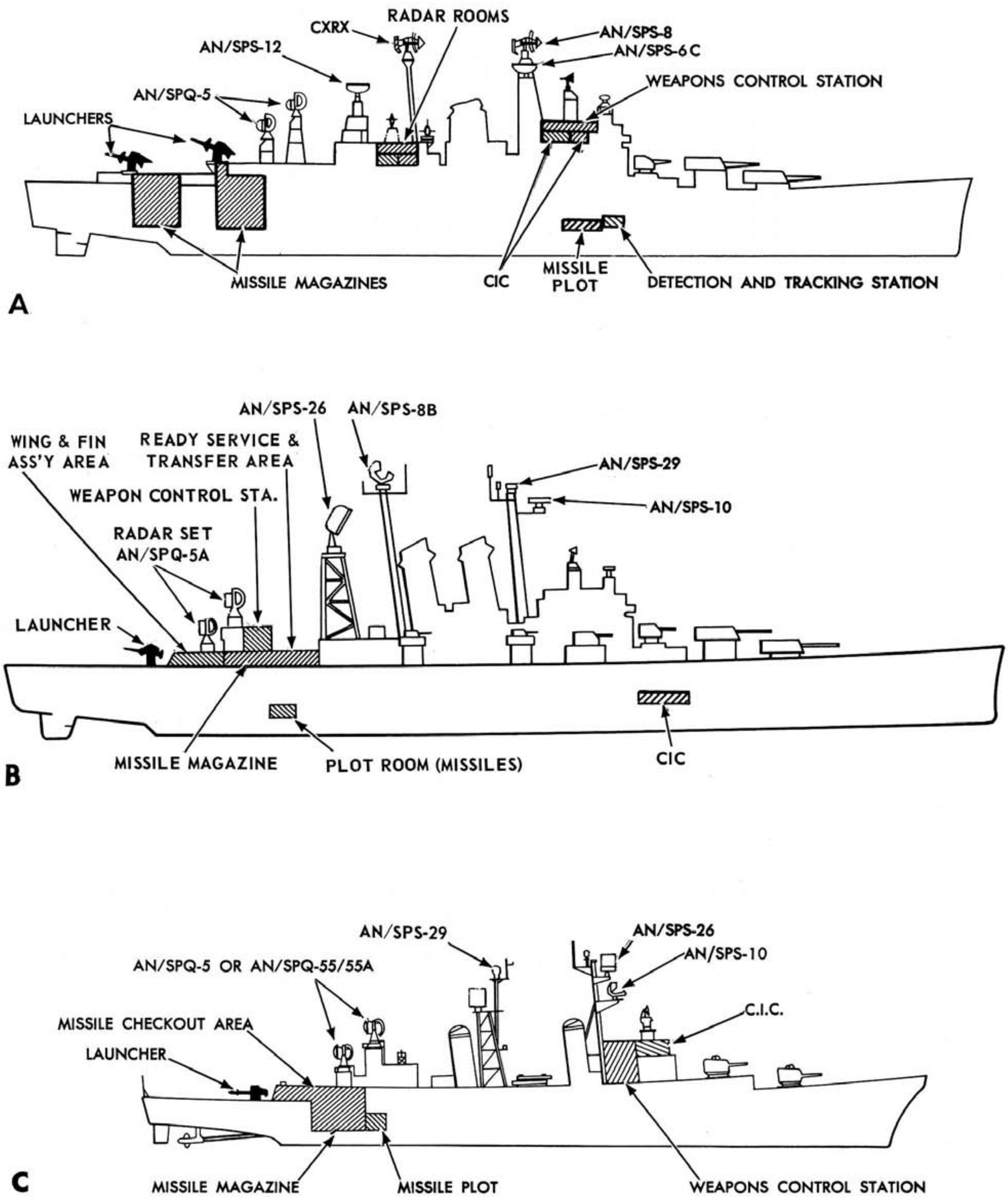


Figure 5-8.—Terrier Missile System Installations: A. On CAG (Terrier); B. On CLG (Terrier); C. On Destroyer Class Ship. 141.4-.6

for the feeder, the launcher, and another panel in the transfer area. These panels provide electric power supplied from the ship's electric power supply.

Hydraulic power is used to rotate the ready service rings: (1) to move the tray shift mechanisms that move the missiles from the trays in the ready service ring to the hoist; (2) to open the magazine doors to permit missiles to pass from the magazine (or return to it); and (3) to operate the hoist mechanism that carries the missile from the ready service ring tray to the loader-rail.

The magazine accumulator power supply system is located on the bulkhead near the ready service ring booster (aft) bearing assembly (fig. 5-4). The four accumulators for the system are located on the ready service ring truss. Separate power supplies are used for each side (A and B). The accumulator system supplies hydraulic fluid for operating the ready service ring drive motor, the tray shift mechanism, the magazine hoist, the load status recorder, and the magazine doors. The accumulator power system consists of the following major components: electric motor, piston pump, supply tank, header tank, control valve block, and accumulators. A conventional B-end hydraulic motor is used. (See Fluid Power, NavPers 16193-B for review of hydraulic motors and valve blocks.) Directional valves control the hydraulic fluid flow so the ready service ring can be turned clockwise or counterclockwise as desired. A power-off brake makes it possible to move the ready service ring manually, which may be necessary during repair.

In the Mk 9 system, hydraulic fluid and power are supplied to the first and second stage rammers, the blast and magazine door mechanisms, and to the rail operating fixtures such as latches and positioning pistons. The launcher power panel Mk 180 contains the circuit breakers, contractors, and overload relays for the launcher power drives. The Feeder Power Panel Mk 183 contains the circuit breakers, contactors, and overload relays for the feeder system motors. They are activated by the launcher captain at the beginning of operations and are then left unmanned. They are located in the after area of the deckhouse.

TRAY-SHIFT MECHANISM. - The ready service ring rotates to bring the selected missile to the loading position at the top, but there must be some means of transferring the missile from the tray that holds it in the ready service ring. This device is the tray-shift mechanism. The tray-shift mechanisms are hydraulic-mechanical devices (fig. 5-9) that shift the weapon and tray as a unit, disengaging the weapon shoes from the ready service ring and engaging them on the hoist. Two tray-shift mechanisms are mounted on each ready service ring, one at each transfer station. Each Terrier has forward and aft shoes by which the booster is secured in the ready service ring. Each tray in the ring has three saddles with two clamp arms that fasten around the missile. When the tray-shift mechanism positions a tray for the hoist, the clamps release by opening the arms. The center and rear saddles have cutouts to receive the forward and aft hoists, respectively.

HOISTS. - The hoist mechanism can transfer a booster or a booster-missile combination (complete round) from the ready service ring trays to the loader rail (or the reverse when unloading). As mentioned above, the forward shoe hoist engages the center saddle and the aft hoist engages the aft saddle on the tray. Power is supplied by a hydraulic drive unit and lower transmission and an upper transmission and drive shaft. As the weapon is raised to the loader, a guide on the aft hoist head contacts the overhead trunk and assures alignment.

MISSILE TRANSFER IN MK 9 SYSTEM. - In the Mk 9 system, with its missiles stored in banks of fixed individual cells, another method must be used to get the missile out of its cell and move it to the assembler. A transfer car which runs athwartship on tracks carries the missile from its cell to the loader (rammer). An extractor beam on the car can be lowered or raised and it can extract a missile round from a cell or return one to it. After extracting the missile round, it deposits it on the overhead loader rail, or it can transfer it to the checkout area for checkout tests. The last named is a semiautomatic operation.

INTER-RING TRANSFER. - If the missile needed is not in the A or B side ready service ring, it is possible to obtain it from the reserve supply. In the Mk 10 Mod 7 system (fig. 5-10), this is in the single lower ready service mechanism. Other Mk 10 mods have two lower ready service rings and the Mk 9 has a rear bank of cells from missiles.

We've mentioned station 1 in discussing the tray-shift mechanism (fig. 5-9). In the upper ready service rings (fig. 5-10), there is a

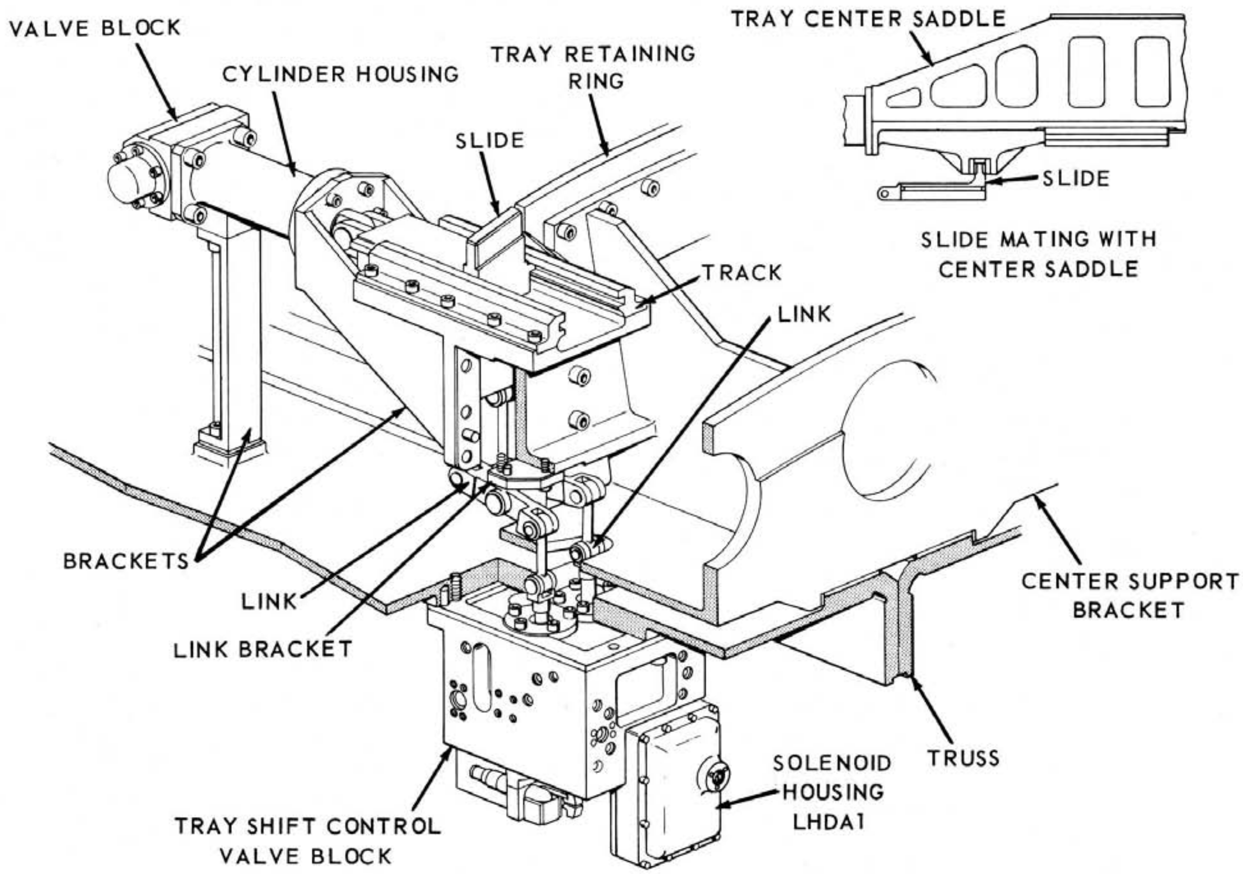


Figure 5-9.—Tray Shift Mechanism At Station 1 on ready service ring.

station 1 on both the A and the B sides, and missiles may be transferred to the loader from those positions. For inter-ring transfer, hoists are positioned to transfer between station 3 on the lower ready service ring and station 13 of the B side upper ready service ring. The other transfer point is between station 19 on the lower ready service ring and station 9 of the A side upper ready service ring.

The Mk 9 system uses the transfer car for this operation.

The Loader Components

The loader consists of duplicate components for the A-side and B-side assemblies. It supports and moves the weapons between the assembly area and the launcher or between the assembly area and the strikedown area. Each loader assembly receives a weapon from the magazine hoist, moves it into position at the assembler, and then moves it onto the launcher. It is also capable of returning individual weapons or adapters (from Asroc) for restowage, or to the strikedown area, where they are tested.

Major components of each loader assembly are the loader trunk assembly and two types of power drives. The loader trunk is made up of several sections; a tilting rail (Mod 8 does not have this), a spanning rail, a blast door, and numerous operational components (fig. 5-11). The tilting rail may be latched in the horizontal position or at an incline. In figure 5-11 it is shown in the horizontal position as it receives the missile from the hoist. It is latched in this position to transfer missiles to the strikedown and checkout area via loader trunk sections I, II, and III. To move the missile to the launcher, the tilting rail is tilted up to meet loader trunk sections VI, VII, and VIII.

The Terrier shoes and the Asroc adapter shoes slide on rail segments bolted to the underside of the trunk sections. A sprocket-driven loader chain travels in the chain track in the

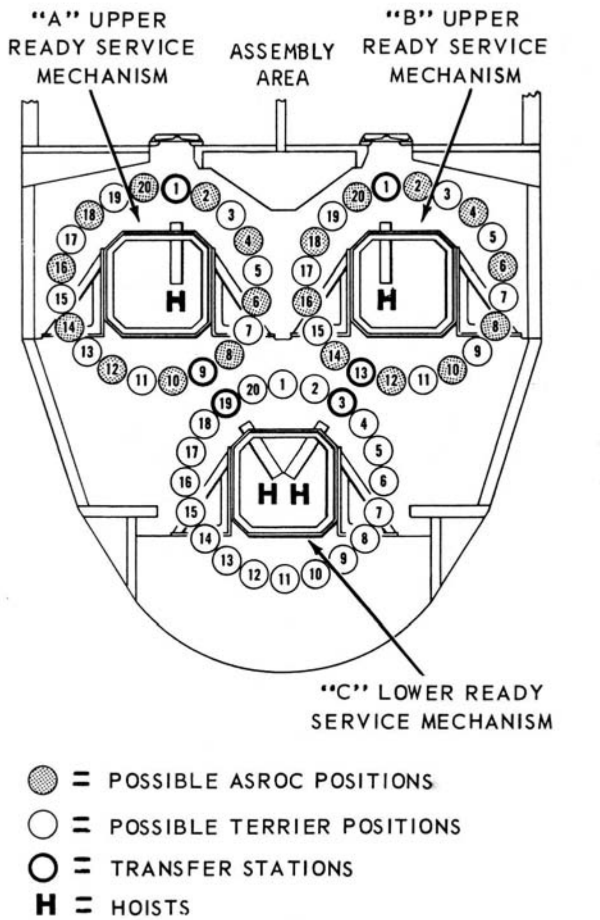


Figure 5-10.—Location of missile transfer stations on Mk 10 Mod 7 ready service rings (cross section of ship's hull).

loader rail. Power is furnished by the CAB- type power drive located in the overhead adjacent to the tilting rail.

LOADER PAWL CONTACTOR. - Missile warmup has been mentioned several times. The pawl contactor (fig. 5-12), a five-prong electrical connector, mates with the warmup contactor pad for Terrier boosters or with the identification contactor pad on the Asroc adapter rail. When the aft shoe of the weapon engages the loader pawl, the contactor is forced onto the booster or adapter rail pad. The five-pronged contactor completes the circuitry to the missile. The loader pawl contactor remains mated until the contactor on the launcher takes over, so the warmup is continuous. Vacuum tubes in the missile must be warmed up to operating temperature, and gyros must reach a stable spinning speed.

SPANNING RAIL. - The spanning rail (fig. 5-11) bridges the gap between the loader rail attached to trunk section No. VIII and the launcher guide arm. It is operated hydraulically. When the blast doors open to permit the assembled weapon to pass onto the launcher, the spanning rail extends to meet the loader rail and provides a continuous path for the missile. After the missile has passed through the blast doors and is on the launcher, the spanning rail retracts and the blast doors close.

All Mk 10 Terrier systems have a spanning rail of this type for each launcher. In the Mk 9 system, the spanning rail is a component of the second stage rammer and bridges the gap between the launcher guide rails and the fixed second stage rammer rail. As the blast doors open, the spanner rail rotates into position and latches to the launcher rails. Although the relative position is different in the Mk 4 system, the operation of the spanner rail is similar to that of other models.

BLAST DOORS. - The blast doors are blast-proof and watertight hinged doors that prevent the entrance of missile blast (when closed) into the feeder compartment. A pair of doors is mounted on the exposed bulkhead between each launcher guide arm (fig. 5-11) and the A- and B-side loaders. The two doors are mechanically coupled to the spanning rail, causing the doors to open when the spanning rail is extended and to close when the spanning rail is retracted. Interlocks prevent opening the doors when there is a missile on the launcher and a condition is set. The position of the blast doors is different in the Mk 4 system, but the purpose is the same and the operation is similar to that of other launching systems.

The second power drive mentioned at the beginning of the section on the loader is the one that operates an accumulator-type power drive. It is located in the strikedown and checkout area. It supplies hydraulic power to operate the spanning rail, the blast doors, the tilting rail, the floating tracks, and the other loader components, such as latches and positioning pistons. The floating track mechanisms are located on the tilting rail to engage the missile shoes, fore and aft. The floating nature of these rail segments assures positive alignment between the loader and the hoist.

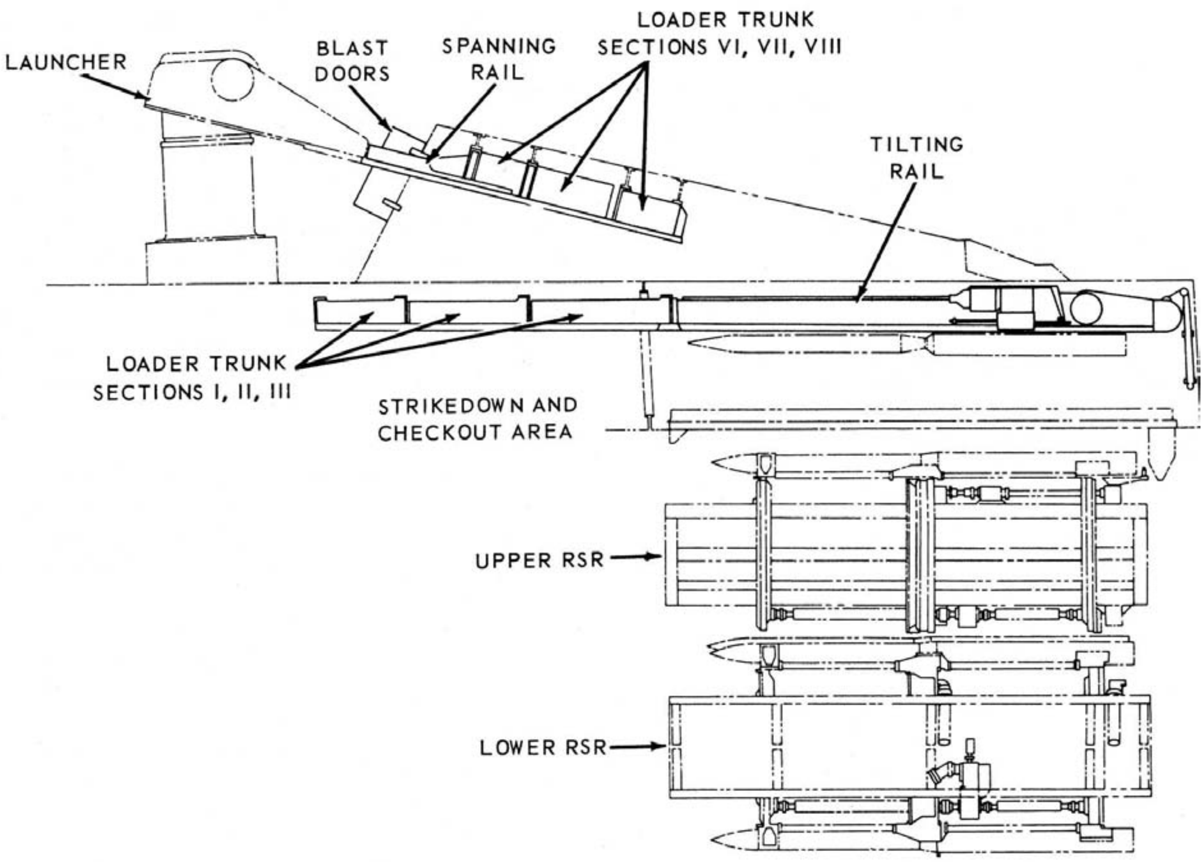


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Figure 5-11.—Loader General Arrangement, Terrier Mk 10 Mod 7 system.

The Assembler and Assembly Area

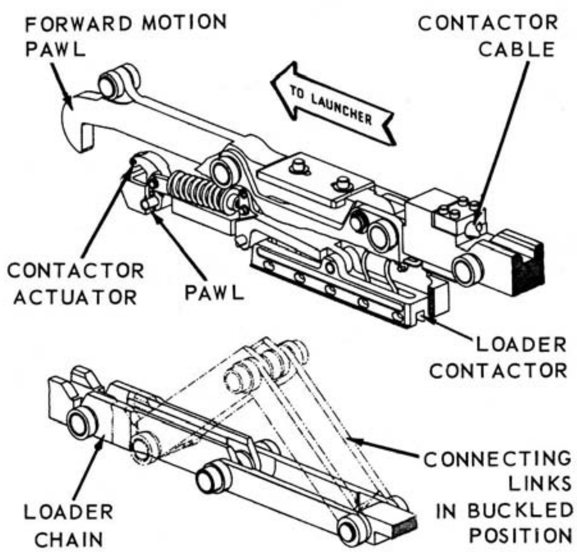
The assembler consists of stowage racks for the wings and fins that are to be assembled to the missile in the assembly- area. The older missiles, the BW type, had to have wings and fins attached, and fourteen assemblymen were required to man the assembly area. Only six men are needed for the BT3 missiles. Figure 5-13 shows the arrangement of the assembly area in the Mk 10 Mod 7 system, which also requires sixteen men, though only six per side (A and B) do the assembly work. It is located directly above the magazine area. Terrier booster fins and Asroc motor fins are stowed in the fin racks, arranged on each side of the loader for easy access. Each man has a safety foot switch which he presses after he has completed his portion of the assembly job and has stepped behind his safety screen. All six assemblymen must have their safety switches depressed before the missile can be moved. If both sides of the launcher are being loaded, simultaneously, there are twelve men, each with a safety switch to depress when he has "finished his work and assumed a safe position. Some foot switches have recently been deleted and twelve men are no longer required in systems with this change.

If the weapon is to be armed, this is done in the assembly area.

If a missile is being returned to the magazine, the removable fins are removed and stowed; the folding fins are folded; and the missile is disarmed in the assembly area before it is allowed to move on to the magazine area.

Strikedown and Checkout Equipment

In the strikedown and checkout area, testing and handling facilities are provided for missile checkout, maintenance, servicing, warhead substitution, and booster or rocket inspection. A checkout car that operates on rails is used when performing tests, checks, and adjustments. The area contains: (1) a guided missile test set (AN/DSM-23), (2) a hydraulic fluid pumping

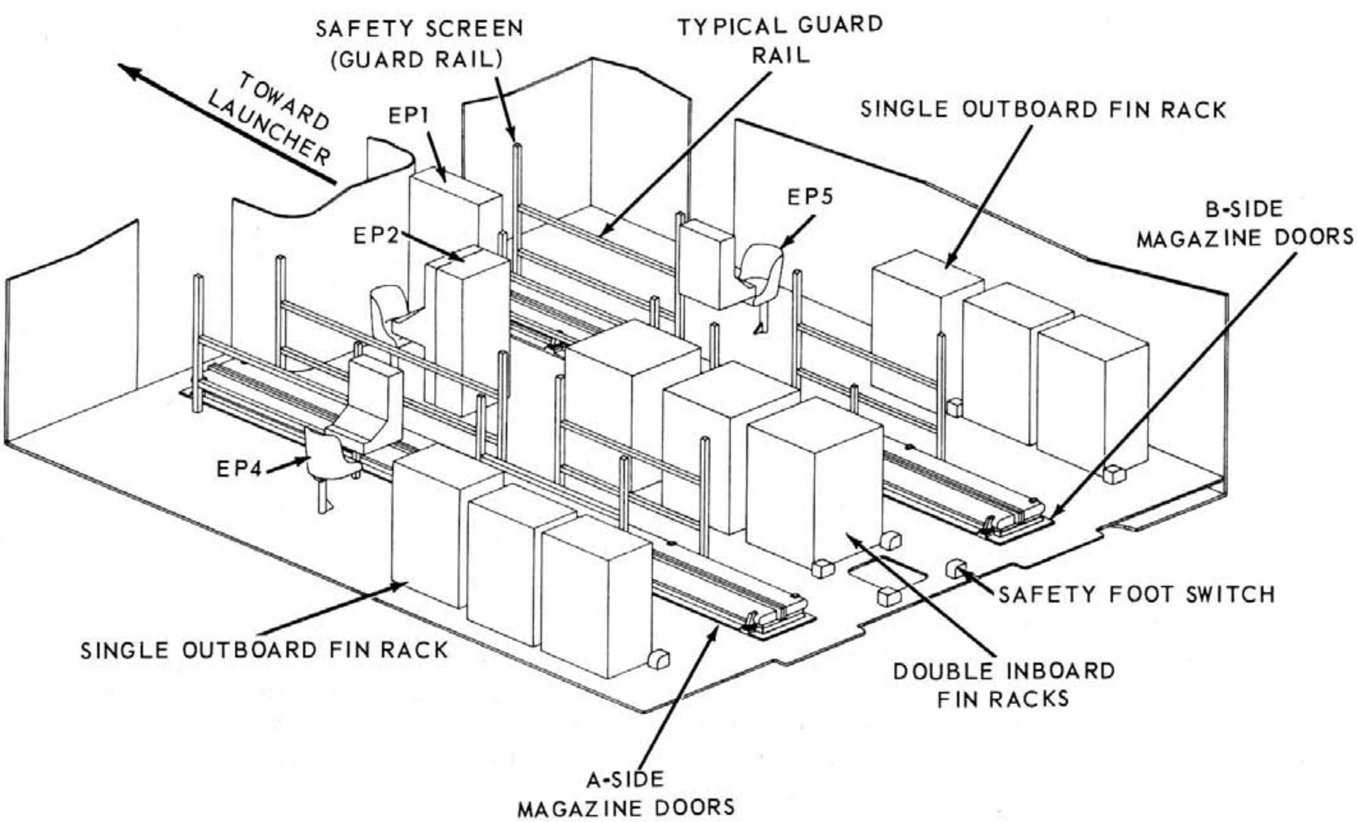


83.166
Figure 5-12.—Loader Chain Pawl Assembly, showing contactor parts.

unit (HD-259/DSM) for filling and flushing the hydraulic system in the missile and for operating the hydraulic system while testing the missile; (3) a compressed air supply; (4) radar test sets; (5) Dynamic Tester Mk 32 and Error Recorder Mk 9, for testing the computing and recording the results; (6) an operations event recorder which is a pen-tape recorder to mark on tape as the missile checkout is conducted; and (7) a photographic recorder which automatically photographs dials of the testers as the missile tests are conducted.

The testing of the missiles is done by other ratings, but you must transfer the missiles to the checkout area, and prepare them for the tests, then return them to the ready service ring. The operator at the control panel follows the step Control procedure to bring the missile to the checkout area. The steps are listed in the proper sequence in the OP for your equipment.

The checkout cars are also used for inter- ring transfer of missiles. Strikedown procedure is used, and the steps listed in sequence in



83.167
Figure 5-13.—Assembler, perspective view.

your OP must be followed. The Asroc is transferred without its adapter, but the tray to which it is transferred must have an adapter in it. Asrocs cannot be loaded in adjacent trays but must always have a Terrier or an empty tray between them. An Asroc with its adapter rail is shown in figure 5-14. When an Asroc is prepared for launching, the adapter is removed from the launcher guide arm after the missile is fired, and is returned to the tray in the magazine. As it is returned through the assembly area, the assemblymen must re-snub the snubbers and check the electrical cable.

THE LAUNCHER

All Mk 4, Mk 9, and Mk 10 launching systems use the Mk 5 launcher, but there are different mods. This means that there are differences but not great differences.

The launcher is a dual-rail mount that receives, aims, and fires single rounds or two- round salvos in accordance with signal orders received from the weapons system. After launching a weapon (or weapons), the launcher automatically returns to its load position, ready to receive the next ordered weapon or to return a weapon to the feeder for stowage. If an Asroc -was fired, the launcher must first return the adapter rail before it is ready to receive another missile. It is only the Mk 10 Mods 7 and 8 that can handle Asroc as well as Terrier missiles. The launcher is Mk 5 Mods 8 and 9. All mods have two guide arms but there are differences in the degrees of train and elevation possible. This is due in part to the location on the ship, for the launcher must never be pointed where a missile could strike any part of the ship.

Components

The main components of the launcher are the stand, carriage, power drive assembly, guide and guide arms, and the train and elevation system. (See figure 5-15.) Each of these is composed of many mechanisms and parts.

STAND. - The stand is a heavy circular steel weldment flange-mounted to the deck of the ship in a fixed position. The stand supports the carriage and the guides.

CARRIAGE. - The carriage is the rotating portion of the launcher. It is mounted within the stand. The electrical, mechanical, and hydraulic equipments for operating the launcher are mounted in it. The two principal parts of the carriage structure are the base ring and the trunnion support. The base ring is bearing mounted in the stand. The bearings permit horizontal movement in train. The trunnion support, a box-like weldment, is secured to the top of the base ring, and is exposed above the stand. Within it is the trunnion tube which supports the guides.

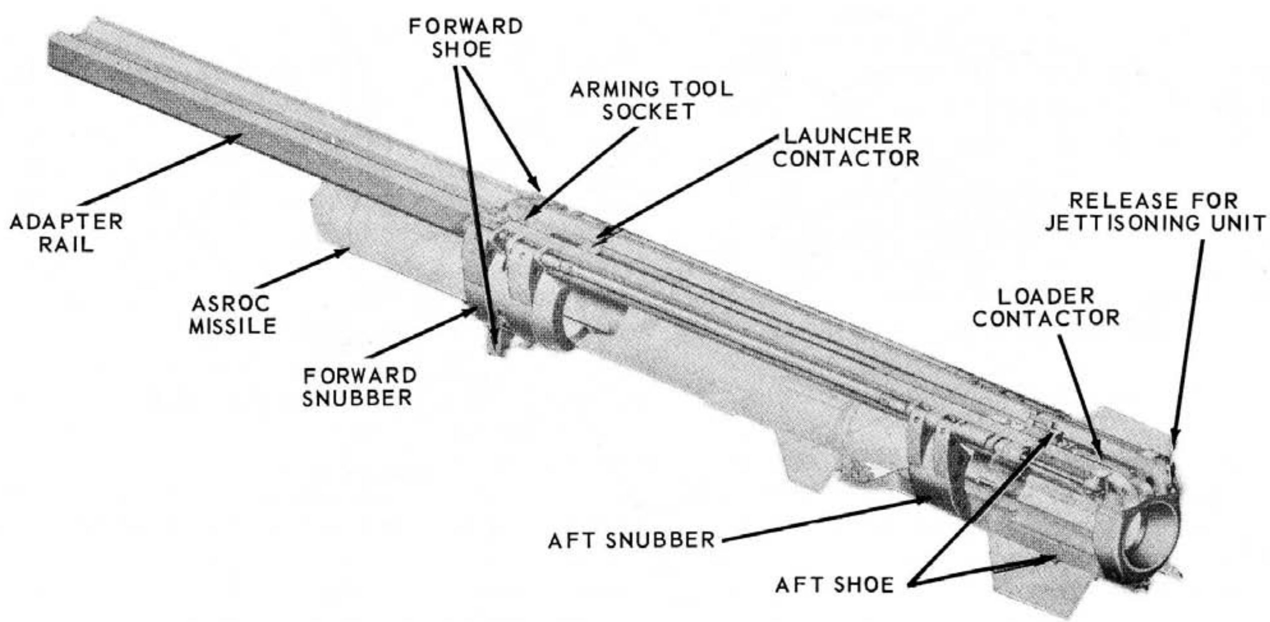


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Figure 5-14.—Asroc adapter for use in Mk 10 Mod 7 launching system.

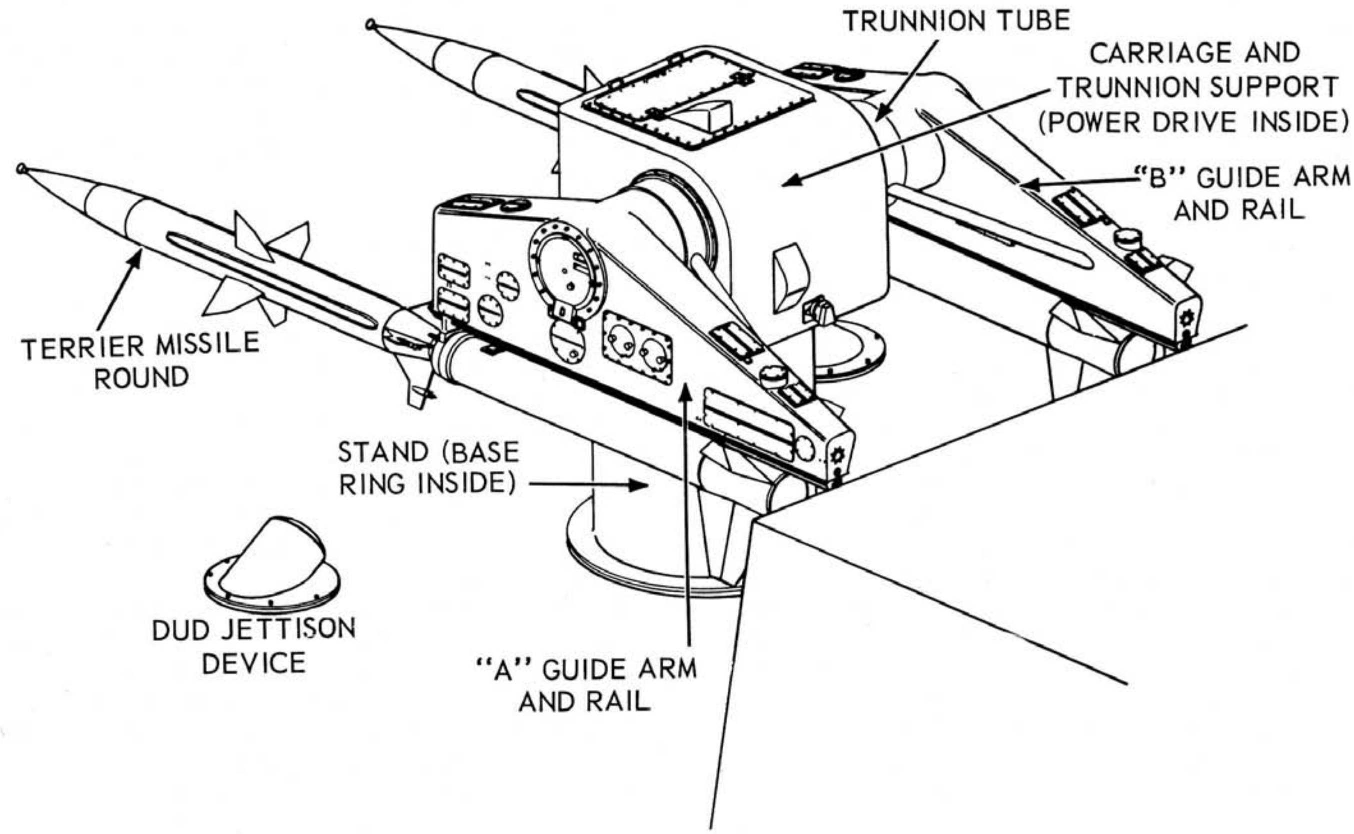

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Figure 5-15.—Guided missile launcher Mk 5 Mod 3, general arrangement.

POWER DRIVE ASSEMBLY. - The power drives for operation of the launcher are mounted inside the carriage. Control orders are fed to the power units from the ship's fire control system.

Power Drive Assembly Mk 46 Mod 1 consists of two separate electric-hydraulic systems. One system operates the train system and the other operates the elevation system. The train and elevation systems position the weapons for firing by rotating the carriage (in train) and the guides (in elevation) as directed by orders from a computer in the Weapons Control Station (remote control).

Each system operates independently, but they synchronize their movements to place the weapon in the desired position for firing. They may be operated locally from an electrical panel at the launcher, but this is only for exercise and test, not for firing.

A third power drive, much smaller than the others with a small electric motor and an accumulator, is mounted in the right-hand corner of the trunnion support and supplies power to the guide arm components that position and retain the weapon on the guide arm, provide external warmup power to the weapon, and arm the booster. An electrical device ignites the booster.

A hand pump is mounted in the left side of the carriage to provide a means of operating the guide arms and the components of the train and elevation latch in case of power failure or during maintenance operations.

GUIDE AND GUIDE ARMS. - The launcher guide consists of two arms, a trunnion tube, a gear segment called the elevating arc, and a buffer actuating arm. The A- and B-guide arms are fastened to opposite ends of the trunnion tube, which is horizontally mounted through the carriage trunnion support.

The elevating arc is fastened to the trunnion tube and is inside the trunnion support. Elevation bearing assemblies located at each end of the trunnion tube allow the elevation movement of the guide arms.

The launcher guide arms are movable in two planes: in the training movement and in the elevating movement. They rotate with the carriage in train, and about the trunnions in elevation. The power is supplied by the train and elevation power drives.

TRAIN AND ELEVATION SYSTEMS. - The train and elevation power drives mentioned above are the main parts of the train and elevation systems. The elevation arc is one comparatively small part of the elevation system. Other parts of this system are the pinion gear (to mesh with the elevation arc), reduction gear assembly, elevation brake, latch, positioning valve, latch- control valve block, elevation and depression buffers, buffer accumulator, firing cutout mechanism, and ventilation power unit. The train system has similar components plus the training circle. The training circle is a heavy gear mounted in the stand. Figure 5-20 shows the training circle for a Talos; for the Terrier, the chief difference is in dimensions.

Each system receives and responds independently to order signals. The principal function of the receiver-regulator and servoamplifier in each unit is to convert electrical order signals into hydraulically powered mechanical movements. These movements control the velocity, acceleration, deceleration, and position of the launcher carriage and the guide arms.

Dud Jettison Unit

A dud jettison unit is associated with each Mk 5 launcher. Its purpose is to rid the ship of a dud missile by tossing it overboard from the launcher without firing the booster. Dud missiles usually are not jettisoned unless there is danger to the ship and personnel.

Dud Jettison Unit Mk 108 Mod 0 consists of two ejectors, mounted to the deck, and a control panel located below the deck near the launcher support, One ejector is located on the starboard side of the launcher and the other on the port side. Figure 5-15 shows the deck appearance of the unit when not in use. Figure 5-16 shows its mounting in cross section and its relation to the launcher when aligned for use.

When it has been determined that a missile must be jettisoned, the launcher is slewed into position to align the defective missile with the dud jettison unit. Launcher control is transferred to the jettison control panel. The ejector is a pneumatic cylinder with a disc designed to engage the after end of the booster nozzle. When the panel operator positions the handle to jettison on the control panel, the missile is pushed from the launcher by a quick thrust of the ejector.

LAUNCHER CONTROL

The launcher is controlled by the following five methods: remote control, local control, dud jettison control, load-order control, and test control. These are also called modes of operation.

Normal operation of the launcher is by remote control from the Weapons Control Station (fig. 5-7), by electrical signal through the control panels there. Remote control is normally used for target tracking and is also the only method used for weapon firing.

A local control station is provided in the launching system for exercise and routine maintenance. This is also called step control because each move in the system is activated by pushing a button on the control panel. Figures 5-3 and 5-13 show the location of a number of the control panels in the launching system. After the EP1 power panel is activated, it is not manned. The launcher captain then stations himself at the EP2 operations panel. During automatic operation, he monitors the panel, quickly reporting anything that seems wrong. In step operation, he pushes the buttons in the required sequence to perform the loading or unloading operation as needed.

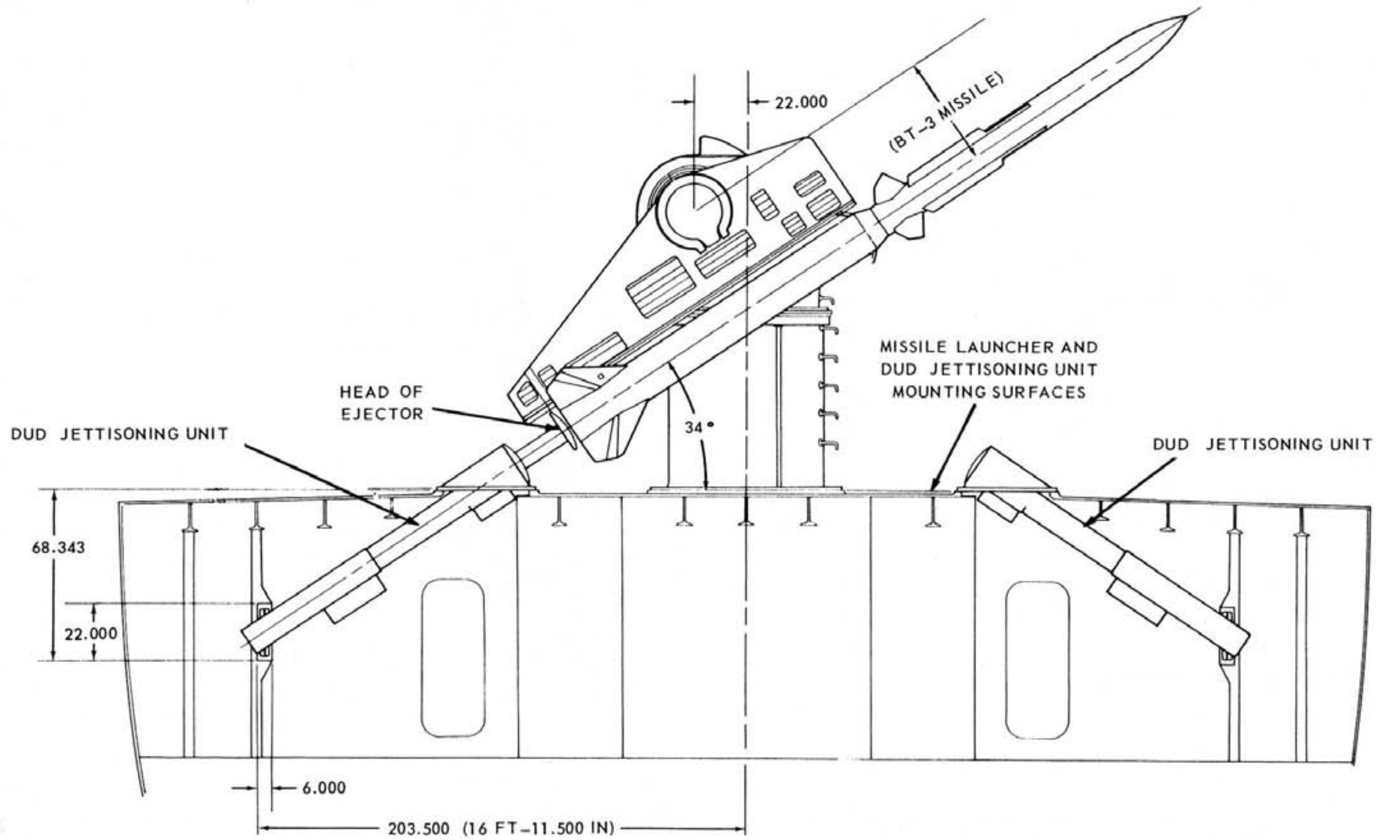
The EP3 panel is primarily the test panel and is not manned during normal launching activities. It can also be used for local control.

EP4 and EP5 panels (A-side and B-side) control assembly, strikedown, checkout, and inter-ring transfer.

Before the dud-jettison panel can be used, it must receive an electrical signal from a preset synchro in the EP 2 panel, which synchronizes the launcher with the dud jettison units.

Load-order control automatically returns the launcher to the "Load" position after the weapons have been fired from both rails. It is provided by means of an electrical signal from a preset synchro in the EP2 panel.

The EP3 panel contains the switches and jack connections necessary to perform tests on the launcher train and elevation systems.

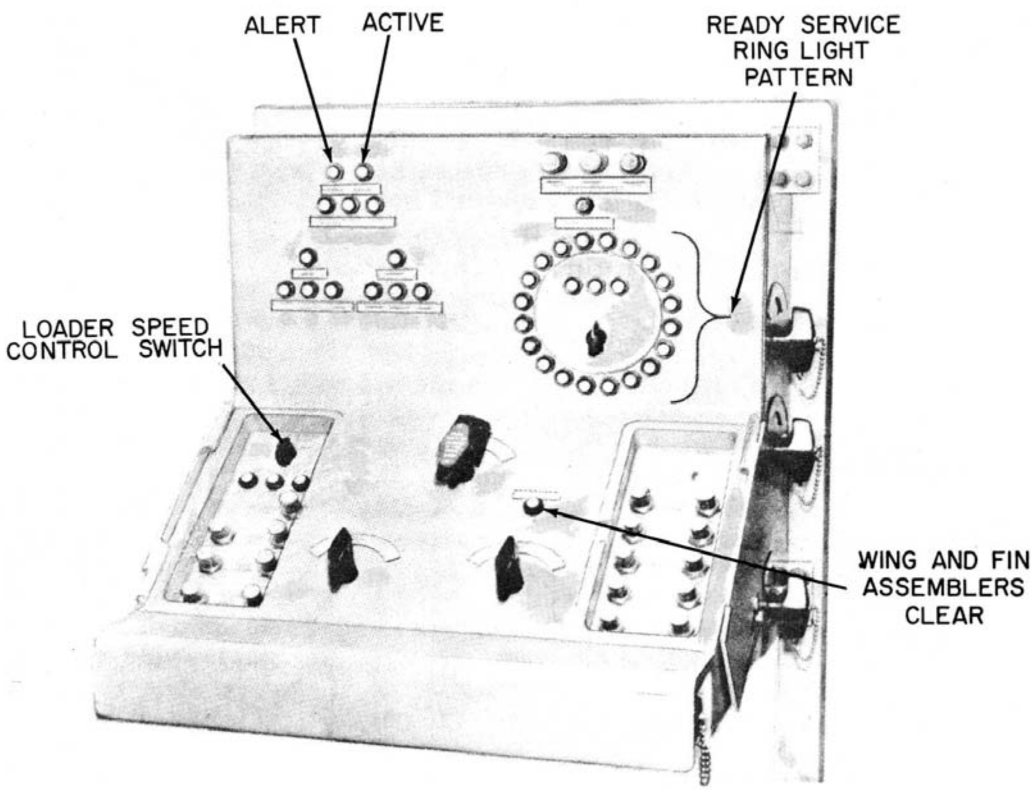


94.22
Figure 5-16.—Dud jettisoning unit Mk 108 mounted for DLG Terrier launching system Mk 10.

Dummy directors, signal generators, oscillographs, and other test equipment may be plugged into the EP3 panel. The test order signals originate in the dummy director. Chapters 13 and 14 describe testing.

Manual control is possible when all other types of operation fail, or for installation, maintenance, and checking purposes. Hydraulic handpumps, handcranks, and air motors are used, and operation of the launching system components is quite slow.

We've talked a good deal about control panels in this chapter. Your quals require you to be familiar with the work at all stations in the launching system which includes control panel stations. Figure 5-17 shows the face of the assembler control panel which is manned by the assembler captain. Each button or lamp is labeled; in automatic control the assembler captain does not operate the panel but watches the lights to see that they light up in proper sequence, so he can notify the launcher captain if anything is not right. When all the assemblymen have completed assembly or disassembly and have depressed their switches, the Wing and Fin Assemblers Clear light goes on indicating that all is clear for the weapon to be moved on to the launcher (or returned to the ready service ring). The ring of 20 lights represents the 20 spaces in the ready service ring. The lights are color coded to indicate the type of missile assigned to each station in the ready service ring. On the Mk 10 Mods 7 and 8 Launching System there is a second ring of light to represent the lower service ring, but those lights do not go on unless there is inter-ring transfer of weapons. In local control or step operation, the assembly captain



83.170
Figure 5-17.—EP4 (EP5) Assembly Panel.

must have before him the step-by-step instructions for operation of the assembler panel. These are in the OP for the equipment and should also be posted beside the panel.

The assembly panel shown in figure 5-17 is a combination strikedown, checkout, and assembly captain's control panel. EP4 is the A-side panel, and EP5 is the B-side panel, identical except for switch and light designations.

LAUNCHING SYSTEM OPERATION

As modes of operation, automatic control and step control have been mentioned several times. With the Mk 10 Mods 7 and 8 launching systems, we also have to consider the Asroc mode of operation and the Terrier mode.

Load Orders

Which mode of operation is to be used and which weapon is to be loaded must be decided before any launching system operation is undertaken. Load orders of the following types may be transmitted from the weapons control station:

1. Missile order-type of round(s) to be loaded.
2. Load select - simultaneous operation of A and B sides, or separate operation of either A or B side.
3. Loading order - hold, single, or continuous loading of the type of missile ordered.
4. Unloading order - unload launcher or unload assembly area.

If the load order (item 3) is for "single", the launching system proceeds to load one missile and then stop until further orders are received. If the order is for "continuous", the system automatically continues to bring up missiles of the type ordered for the launcher, each time the empty loader pawl returns to the load position in the assembly area. If both A and B sides are to be loaded, both sides proceed to load their launcher.

Sequence of Operation in Automatic Mode

At the sounding of General Quarters, the launching system captain activates the EP1 power panel, takes his station at the EP2 panel, sets it up for" step" operation, starts all motors, and then turns his ready switch to "Standby." This indicates to the EP4 and EP5 assembly captains and to the weapons control station that the launching system is activated and is at standby.

When the alert signal is given by the weapons control station, the" Alert" signal light flashes on the EP2, EP4, and EP5 panels, and an audible alert signal sounds.

The launching system and assembly captains signal the weapons control station when their crews are ready. The weapons control station signals what type of weapons are to be loaded, and the missile order signal lights on the EP2 panel.

ASROC MODE OF OPERATION. - If the signal is for an Asroc weapon (Mods 7 and 8 can handle Asroc), the launcher captain checks to be sure everything is clear and that there are no missiles outside the magazine. Then he presses the ASROC MODE button on his panel, which automatically switches the launching system. When the ASROC MOD E light becomes steady, the switching is completed and the launcher captain can press the LOAD button. Only one side can be used for Asroc loading and loading cannot be continuous. After a missile leaves the launcher, the adapter must be returned to the magazine. While the adapter is in the assembly area on its way back to the magazine, the fin assemblymen must close the snubbers and make sure that the umbilical cable is clear. The hoist then returns the adapter to its tray in the ready service ring of the magazine.

If another Asroc missile is wanted, another order is signaled from the weapons control station.

TERRIER MODE OF OPERATION. - On Mods 7 and 8, the launcher captain must switch to the Terrier mode after he has received the signal from the weapons control station that a Terrier missile is to be loaded. All other Mods handle only the Terrier, so this switching step is not necessary. Assuming that the system is activated and on Automatic, pushing the LOAD button starts the loading operation. The ready service ring rotates to bring the designated missile to the hoist station. Then the tray holding the round shifts to engage the booster shoes on the hoist. Simultaneously, the magazine door opens. The hoist raises the round to the loader rail. At this point the warmup contactor on the missile booster engages the electrical connector on the loader chain pawl and warmup power flows to the booster. The loader chain moves the round off the hoist and onto the loader rail, or tilting rail, which moves it to the assembly area. As soon as the hoist is free of the round, it lowers, the tray shifts back to its place in the ready service ring, and the magazine doors close. The ready service ring rotates to place another round at the no. 1 hoist station.

In the assembly area the crewmen attach the booster fins, erect the missile wings, then take safe positions and operate the safety foot switches. As soon as the assembler captain sees (on his control panel) that all the switches are closed, he positions his assembly ready switch to ASSEMBLED and the tilting rail can move on with the assembled round. As soon as the tilting rail elevates, the blast doors open, the spanning rail extends and the loader moves the Terrier onto the launcher rail. The loader chain pawl and its warmup connector disengage and retract from the round before the blast doors close.

The round is rammed onto the launcher where it is positioned and retained by the launcher positioning mechanism. Warmup power is applied through the launcher-booster electrical contactor. The arming tool extends. The train and elevation latches retract. As soon as the order is received from the weapons control station, the launcher synchronizes to the director signal, moving in train and elevation until the missile is pointed where ordered.

With a firing rate of approximately two rounds per minute, you can see that all the actions must take place very rapidly and in measured time sequences. If the wing and fin assemblymen, for example, were too slow in doing their work, it would disrupt the loading sequence. The next missile would have to be held at the no 1 station in the ready service ring until the way was cleared.

TALOS LAUNCHING SYSTEM

The Guided Missile Launching System Mk 12 is designed to stow and to launch all types of Talos missiles. The Mk 12 is made up of three major groups of equipment. Figure 5-1A shows a cutaway view of the Mk 12. You can see in a general way the three equipment groups and their physical location in relation to each other. The names of these groups are:

1. Guided Missile Launcher Mk 7. It serves as a launching platform for the Talos weapon. The launcher has two launcher guide arms which can be trained and elevated to point the missile at a capture beam.
2. Guided Missile Feeder Mk 11. This group of equipments provides for weapon stowage, for missile warmup, and for loading the weapons on the launcher.
3. Missile Launching System Control Mk 10. This group of units includes consoles and electrical devices and circuits to control and to monitor system operations. Now we shall take up each of these major equipment groups and explain what they do. We will use the Mk 12 GMLS to illustrate how they do it.

MISSILE LAUNCHER Mk 7

The Mk 7 launcher (fig. 5-18) is designed for installation aboard Talos missile ships. It is an automatically loaded, remotely controlled, dual-arm launcher which provides a launching platform for all types of Talos missiles. 1 We can consider the structure of the Mk 7 launcher as being made up of three major components:

1. A launcher stand which is a stationary structure.
2. A carriage which rotates (trains).
3. A launcher guide which also rotates (elevates).

The stand is a round metal structure which is fixed to the deck and forms a permanent foundation for the launcher. The carriage, which is bearing mounted on top of the stand, is capable

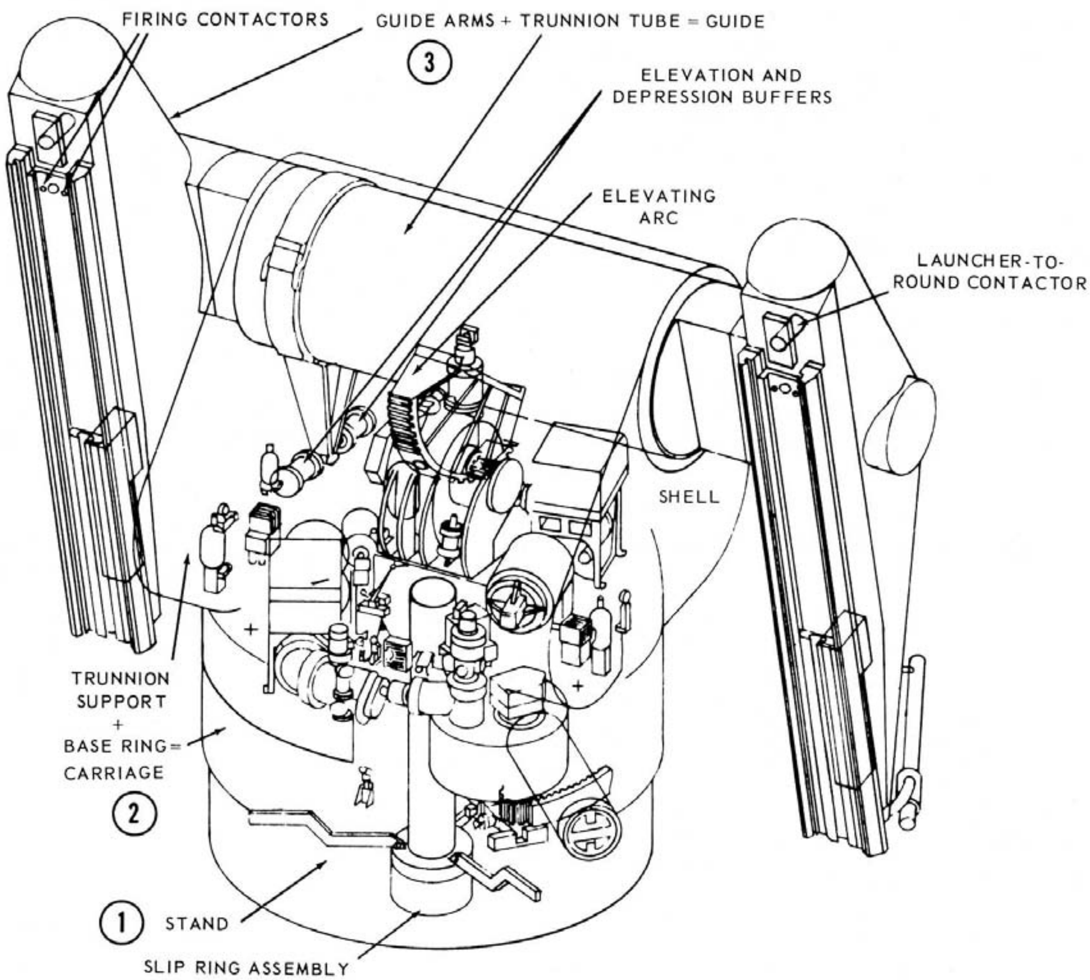


Figure 5-18.—Main parts of the Talos launcher (Mk 7).

of unlimited train. Electric, hydraulic, and mechanical gearing devices used to rotate the carriage are mounted directly within it. The carriage itself is composed of a base ring section and a trunnion support section.

The major components of the launcher guide are the trunnion tube and the guide arms. These components form an H-shaped assembly. The trunnion tube is a shaft that is common to both arms and extends through the trunnion's support. The trunnion support is bearing mounted to the carriage. Rotation of the trunnion tube elevates and depresses the guide arms as the elevating arc moves up or down. Electric, hydraulic, and mechanical devices necessary for rotating the trunnion tube are housed within the launcher carriage.

Again consider the carriage. It houses the power drives for operation of the launcher. Control orders are fed to the power drives from a selected fire control computer. When the launcher is loaded and assigned to a fire control system, it is controlled by orders from a remotely located missile fire control computer. When the launcher is released or when both rails are empty, launcher control is transferred from remote control to fixed load order signals from load control transmitters in the launching system. Under control of these fixed signals, the launcher returns to and latches in the load position.

The train and elevation systems are electric-hydraulic power drives. The train system (fig. 5-19) rotates the launcher carriage; the elevation system (fig 5-19) rotates the launcher guide. These systems operate independently but simultaneously for synchronized operation of the launcher.

Components of the launcher guide prepare the missiles for flight, and arm and ignite the booster. The guide power drive operates the guide components. It is an accumulator type of hydraulic unit that operates the arming devices, the warmup contactors, the aft motion latches, and the emergency igniter injectors. The booster, as you learned in chapter 3, is ignited electrically.

The launcher guide components function independently of the train and elevation systems but are interlocked with them to ensure proper loading and safety during firing.

The launcher functions as part of the guided missile launching system and also as a part of the fire control system. When empty, the launcher aligns with its feeder system and is loaded. When loaded, the launcher is isolated from its feeder and is under the control of the missile fire control computer (remote operation).

As the launcher follows a remote signal, its missiles receive external warmup power to prepare them for flight. When firing is ordered (upon closing the firing key) and all conditions (safety and missile functions) are satisfied, the booster is armed, the warmup contactor and the arming tool are retracted, and the weapon is fired by electrically igniting the booster.

In salvo firing, two weapons are fired from the launcher with a short time interval between firings. Only the S-type Talos weapons can be fired in salvos. Nuclear tipped (W) missiles are fired singly.

A weapon, as loaded onto the launcher, consists of a mated missile and booster with wings and fins installed (and missile arming devices if necessary): it is in a ready-for-firing condition.

Stand

The stand (fig. 5-20) supports the carriage and guide. (The carriage and guide, when considered as a complete unit, are called the rotating structure.) The stand is a fixed round steel structure attached to the ship's deck. The carriage, together with the guide, is free to rotate on the stand.

A large ring-shaped internal gear is mounted inside the stand. This gear has many names. Some of these are: training circle, training rack, and train circle gear. A pinion gear engages the teeth of the training circle, so that when the pinion gear turns, it trains the carriage and thus the guide. Bearing assemblies are mounted in the stand to support the rotating structure and to reduce friction between the stand and carriage.

Figure 5-20 shows the major subassemblies of the launcher stand. A drilled flange on the inside bottom of the stand is used to bolt it to the ship's deck. (You won't see the drilled holes in the illustration because the photograph was taken before any holes were drilled.) Now locate the upper thrust bearing assembly, sometimes called the main thrust bearing. The carriage assembly sits on top of this assembly. You can see that the entire weight of the carriage and guide rests on the upper thrust bearing assembly. At this point you may be wondering what keeps the launcher from leaving the stand if vertical movement of the ship pushes up on the bottom of the carriage, tending to push it off of the stand. Figure 5-21 gives us a better view of the train bearing assembly and the method used to oppose a

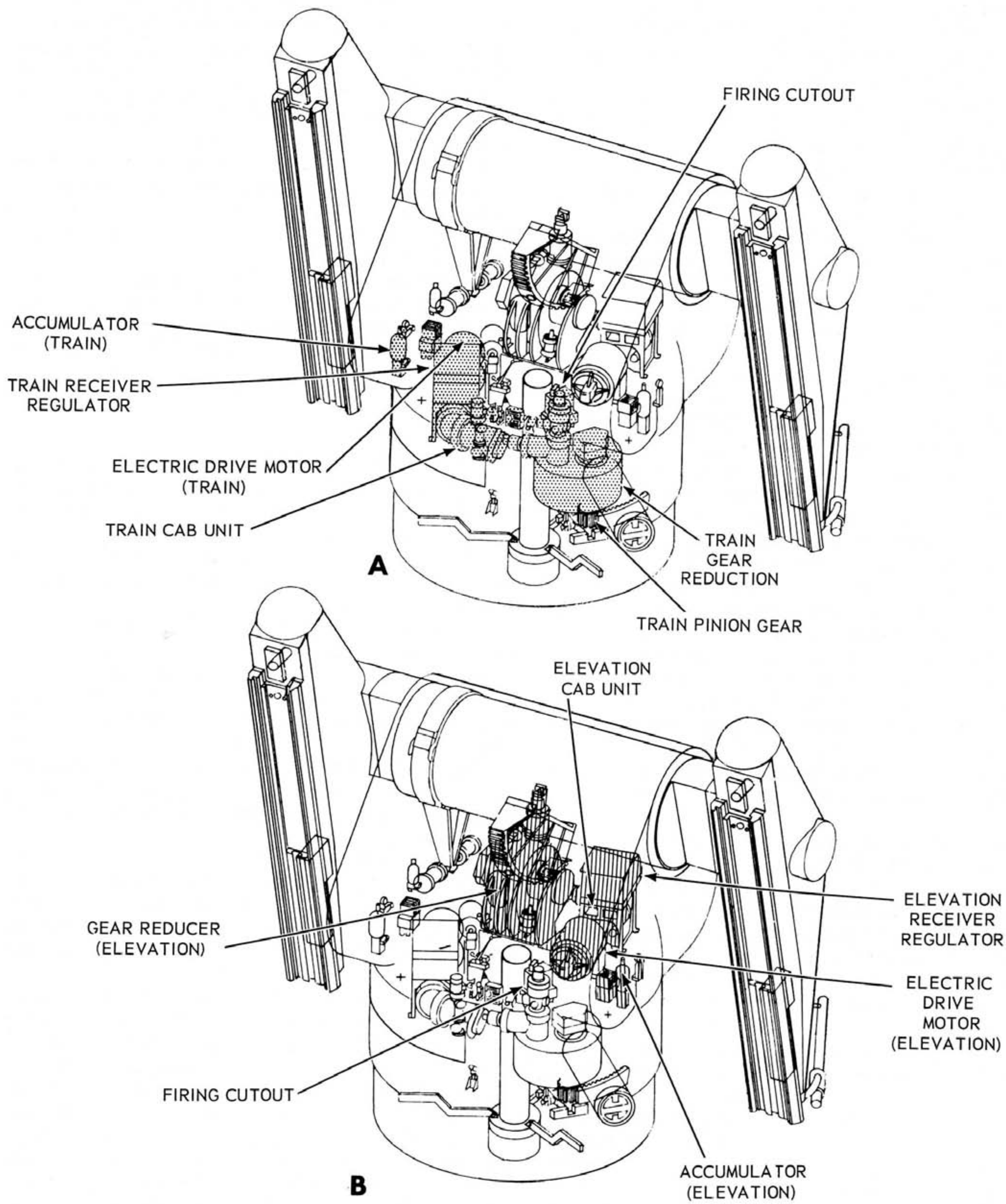


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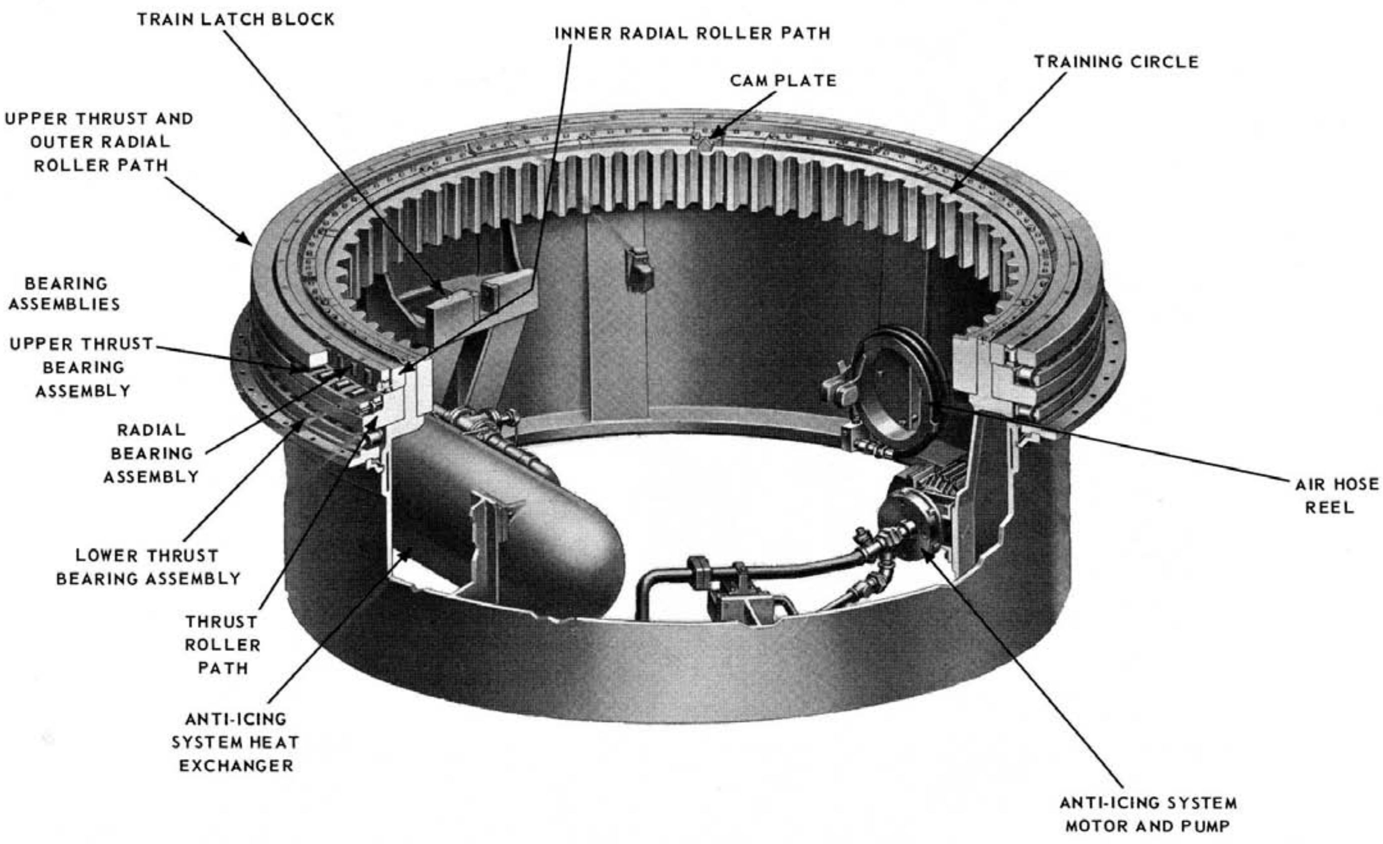
Figure 5-19.—A. Launcher train system. B. Launcher elevation system.

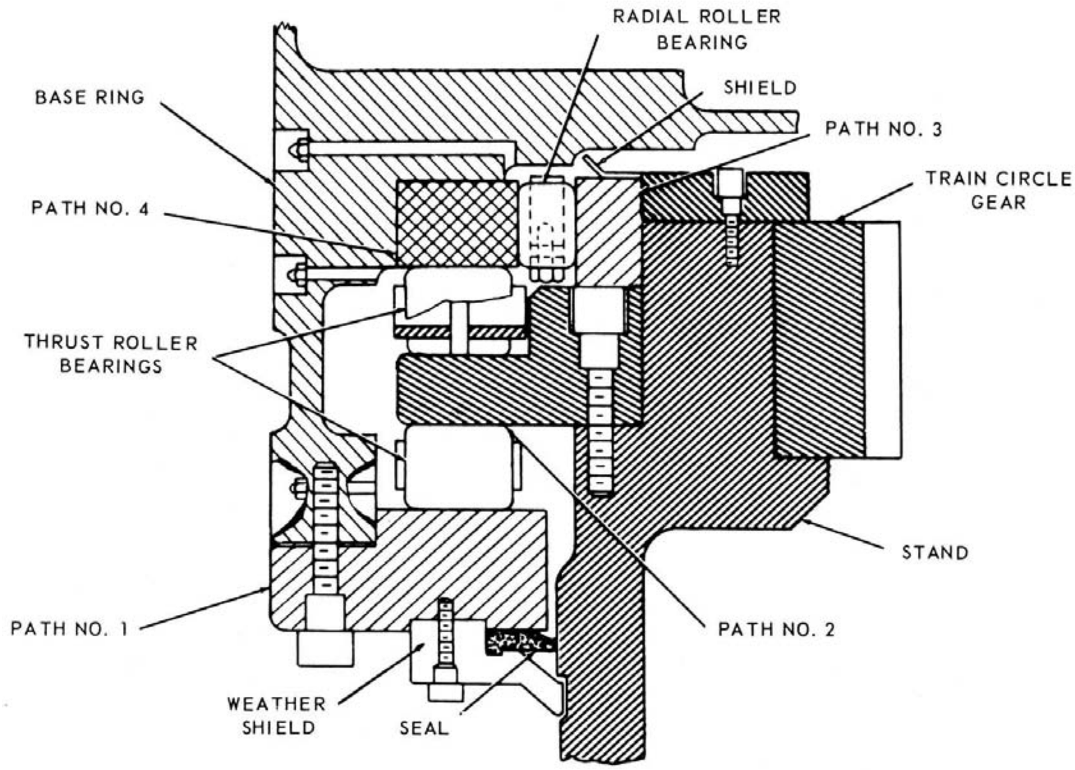


83.41
Figure 5-20.—The launcher stand and its main parts.

vertical upward thrust (force) on the base of the carriage. Essentially, the way this is prevented is to connect the carriage to the stand through a lower thrust bearing assembly. This arrangement also reduces frictional forces as the carriage is trained. The upper and lower bearing assemblies pretty well restrain the rotating structure in the vertical direction. But what about in a lateral or horizontal direction? The radial bearing assembly takes care of this problem. This assembly prevents lateral movement between the carriage and stand, and also decreases frictional forces between the carriage and stand.

Now look at figure 5-21 again. The big gear with teeth on its inside face is the training circle. This gear is classed as an involute gear, an internal ring gear, or an internal spur gear. A small pinion gear meshes with the training circle. The pinion gear is part of the carriage, and is driven by the train power drive. As the power drive motor rotates in response to an electrical order from the computer to move the launcher, the pinion gear rotates and walks around the ring gear, carrying the rotating structure (carriage and guide) With it. Look back at figure 5-19 and you can see how the pinion gear meshes with the training circle.

The weather shield and seal (Fig. 5-21) prevent water or spray from getting into the bearing assemblies. The shield is metal, and the seal is synthetic rubber. Both are attached to the carriage. The shield supports the seal and keeps it pressed against a smooth surface on the stand. The shield and seal form continuous rings which rotate as the carriage turns. Notice that the shield fits into a groove cut in the outside of the stand. Most of the water or spray will be kept out of the bearing assemblies by the shield; the seal is designed to stop the rest. But don't count on this; seals wear out or tear, and must be replaced periodically. All launcher stands, regardless of Mark or Mod, have the same component assemblies we have covered here. It is true



83.42
Figure 5-21.—Sectional view of train bearing assembly (launcher stand).

that these assemblies are different in construction in various stands, but their function remains the same. Gun mounts are placed on the same type of stand; in fact, some missile installations have made use of the already emplaced stand formerly used for a gun. The anti-icing units shown in figure 5-20 have pipes that extend to the blast doors up on the deck at the launcher, through various internal passages in the launcher, and to emergency igniter units. All launchers that are exposed on the deck have anti-icing systems so they will be ice-free and operable in the most severe weather.

Carriage Assembly

The carriage (see fig. 5-22) is the part of the launcher that trains. As we said before, the missiles must be aimed before they are fired. This means the launcher guide must be trained and elevated to point the missiles in the right direction. Since the carriage is trainable, it meets the first aiming requirement. Later you will see how the missiles are pointed in elevation by the guide.

The carriage consists of two basic parts: the base ring, and the trunnion support. The base ring makes up the lower part of the carriage. The trunnion support fits on top of the base ring. The stand and carriage are joined together by the base ring, and the base ring sits on the stand.

The trunnion support holds up the guide. A long hollow tube (trunnion tube) is supported in bearing assemblies of the trunnion support so that the tube can be elevated and depressed. Attached to each end of the tube is a guide arm. As the tube is rotated, the guide arms follow this motion. The inside surfaces of the carriage provide mountings for other launcher components. The shell of the trunnion support protects units in the carriage assembly from the weather.

Guide Assembly

The guide assembly (fig. 5-23) provides the platform from which the missile is launched. It consists of four major parts: trunnion tube, two guide arms, and the guide power drive. The trunnion tube is mounted in bearings. A guide arm is attached to each end of the trunnion tube. An elevating arc is located at the center of the

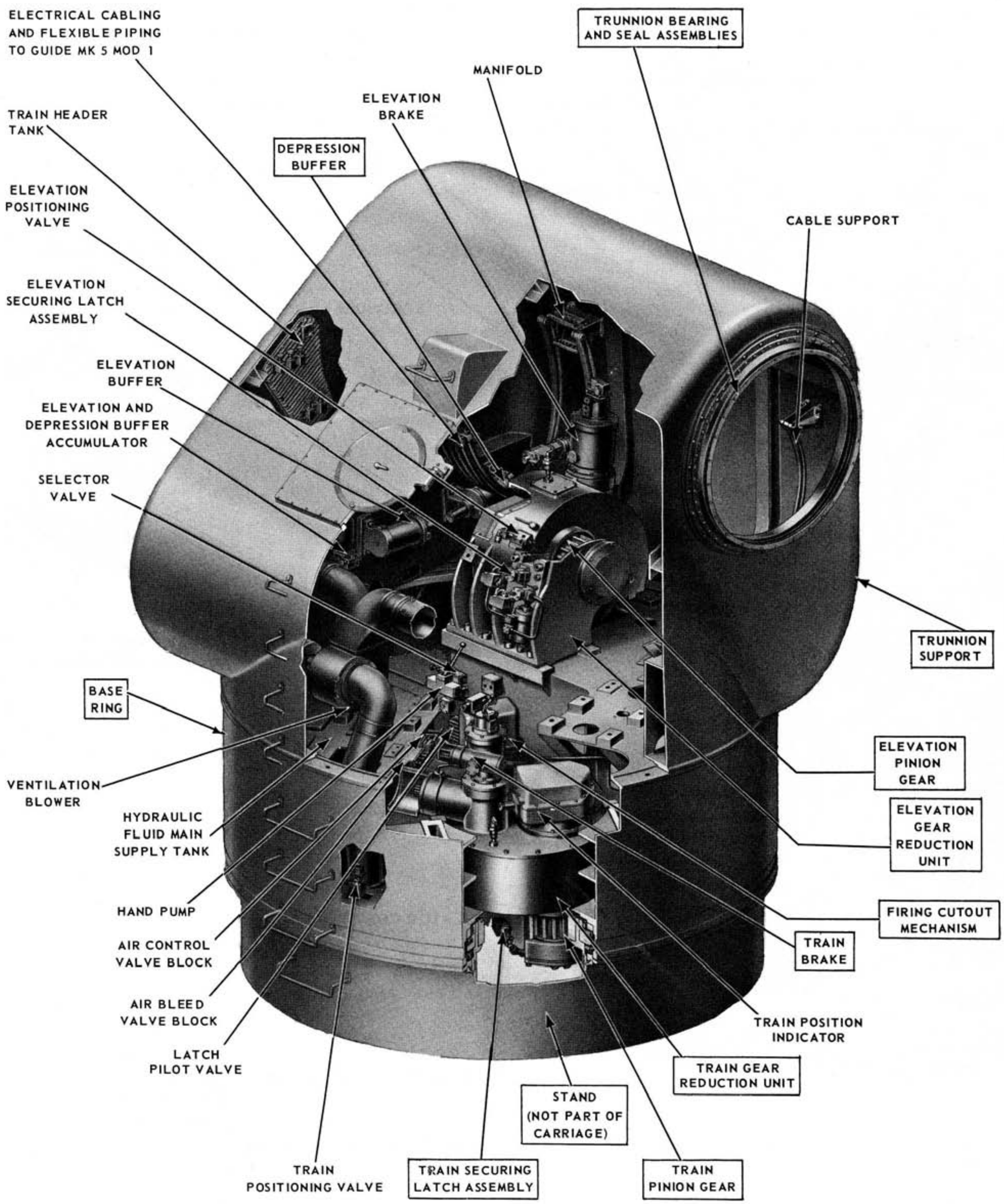


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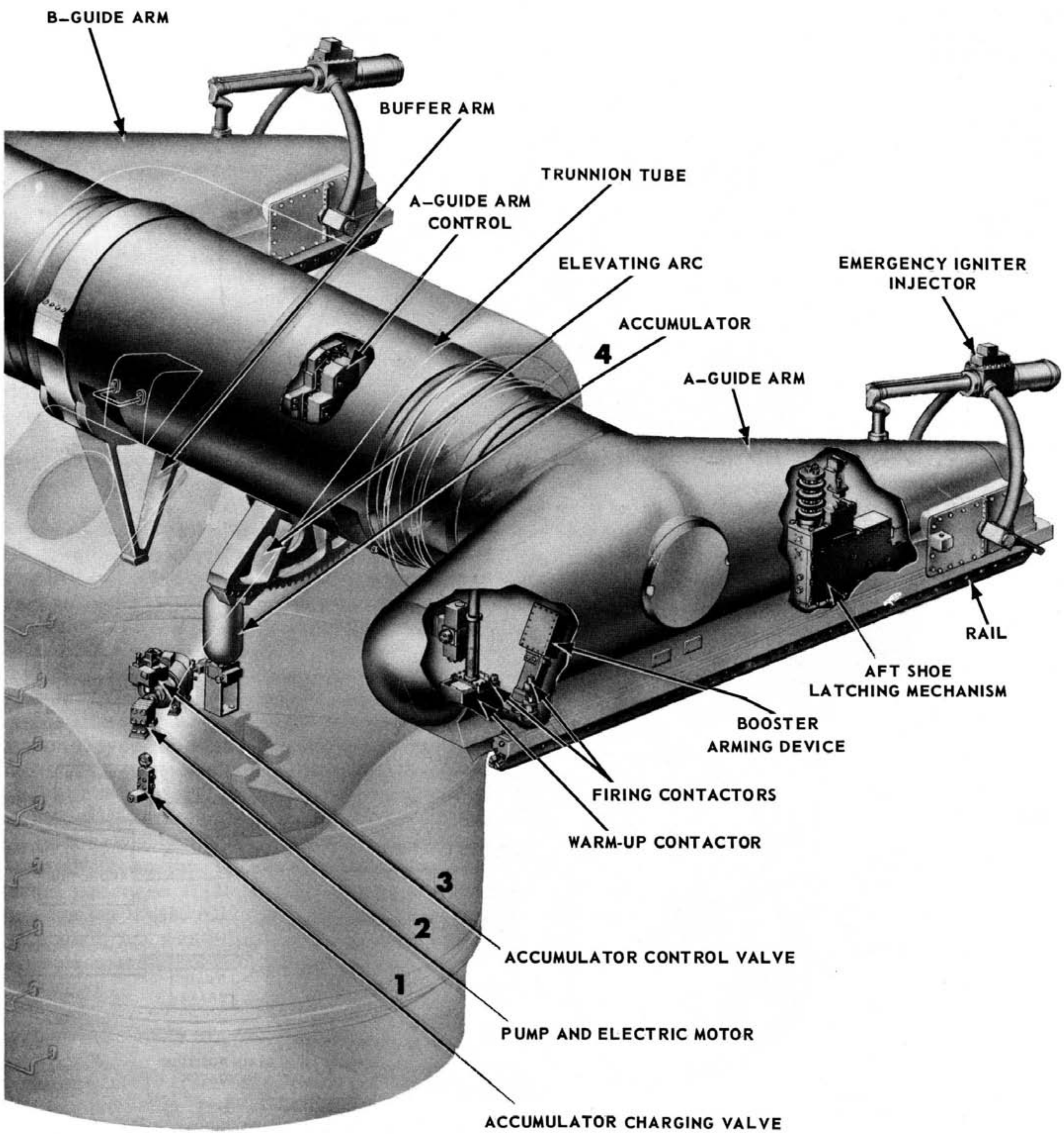
Figure 5-22.—Carriage assembly for Talos missile system.



83.44
Figure 5-23.—Major parts of the guide, Talos missile system.

tube. The arc is driven by the elevation power drive through a pinion gear which meshes with the teeth in the elevating arc.

GUIDE ARMS. - The guide arms are similar structures, so we will talk about only the A-arm. But what we say pertains to the B-arm also.

The bottom of the arm is flat, and contains the rails. The weapons are suspended from the rails by shoes on the booster. At launch the rails provide guidance for a short distance.

The main operating (moving) parts of the guide arm (fig. 5-24) are:

1. Guide arm control (not shown in figure 5-24).
2. Aft shoe latching mechanism.
3. Warmup contactor.
4. Firing squib contactors.
5. Arming device.
6. Emergency igniter injector.

Guide Arm Control. - This is an electro-hydraulic assembly that controls the operation of the arming device, warmup contactor, and aft shoe latching mechanism. The emergency igniter injector has its own control assembly.

Aft Shoe Latching Mechanism. - The aft shoe latching mechanism (see the simplified diagram in fig. 5-25 is located at the aft end of the guide arm. The latching mechanism positions and retains the weapon on the guide arm by the aft booster shoe. The latching mechanism consists of two major parts: a forward motion restraining latch, and a reverse motion latch. The two latches simply pinch the aft booster shoe between them. The forward motion latch prevents the missile from moving forward until it is ready for launching. The reverse motion latch prevents the missile from falling off the rear of the launcher. During firing, the forward motion latch holds back the missile booster combination until the booster has developed enough thrust to overcome the restraining force of the latch. When this happens, the latch buckles (trips) and the weapon leaves the guide arm.

Other missile systems use the same type of mechanism for the same purpose.

Warmup Contactor. - Another component of the launcher guide arm, called the warmup contactor, prepares the missiles for flight. This device is located in the front of the guide arm. The expression "prepares the missile for flight" is very general; so we will explain it. Most Navy surface-to-air missiles contain some vacuum tubes. As you know, it takes time for vacuum tubes to heat up and to reach the temperature at which their operation becomes stable. To illustrate, it takes your home vacuum tube radio or TV set 20 or more seconds to warm up after you turn it on. Of course, a transistor set is in operating condition almost immediately after it is turned on. But RIMs are not completely transistorized, and they will have at least a few filament type tubes which require a warmup period.

Warmup power is also required for gyros. All Navy RIMs have gyros. These units must have their rotor wheels spinning at a specified number of revolutions per second to be effective. Otherwise the gyros will provide inaccurate

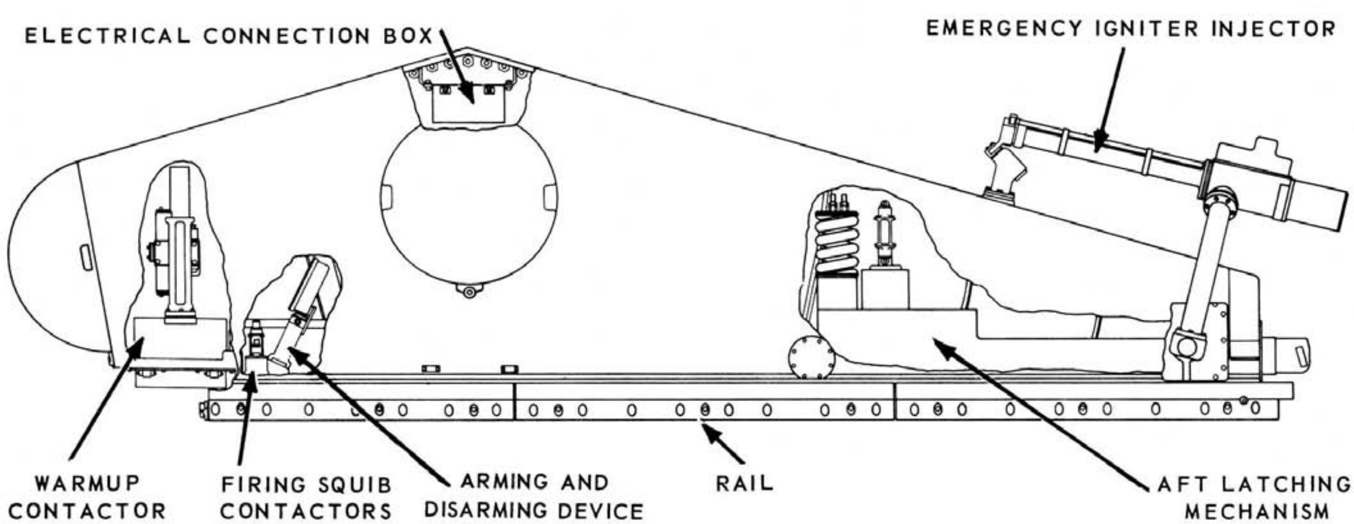


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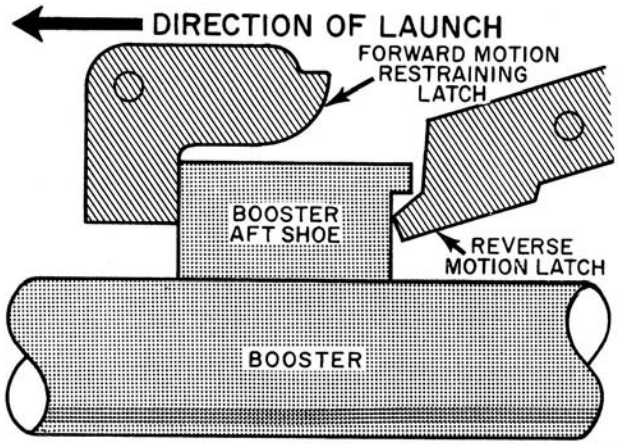
Figure 5-24.—Launcher guide arm, A-side, Talos missile system.



83.46
Figure 5-25.—Simplified diagram of the aft shoe latching mechanism.

references or information. If the gyro wheels are not spinning fast enough, the rotors will wobble.

The warmup voltage is supplied from a source outside the missile because we don't want to use up the power source inside the missile. The missile internal power supply is limited as to how long it will furnish power, and it would be foolish to use up any of its energy before flight.

Now back to the contactor. It applies external warmup electrical power to the missile while the missile is supported on the launcher guide arm. The contactor can be extended and retracted. When it is extended, a series of points on the contactor fit into a pad on the top rear of the missile. Current then flows through the contactor-missile connection to the missile electronic and gyro components.

The warmup contactor also provides an umbilical connection to pass information back and forth between the missile and the weapon control system.

Warmup contactors were mentioned several times in the discussion of the Terrier system, and you will also find them mentioned in regard to the Tartar system. Essentially, they are all electrical contacts to the ship's electrical system to warm up gyros and electronic components in the missile and the booster.

Firing Contactors. - All RIM booster propellants are ignited electrically and use igniters to start the propellant burning. Basically, an igniter (figs. 3-27, 3-29) consists of a charge of black powder and a small electrical heating element called a squib. When electricity passes through the heating element, enough heat is generated to start the black powder burning. The flame from the black powder shoots down the hollow center of the propellant grain and ignites it.

When a missile is on the launcher and the intent is to fire it, some device is necessary to bridge the gap between the launcher arm and the missile booster so the booster igniter firing circuit will have a circuit from the firing key to the squib. Look again at figure 5-24. It shows a cutaway view of the A-arm of the Talos launcher. Notice the booster firing contacts at the arm's forward end. These contacts engage similar contacts (called ignition contacts) on the top of the forward booster shoes. Electrical wires run from the booster contacts to the squib electrical heater. Thus when the firing key is closed, and all other required circuit closures are made, an electrical circuit is completed to the squib which ignites the booster propellant.

Firing circuits are interlocked mechanically and electrically. This means that certain events must take place in the weapon system, in the correct order, before the firing circuit will work. The fact that the events took place, and in their proper sequence, is indicated by the operation of electrical and mechanical devices. You are going to learn more about interlocking and firing circuit operation later in this course; but for the present just take our word that firing circuits are interlocked.

Booster Arming Device. - Another reason for interlocking firing circuits is for safety. Consider the booster. Boosters are not ready to fire when they are stowed in a magazine, or even when they are first put on the launcher. There is a chance that they might be accidentally set off. So boosters are put in a safe condition until immediately before firing. And how are they made safe? Just by the simple technique of opening the firing circuit inside the booster. Generally, the igniter is mechanically rotated in such a manner that the squib element's electrical contacts are physically disconnected from the rest of the firing circuit.

When a missile is to be launched, some device must be used to move the igniter back into its firing position. You can see now that another device is needed to bridge the gap between the launcher arm and the booster. The launcher we have used as a study example has a plunger type mechanism in the launcher arms. The plunger, when it is extended, connects with a system of levers and gearing in the booster in such a way as to rotate the igniter assembly into the proper firing position. This process is called booster arming.

In case it is decided not to fire the missile, the booster arming and disarming device can be used to disarm the booster before it is unloaded and then placed back into stowage.

Emergency Igniter Injector. - A hydraulically operated emergency igniter injector is mounted on the after end of each launcher guide arm, see fig. 5-23. This device inserts a high-explosive cartridge into the missile booster. The arrangement of injector and cartridge permits electrical firing from the control station when a misfire occurs.

The operation of the emergency igniter injector is normally controlled by the launcher captain from the EP2 panel.

The Talos system is the only one that uses this method of disposing of duds or misfires. Terrier and Tartar systems use the dud jettisoning device to place dud or misfire missiles overboard when it is necessary to dispose of a missile that cannot be fired from the launcher.

TRAIN AND ELEVATION POWER DRIVES

Two electrohydraulic power drives (fig. 5- 19) position the launcher. One trains the launcher by rotating the carriage, and the other elevates the guide arms by rotating the trunnion tube. Both the train system and the elevation system receive orders in the form of electrical signals, and act on these orders to position the launcher and guide arms accordingly.

The launcher can be positioned by either of two methods of control: remote order control, and local order control. In remote order control, signals are received from a missile fire control computer. Local order control is used to position the launcher from a local station in the launching system.

The train and elevation systems operate in a similar manner. In most cases they contain the same operating components. These components, with the exception of the magnetic amplifiers, are located within the launcher carriage.

The simplified schematic in figure 5-26 is provided to promote a general understanding of how the train drive responds to an input signal. Only the basic drive components are pictured.

Two channels of control signals are fed to the drive. One is a position order. This one will be discussed first. The order is a velocity order.

We will start with the synchro transmitter in the computer. It transmits a position order to the IXCT in the receiver regulator of the launcher. The stator of this CT is geared to the B-end of the hydraulic transmission. If the launcher is not positioned at the same bearing as the transmitted order, a voltage is developed on the rotor of the CT to represent launcher position error (angular difference between actual launcher position and ordered launcher position).

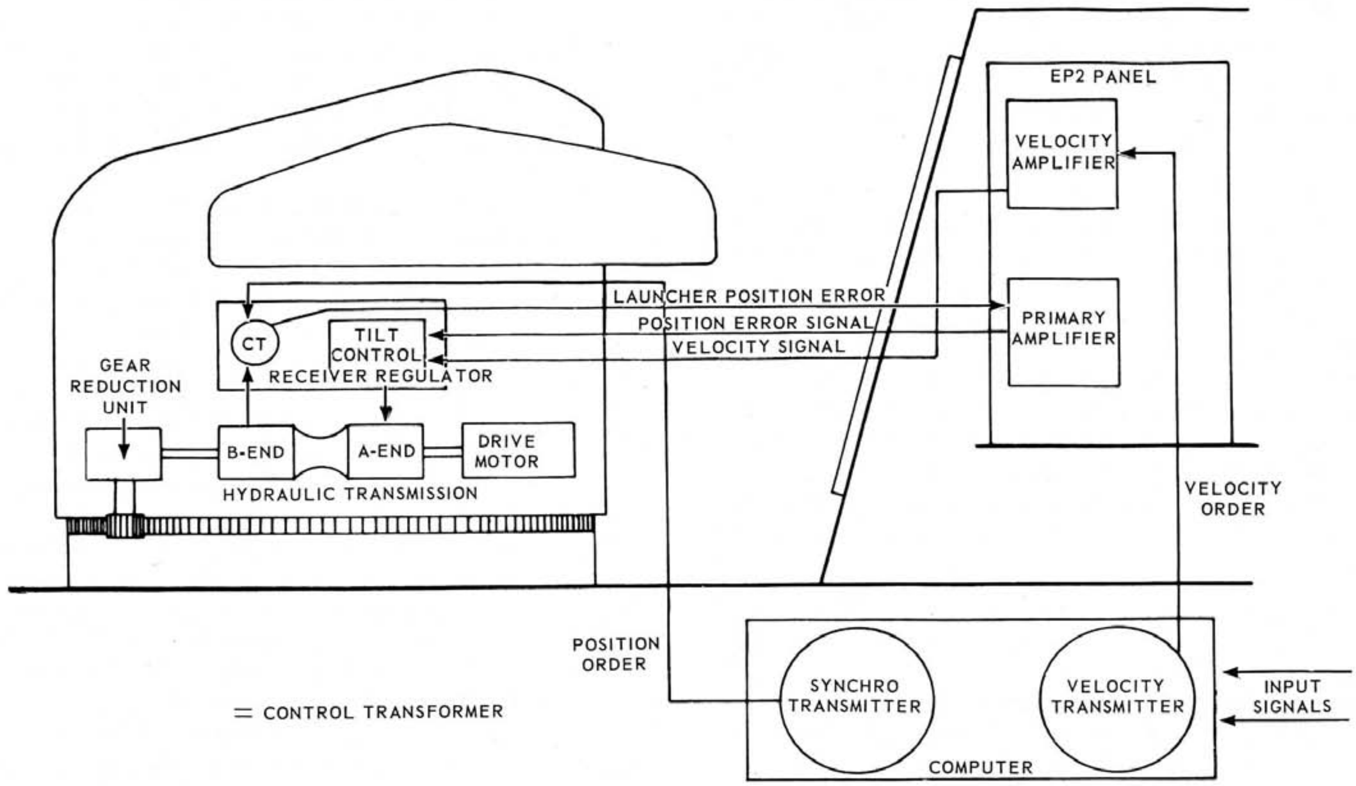
This error voltage is placed on the input terminals of a magnetic amplifier. The output position error signal of the amplifier is sent back to the receiver regulator. Through the receiver regulator, tilt is applied to the A-end of the hydraulic transmissions by an amount that corresponds to the strength of the error voltage. The receiver regulator, which is primarily a device to change an electrical input into a corresponding hydraulic output, is used to obtain the hydraulic pressure needed to stroke the A-end.

The A-end is driven by an a-c electric motor. The speed of the B-end rotation, which is governed by the amount of A-end tilt, is reduced by a gear reduction unit and applied to a drive pinion to rotate the carriage.

As the carriage rotates toward the ordered position, the launcher error, and therefore the error signal, decreases. When the launcher reaches the ordered position, the error will no longer exist and the A-end tilt will be reduced to zero.

Consider the situation where the position order is not static but is continually changing. This would be the case when the director is tracking a moving target. Here, movements of the director must be followed by the launcher with a minimum of error. This would be difficult to accomplish with only a position order channel, because an error would have to be developed to move the launcher. This problem is greatly reduced through the use of a velocity channel as an additional means of stroking the A-end.

The velocity order is a voltage received from the computer, which corresponds to the rotational speed of the director. This signal



83.49
Figure 5-26.—Block diagram of train drive system.

is amplified by the velocity amplifier, and then sent to the receiver regulator in the launcher. The regulator acts on the signal by applying a proportional amount of tilt to the A-end.

With both channels controlling the launcher during a dynamic (moving) signal condition, the position channel is used to reduce the initial error.

The velocity channel is used to maintain rotation of the carriage so the position error will have little or no chance to develop. The small amount of position error that does develop is reduced by the position channel.

In the interest of simplicity, many refinements of the train drive system have not as yet been discussed. These refinements will be discussed through the remainder of this section which will deal with power drive refinements.

The refinements include the automatic tracking cutout system, the firing cutout system, and the limit stop system. These refinements impose limitations on the power drives when they respond to input orders.

The limit stop system restricts launcher movement to definite established limits, and prevents launcher components from being damaged. The system also halts the launcher if it loses power. The limit stop system is designed with a lead input which is proportional to launcher velocity. Therefore, the launcher movement can be stopped at the established limit regardless of its speed.

The automatic tracking cutout system works with the power drive to prevent the launcher from pointing into areas where a fired missile would hit the ship's structure, masts, or other parts of the ship.

The firing cutout system disables the firing circuit whenever the launcher moves into areas where a fired missile could cause damage to the ship structures.

The Terrier and Tartar systems also have these "refinements" in their train and elevation systems so the missile cannot be fired into own ship's structure.

GUIDED MISSILE LAUNCHER FEEDER MK 11

Figure 5-1 shows the Launching System Mk 12 of which we have discussed the launcher. All Talos systems make use of the Mk 7 launcher, and there has been only one modification, Mod 1. The launching System Mk 12 Mod 0 and Mk 12 Mod 1 are identical except for the size of the two hoist magnetic controller panels (they are larger on the Mod 1) and the arrangement of cabling for the panels.

If you think about the name of this equipment group, you can get a picture of its main function. It simply feeds the missiles to the launcher. Of course, the feeder has other functions too, but we'll talk about them later.

Figure 5-27 A shows a pictorial view of the major units that comprise the Mk 11 feeder; figure 5-27B shows a block diagram of the feeder. Note that there are three main components; the magazine, the loader, and the assembler, each with its components.

The feeder is composed of two separate but similar parts. One part is associated with the A-arm of the launcher and the other part is associated with the launcher's B-arm. The part of the feeder that provides missiles to the A-arm is called the A-side, and the part that feeds the B-arm is called the B-side. (You can tell the side of the launcher or feeder by the conventional way. Just look in the direction of missile flight from the launcher or from the after end of the system, and the A-side is to your left. The B-side is to your right. This identification technique works regardless of the launching system's location on the ship.)

Although each side of the feeder operates independently, both sides usually work simultaneously, so that both launcher arms can be loaded at the same time. Since the A- and B- sides are almost identical, we shall describe only the A-side.

Guided Missile Magazine Mk 7

The components in this equipment group provide the stowage space for the missile- booster combinations. The magazine equipment also transfers the missile-booster combinations from their stowage positions to the loader, and puts them on it. Figure 5-27A shows the below-deck location of the magazine. It is placed below deck to prevent the entry of salt water and spray into the magazine spaces. Also, this location affords some protection from enemy gun and missile fire.

The main components of the magazine are:

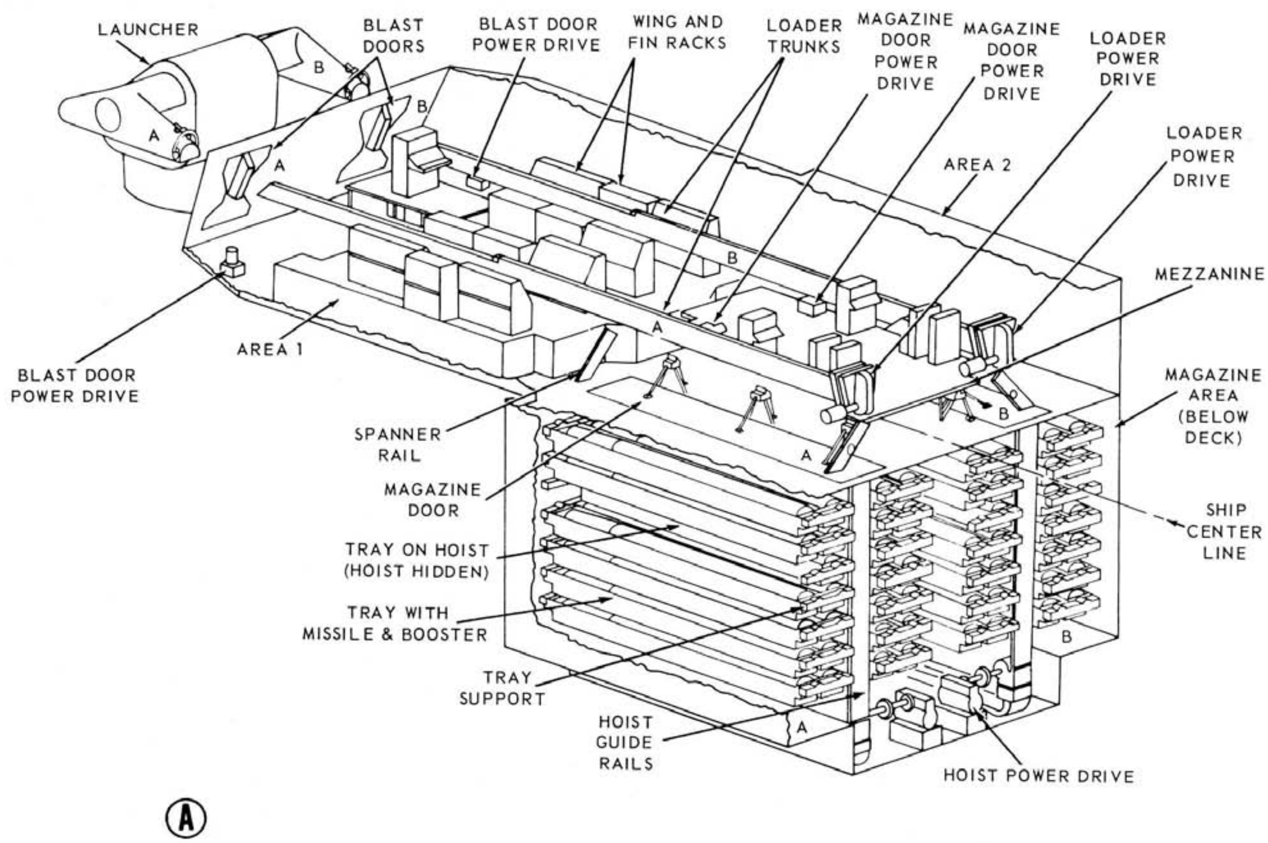
1. Trays.
2. Tray supports.
3. Hoist and its power drive.
4. Lower buffers.
5. Magazine door and its power drive.
6. Spanner rails.
7. On-hoist power drive.

The magazine (A- and B-sides combined) can hold 52 missile-booster combinations. Keep in mind that a combination is a missile and booster' connected together and handled as a single-unit. The A-side magazine has 7 layers with space to stow four weapons at each level. Each weapon is placed in a long rectangular box called a tray. A hoist divides the magazine so that two trays are on either side of the hoist at each level. Vertical rails guide the hoist as it moves up and down. The vertical rails are at each end of the hoist. The hoist is used to raise a weapon and its tray up to the loader and to return an empty tray to the magazine. Notice the magazine door that separates the magazine from the loader. The door is a safety device. It is a flame and gas seal between the magazine and the deckhouse. Hoist spanner rails are linked to the door. When the magazine is opened, the spanner rails connect with the hoist vertical guide rails. Thus the spanner rails provide a vertical extension of the guide rails up to the loader. In other words, they span the gap between the magazine and the loader to give the guide rails a continuous track.

Now that you have a general idea of what units make up the magazine and what they do, we'll cover them in more detail.

TRAYS. - A typical tray is shown in figure 5-28. There are 26 of them in our magazine, one for each missile-booster combination. Each tray has a device for locking the weapon in the tray. Also, the tray is equipped with parts that help transfer the tray on or off the hoist.

In figure 5-28 you will see four rollers at the booster end of the tray. These four rollers engage the associated tray support. The two large rollers are mounted with their axes horizontal. They support the booster end of the tray. The two small rollers prevent the tray from moving back and forth. At the launcher end of the tray there are only two large rollers and these support that end. You can't see them in figure 5-28 but they are similar to the large rollers at the booster end.



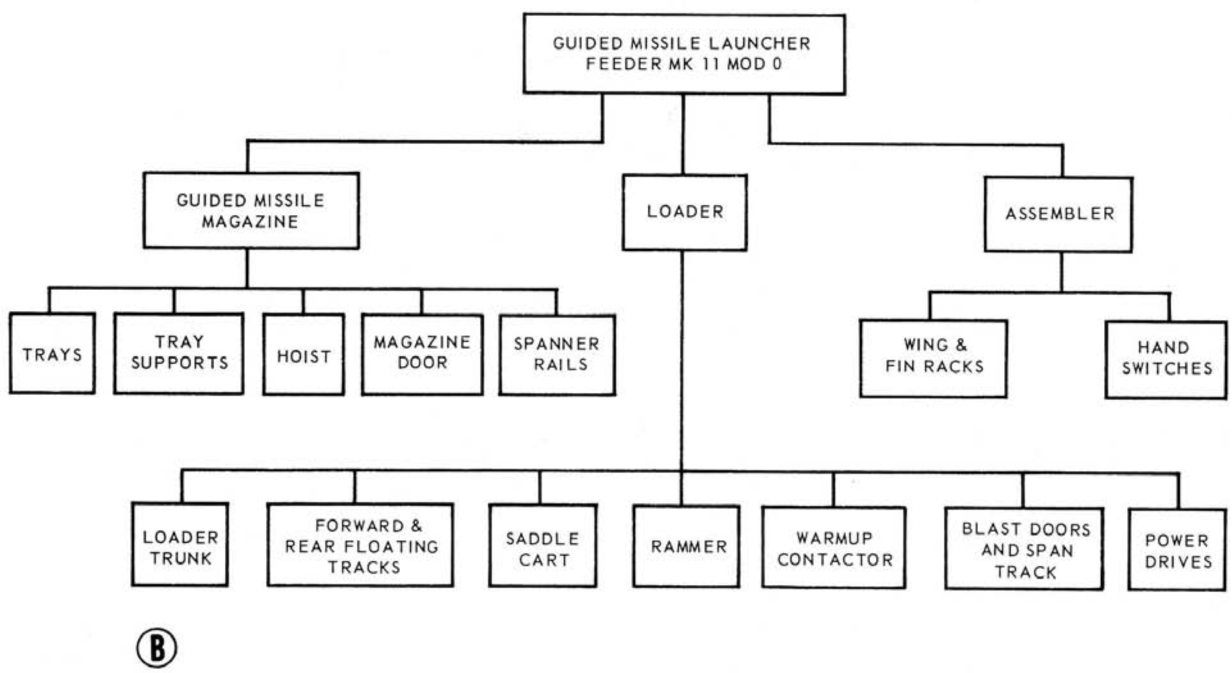


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Figure 5-27.—The Mk 11 launcher-feeder system for Mk 12 launching system: A. Components of the launcher-feeder system; B. Block diagram of the feeder system.

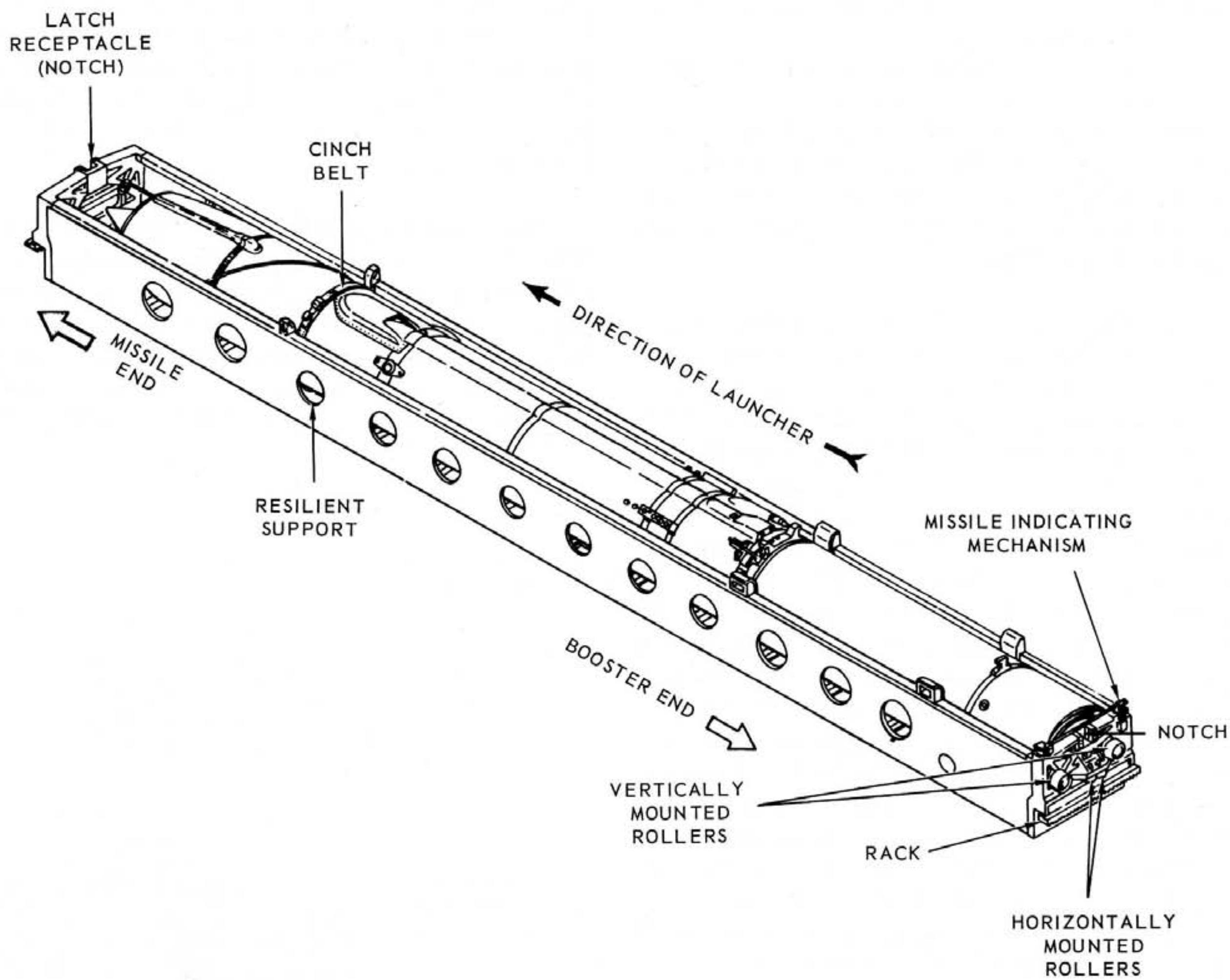

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Figure 5-28.—Tray with Talos missile in it.

A shoe latch secures the missile-booster combination to the tray. The latch is inside the tray at the booster end. The latch is spring loaded and engages the bottom rear booster shoe. This prevents the missile from shifting its position within the tray. A hydraulic actuator on the hoist releases the latch when a weapon is to be transferred from the tray. The missile part of the combination is also secured to the tray. A cinch belt does this. It is located at the end of the tray that points in the direction of the launcher. When ramming action moves the combination forward, the cinch belt is automatically released. You'll see this action later when ramming in the tray takes place.

Now the missile is securely placed in the tray, but what prevents the trays from falling off their supports? On the top edge of each end of a tray is a notch. Latches on the tray supports fit into these notches (latch receptacles). This prevents the trays from rolling off the tray supports. The same type of arrangement is on the hoist. Both the tray support and the hoist latches are operated hydraulically. Each tray is kept latched in place, except during the time it is being transferred from the tray supports onto the hoist and from the hoist to the tray supports.

A rack, used for transferring the tray on or off the hoist, is located at each end of the tray. Pinion gears located on the tray supports and hoist mesh with the racks to provide necessary horizontal movement for affecting tray transfer. As the gears rotate, the tray moves linearly to transfer the tray to or from the hoist. These gears are driven by a hydraulic unit on the hoist. This unit is referred to as the on-hoist power drive (fig. 5-27A).

Missiles are not particularly rugged, and must be protected from shock and vibration. So each tray has a resilient support on which the missile portion of the combination rests. The resilient support is composed of hydraulic dampers and mechanical springs. This device acts like a shock absorber on a car.

TRAY SUPPORTS. - It takes two tray supports to hold up a tray, one at the launcher end of the tray and one at the booster end. Each set of tray supports holds up two trays. The tray supports are bolted to the magazine bulkhead. Each support contains the means for transferring trays to and from the hoist. Fig. 5-29 shows a tray support. Its location in the magazine is shown if figure 5-27 A. The on- hoist drive is coupled to the transfer clutch to provide a means for moving the trays. When the on-hoist drive moves, the pinion gears turn. These gears are meshed with the tray's racks. As the inboard tray is moved onto the hoist, the outboard tray is moved to the position originally occupied by the inboard tray. If you look closely at the right-hand end of the tray support, you can see the track in which the tray rollers ride. Similar tracks on the hoist line up with these, so a tray with or without its weapon can be taken off the supports.

HOIST. - The hoist (fig. 5-30) spans the length of the magazine. It is used to move trays up and down between the loader and the individual levels. The hoist is guided in its vertical travel by guide rails (fig. 5-27A). Each end of the hoist is fitted with rollers to make sure the hoist moves freely up and down the guide rail. A roller track at each end of the hoist receives tray rollers. When a tray is slid over onto the hoist, the tray is latched to the hoist so it won't falloff.

The hoist itself is latched when it is at the correct transfer position. This is the position where the hoist and a selected tray support are in almost perfect alignment, and a tray can freely move back and forth between hoist and support. Two locks at each end of the hoist hold it at the transfer position.

A power drive on the hoist provides hydraulic power to transfer a tray on and off the hoist, to lock the hoist to the guide rails, to latch a tray on the hoist, and to unlatch a missile- booster combination from the tray.

An electromechanical power drive lowers and raises the hoist. This drive is not on the hoist, but is located at the bottom of the magazine (fig. 5-27 A). Buffers on the hoist and at the base of the magazine prevent equipment damage when the hoist reaches either its upper or lower limit of travel.

MAGAZINE DOOR - AND SPANNER RAILS. - The door acts as a gastight and flametight seal between the magazine and the deckhouse space. (See figs. 5-31 and 5-27 A.) The spanner rails are not part of the door, but they are linked to it. When the door is opened, the spanner rails form extensions of the hoist rails. This permits the

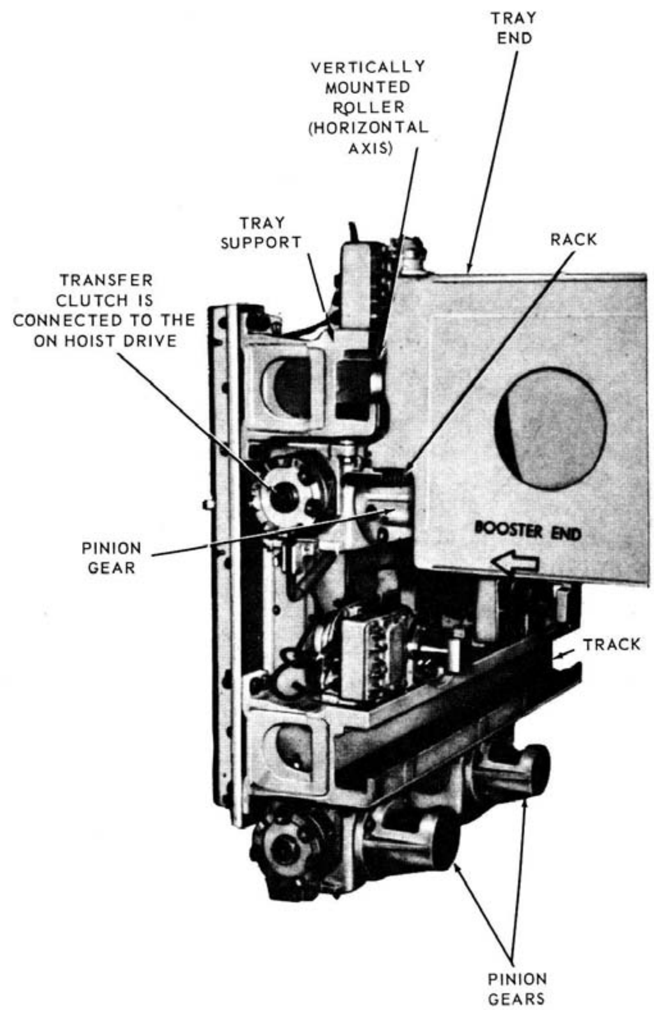
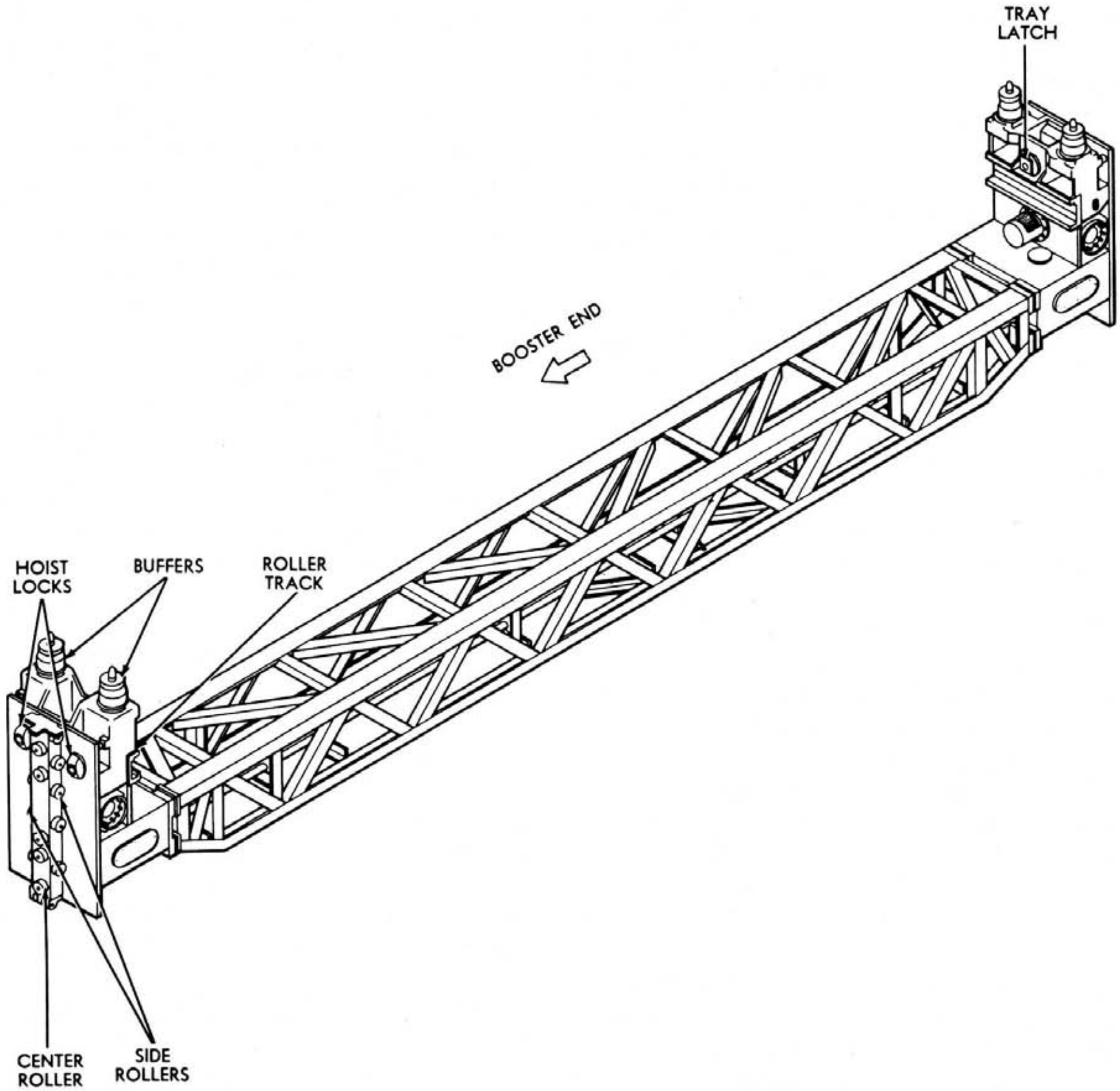


Figure 5-29.—Tray end and tray support in Talos magazine. 83.52



83.53
Figure 5-30.—Hoist in Talos magazine.

hoist to travel through the door opening to the loader. A hydraulic power drive (fig. 5-27A), provides the power to open and close the magazine door.

We have now brought the missile up from the magazine and are ready to move to the next area and the next steps in preparing the missile for firing.

Guided Missile Loader Mk 5

The loader is located in the deckhouse. You can see the loader in figures 5-1 and 5-27A, and in figure 5-32. The loader equipment transfers the weapon from the tray to the launcher.

During the transfer operation a device in the loader applies warmup power to the missile. The main components of the loader are:

1. Loader trunk
2. Forward and rear floating tracks
3. Saddle cart
4. Rammer
5. Positioners
6. Warmup contactor
7. Blast doors and span track
8. Power drives

When the hoist raises a weapon to the loader level, three units put the weapon on the loader trunk. These units are the floating tracks, saddle cart, and rammer. A power drive pushes the weapon along the loader trunk and stops it in the forward part of the deckhouse (the assembly area). Here, warmup power is applied and wings and fins are put on the missile. Just fins are attached to the booster. Then the blast doors are opened and the weapon is rammed onto the launcher guide arms. Now let's talk a little more about the principal units in the loader.

LOADER TRUNK. - This is a long metal structure composed of sections butted together and bolted to the underside of I-beams on the overhead of the deckhouse. The weapon is horizontally suspended from a rail on the loader. The top set of shoes on the booster are used to hang the weapon from the rail. You learned about these shoes in chapter 3. The forward handling shoe slides in skid tracks cut in the rail. The after handling shoe is retained in a saddle cart which also travels in the rail skid tracks. The cart is connected to a drive chain. The chain provides the means for moving the cart and weapon along the loader rail. A sprocket drives the chain. Connected to the sprocket is a drive motor. The drive motor is part of the loader power drive which controls the movements of the saddle cart and therefore the weapon.

FLOATING TRACKS. - Two floating tracks, (fig. 5-32) the magazine end of the loader trunk, raise the missile out of the tray and place it on the skid tracks. The floating tracks are designated as forward and rear to coincide with the forward and rear booster shoes on the Talos weapon. The tracks are designated "floating" because they can be raised and lowered.

When the missile-booster combination is ready for transfer to the loader, the floating tracks are lowered. Before the tracks are lowered, the forward part of the saddle cart is positioned on the rear floating track and is lowered with it. When the hoist raises the weapon to transfer it to the loader, the forward booster shoe projects through slots in the skid tracks and slots in the forward floating tracks.

The weapon is not on the loader yet. A rammer moves the weapon in the direction of the launcher while the weapon is still in the tray. Now the forward booster shoe is in the skid tracks and the rear booster shoe is moved forward onto the saddle cart.

After the ramming operation, the forward and rear floating tracks raise. The weapon is lifted out of the tray. Then the floating tracks are aligned with the loader trunk and the weapon can be moved along the loader trunk.

SADDLE CART. - The saddle cart (fig. 5- 33) rides in the loader skid tracks. Two metal latches on the cart hold the top rear booster shoe between them. These latches are called the reverse motion pawl and the forward motion pawl. The saddle cart is connected to the loader drive chain and provides the means of moving the weapon along the loader.

RAMMER. - This is essentially a hydraulically operated piston which is raised and lowered to transfer the weapon on to the loader. It pushes the weapon forward 4 inches, enough to slide it into receiving slots in the saddle cart and the track.

POSITIONERS. - Two hydraulically operated devices called positioners are on the loader. One is at the sprocket housing end of the loader; the other positioner is near the center of the loader trunk. Both of them position and lock the saddle cart. The positioner in the sprocket housing positions and holds the weapon on the rear floating track. The other positioner places the saddle cart so that the warmup contactor can mate with the booster warmup pad.

WARMUP CONTACTOR. - The warmup contactor is located near the center of the loader trunk in area 1 (figs. 5-1 and 5-27). The contactor applies electrical warmup power to the missile while the wings and fins are being put on. The contactor is controlled hydraulically so it Can be lowered to contact the pad on the booster.

BLAST DOORS AND SPAN TRACK. - There are two blast doors, one for the A-side and one for the B-side. Blast doors prevent hot gas and flame from fired boosters from entering the missile deckhouse. Of course, they also keep water from entering. When they are opened, they allow Talos weapons to be transferred from the loader to the launcher guide arm. Each blast door is composed of an upper and lower door. A span track is attached to the inside face of the upper door.

Both blast doors are mounted in a slanting bulkhead which forms the end of the deckhouse. You can get a general idea of what they look like in figure 5-27. When the doors are opened, the tracks connect the launcher rails with the

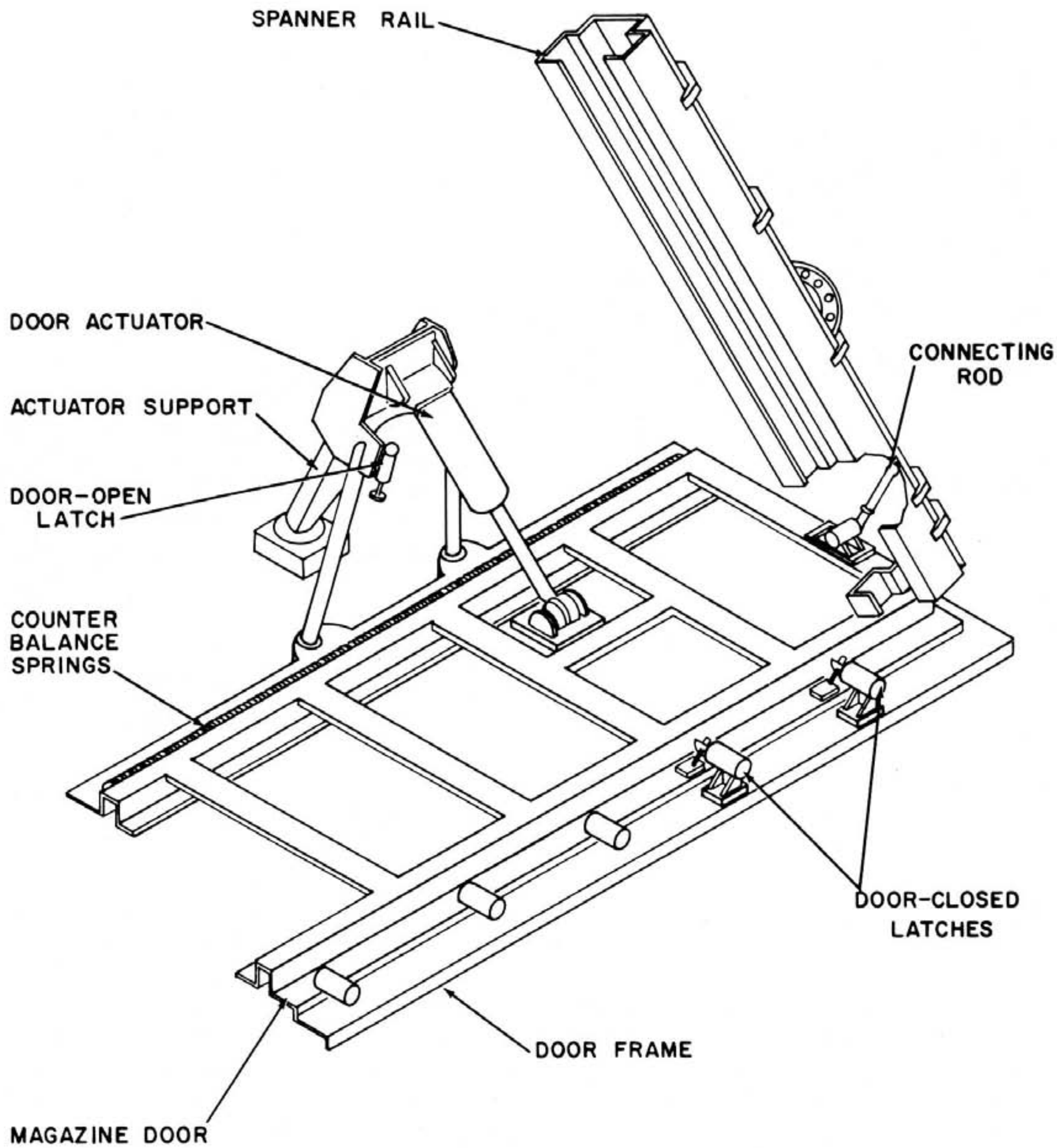


Figure 5-31.—Magazine door and spanner rail, Talos launching system.

loaders. This permits Talos weapons to be loaded on (or unloaded from) the launcher.

The upper and lower doors are hinged. The lower door is hinged to the bottom of the frame and the upper door to the top. Each door is opened and closed by two hydraulic pistons. The two doors do not open or close simultaneously, but act in sequence. The lower door opens first. When it is fully open, the upper door opens. When closing, the upper door closes and then the lower. Latches secure the door in the open or closed position. A deicing system prevents frozen water or spray from sealing the doors shut. A power drive on the main deck near the doors provides the power to operate the doors.

Guided Missile Assembler

Guided missile assembler is a fancy name for wing and fin stowage racks. The work done in this area is like that done in the Terrier assembly area.

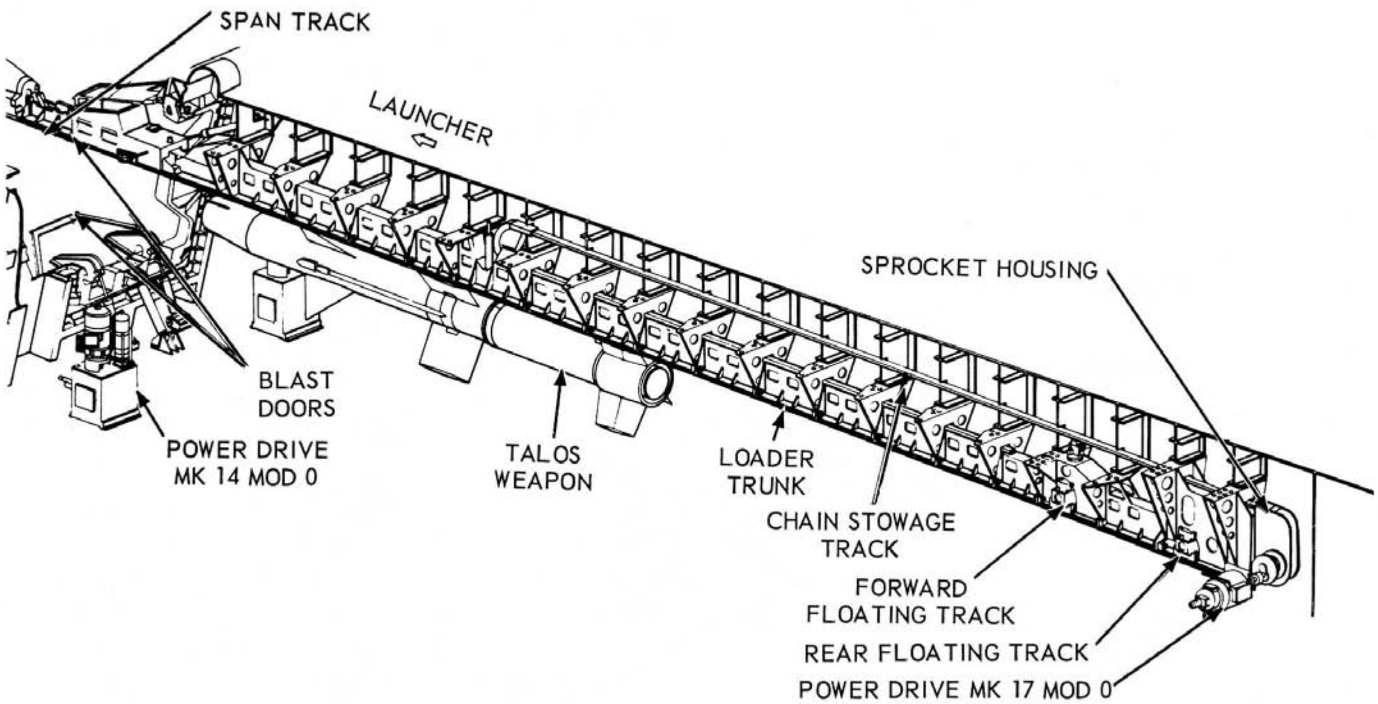


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Figure 5-32.—Loader, B-side, Talos launching system.

MISSILE LAUNCHING SYSTEM CONTROL

A guided missile launching system is made up of many interrelated parts. All of these parts must work together as a whole to accomplish the purpose of the system - in this case, to stow, load, and fire missile weapons. To perform its mission, the system goes through a predetermined sequence of operations. For example, consider briefly how the loader works during loading. Loader equipment picks up the weapon from the tray and puts it in the loader skid tracks and saddle cart. Then the weapon is moved to the assembly area, where wings and fins are put on the missile-booster combination. Now the weapon is completely assembled. It is then rammed and attached to the launcher. The hardware that did the loading operation is brought back (retracted) and put into a position where it will grab another weapon and prepare to load it on the launcher. You can see that many events occur just in this small portion of the loading operation. Also, these events occur in a set sequence. If the equipment is working properly, nothing can happen out of step. But failures occur, and the launching system senses them when they happen. For instance, we forgot to open the blast doors in the above description of a loading operation. Well, a properly operating loader won't forget. It has electrical interlock circuits that indicate when a blast door is open or shut. If a door is open when it should be shut and the GMLS is ordered to load a weapon, the system will not obey the order. And you will agree this is a logical decision. Since the system as a whole must make thousands of logical decisions, electrical circuits have been designed to make them. These decision- making circuits are part of the system control. Also, the launching system control contains circuits that "keep tabs on" (monitor) the operation of the complete system. When an event takes place in the system, say the blast doors are opened, the completion of the event is indicated on a display panel. Almost every event that happens in the system is displayed visually on a panel. These panels are also part of the launching control.

Missile Launching Control Mk 10 consists of electrical switches, circuit breakers, relays, and other electrical devices that make up control circuits. Consoles and power distribution panels are also included.

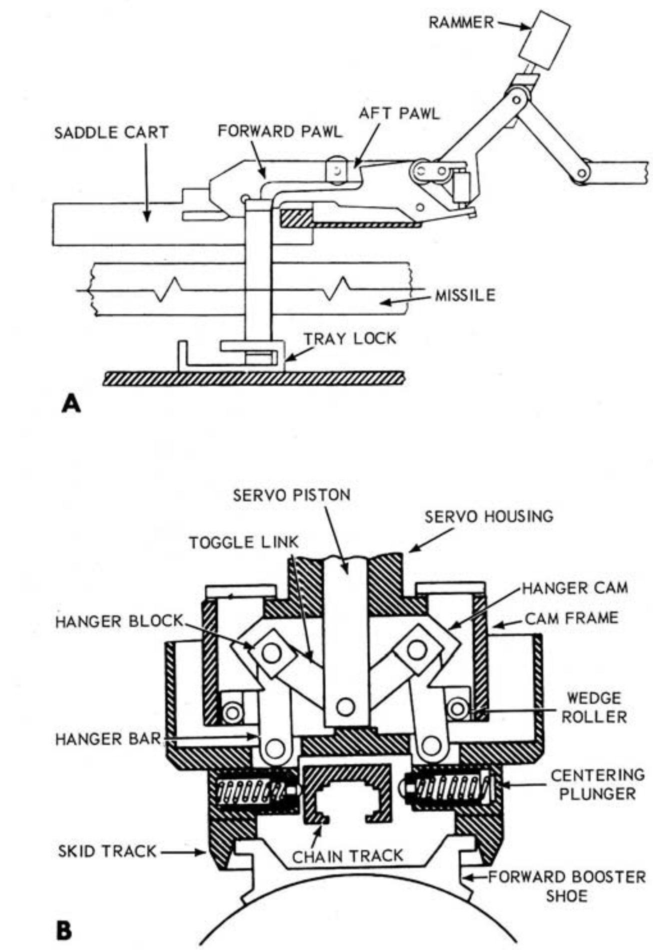

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Figure 5-33.—Mechanics and hydraulics of the loader: A. Engagement of the aft booster shoe with the saddle cart; B. Floating track aligned to shoe.

Types of Control

The missile launcher train and elevation power drives are controlled through the launching system control. Also, the system control permits step and automatic control of the rest of the system. We had better define what we mean by "step" and automatic operation.

In step control each individual operation is started by a switch or pushbutton. In automatic control each step of an operation is performed automatically. Once a process has been started, it follows through without interruption; whereas, in step control the operation is performed in discrete steps.

Control Panels

The GMLS Mk 12 has 13 control panels. We are going to talk briefly about the more important ones. All of these panels together control, monitor, and test system operation. Also they provide a means for distributing electrical power. The location of these panels is shown in figure 5-34. These are in areas 1 and 2, or feeder and assembler areas.

POWER PANELS. - Panel EP-1A provides power distribution for the launcher power drives, missile warmup power, and electrical power to the launching system control circuits.

Power panel EP-1B distributes power to the magazine equipment, loader power drives, and the anti-icing equipment. The reason for two separate power distribution panels is that you don't want all your electrical eggs in one basket.

Launching System Panel EP2 contains switches, indicators, amplifiers, and relays needed to operate and control the launcher and feeder. Following are some of the functions that can be performed through the EP2 panel:

1. An operator, called the Launcher Captain, can select the launchers train and elevation signal source. If you want to control the launcher in train and elevation from a signal source other than the computer, you just throw a switch on the face of the EP2 panel to the appropriate position. You would do this if you wanted to test how well the launcher power drives were operating.

2. There are many lights on this panel. Some are red, some are green, and others are amber when lighted. A red indicator light might indicate there is a casualty in a hydraulic system, or that an electric motor is stopped. A green indicator light shows that a motor: is running. An amber indicator light might glow to show that a launcher rail has a missile on it and what type of Talos missile. A series of lights is used to monitor the movements of a missile as it flows through the launching system.

3. By throwing the right switches you can start electric motors as you need them. Under certain conditions you don't need all of them running at the same time, so independent start control is provided.

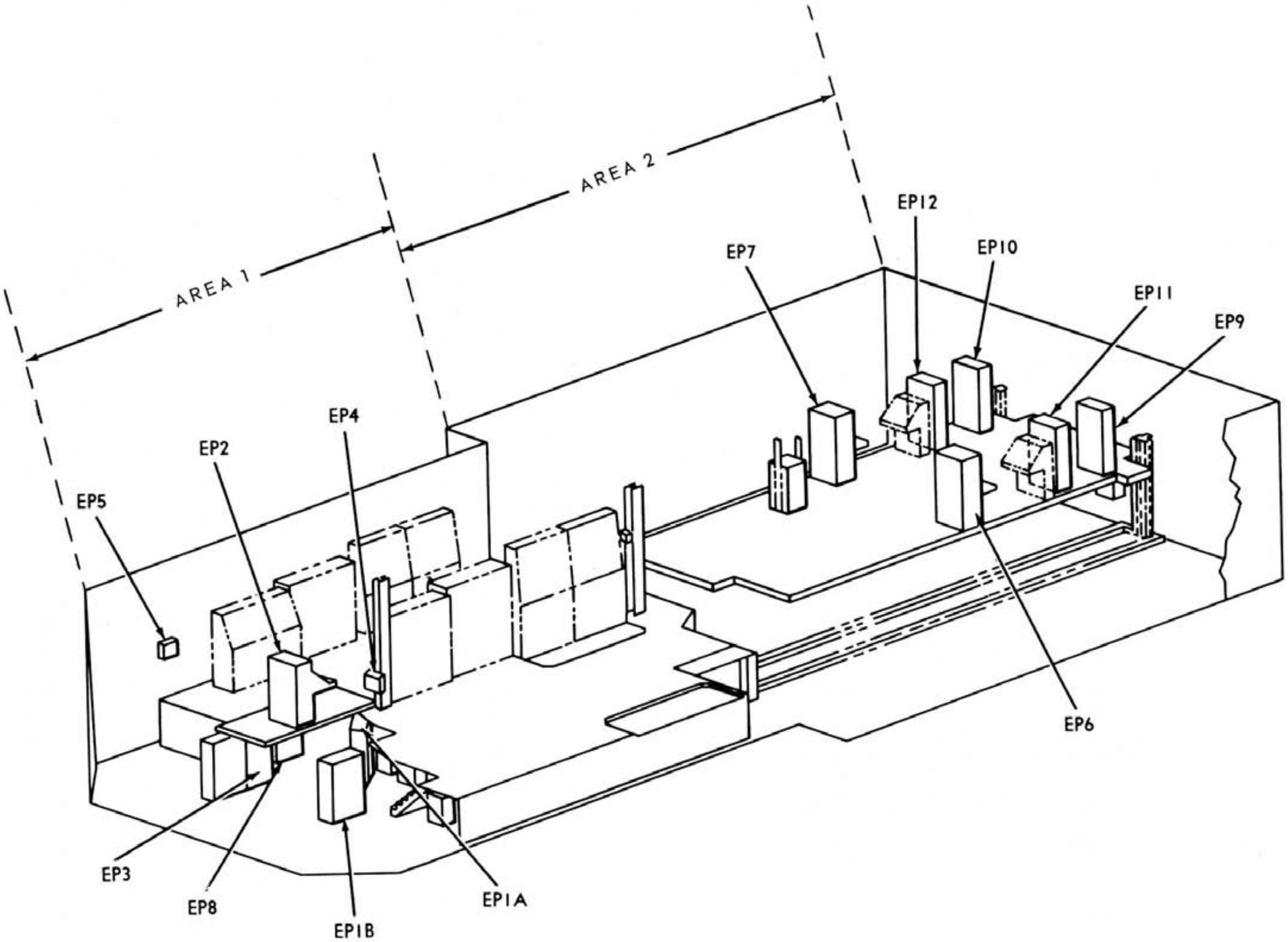

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Figure 5-34. — Control panels in the Talos missile launching system control.

4. The launcher captain can select one of several ways of operating the system. With switches he can put the system in the load method of control. In this operation the system takes a missile out of the magazine and puts it on the launcher. Sometimes it is necessary to remove a missile from the launcher. By throwing switches, this unloading operation is started. Then the system takes the missile off the launcher.

TEST PANEL EP3. - This panel contains switches, synchros, and jack plug connections to perform complete tests on the launcher power drives and to operate the launcher in local control. Dummy directors, signal generators, recorders, and other test equipment may be plugged into the panel to conduct tests.

ASSEMBLER PANELS. - Panel EP4 contains switches, relays, and indicators for monitoring and controlling the operation of the A-side of the assembler. EP5 panel is identical to, and has the same function as EP4 except that it controls the B-side of the assembler.

MAGAZINE PANELS. - EP6 panel provides for monitoring and controlling the" A" magazine mechanisms while in step control. Magazine Panel EP7 is the same as EP6 except that it controls the B-side magazine.

RELAY PANEL EP8. -This panel contains relays associated with launching system control.

LOCAL CONTROL PANELS.-EP9 panel contains the equipment for the local control operation of the A-side loader power drive. The loader can be operated at variable speeds through controls on this panel. Panel EP10 is identical to Panel EP9 except for the fact that it controls the B-side loader power drive. Local Control Panel EP11 contains the equipment for local control operation of the A-side magazine hoist drive. The velocity and movement of the hoist can be controlled through this panel. Panel. Panel EP12 is identical to the EP11 except that it controls the B-side magazine hoist drive.

LAUNCHING SYSTEM FUNCTIONING

Now let's follow the functioning cycle of the Mk 12 launching system as it fires a round. Except for installing wings and fins, the cycle is completely automatic.

We begin the firing cycle when the weapon control station (WCS) gives the order for system alert followed by a load launcher order. The wing and fin assembly operators (12 of them) are alerted and the decision is made in WCS as to whether the first load to be put on the launcher is a double- or a single-rail loading and, when a single-rail loading is chosen, which side (A or B) is to be used. The launcher area is checked to see if it is clear, and the load launcher switch is moved to the load position. The WCS also selects the type of missile to be fired.

When the load order is given, the magazine hoist automatically indexes (moves up or down) to the selected tray position and removes around and its tray. With the round and tray on the hoist, the hoist moves upward to the standby position. The magazine doors open and the hoist rail spanner sections rotate to align with the hoist rail. The magazine hoist raises the round in the tray from the standby position to the load position, and the floating section of the loader rail lowers. The rammer retracts, engaging the aft booster handling (upper) shoes, and the missile unlatching actuator is extended, causing the shoe latch to retract. When the shoe latch has retracted, the rammer moves the round four inches, and the top booster shoes engage the floating rail portion to the loader track. As the missile-booster combination is moved forward by the rammer, the cinch belt (fig. 5-28) which holds the missile to the forward end of the tray is released automatically. The missile unlatching actuator retracts, and the floating rail elevates the round to the loader rail, about 2 inches.

When the floating rail has fully elevated and latched, the hoist lowers the empty tray into the magazine, the hoist rail spanner sections retract, the magazine doors close, the loader moves the round to the wing and fin assembly area (area 1), and the loader chain positioner locks the chain. The empty magazine tray is returned by the hoist to the stowage position, and the hoist returns directly to a standby condition, or it selects another round when ordered, and then returns to the standby position until the next cycle.

When the weapon arrives at the wing and fin assembly area, the positioner latches, and the electrical contactor extends to start missile warmup. When the magazine doors are closed, the blast door may be opened. However, normally the blast door opening is delayed for five seconds by a time delay relay, thus making sure that the door is open a minimum amount of time. Interlocks insure that the launcher is in the load position before the blast. doors open. The lower blast doors open first, and the upper doors and spanner rails raise and latch into the launcher rail, forming an inline extension of the launcher loader (feeder) rail system. Wing and fin installation (this operation should require a maximum of ten seconds) is completed, the arming plug installed, and 12 operators actuate their individual safety (hand) switches, indicating that each operator is clear of the round. External warmup power is removed, the missile switches to internal power, the electrical contactor retracts, the assembly area positioner retracts, and the round moves onto the launcher.

As the round reaches the launcher, the reverse motion latch extends and, when it is fully extended, the loader saddle cart returns to a position above the magazine, and the launcher electrical contactor extends. After the contactor is in place, missile internal power is removed and external power is again applied to the missile. The contactor also completes circuits for missile identification and type of warhead indication. As the loader saddle cart retracts past the upper blast door, the blast doors close. When the upper blast door is clear of the launcher, the train and elevation latches retract, and the launcher remains at the load position awaiting assignment; or it synchronizes with the launcher order signals from the computer if these signals are present (assignment has been made). After assignment has been made, the launcher trains and elevates to the firing position. The missile may now be fired by the WCS. The first loading operation requires approximately 57 seconds.

Subsequent salvos usually require less time. The exact time varies with the location of the missile required.

TARTAR LAUNCHING SYSTEM

The Tartar missile launching systems are installed on guided missile destroyers. Tartar missiles are also used as backup missiles for the Talos systems aboard heavy cruisers. The Tartar Mk 11 launching system is used on DD3- and CG-class ships. This system has a two-arm launcher located over two rings of vertically stowed missiles. The Mk 13 launching system is used on small ships. It has a single launcher guide arm that loads in the vertical position. The missiles are stowed vertically in two rotatable ready service rings.

Tartar Launching System Mk 22 was developed for use on small ships where space and weight allowances were too limited to permit the use of the Mk 11 or the Mk 13 system. The Mk 22 system was designed to replace a 5"/54 gun mount. A single ready-service ring is located directly below the launcher with the missiles stowed vertically.

The main components of the Tartar launching system are the launcher, the missile magazine, and the missile launching control system. As Tartar missiles are completely assembled before stowage, and the folded tail surfaces are erected automatically after the missile is on the launcher, there is no need for an assembler. This also eliminates the space for the control panels, which have to be placed outside the launching system.

Figure 5-35 shows the Mk 11 launching system.

The launcher and magazine require no operating personnel; three men are required for the control panels.

During automatic operation, the launching system control initiates and controls the loading cycle, but the launcher is positioned and the missile is fired by the ship's fire control system

LAUNCHER

The Mk 11 launching system uses Launcher Mk 8, Mods 0, 1, and 3. The Mk 13 launching system uses Launcher Mk 116 Mod 0. Launching System Mk 22 uses Launcher 123 Mod 0. Figure 5-35 shows the Mk 8 launcher in the vertical position with a missile on each guide arm, before the launcher is trained and elevated to the correct launching position as ordered by the fire control system on the ship.

Guided Missile Launcher Mk 8 Mod 0

The missile launcher consists of a dual- arm launching guide, a rotating carriage with trunnions, a supporting stand structure, and a combination electric and hydraulic slipring assembly. The general layout is much like that of a gun mount. Both guide arms can be loaded from either the inner or outer ring of the magazine. The two arms are similar in construction, except for right- and left-hand parts. The launcher is remotely controlled by Missile Launching System Control Mk 9 Mod 0.

The major components of the launcher are the stand, the carriage, the missile launcher arms or guides, and the slipring assembly. The train and elevation power drives are components of the carriage.

The stand assembly includes a stationary training rack and hydraulic and mechanical components required to rotate and index the magazine cover.

The carriage is bearing mounted in the stand, is capable of unlimited train in either direction, and supports the bearing-mounted torque tube. Besides the carriage structure, the carriage assembly includes a hydraulic system, train and elevation power drives with associated control equipment, latches and securing pins, and the blast door operating mechanisms.

The train and elevation power drives are independent hydraulic drives each with its own electric motor. The pinion of the train power drive meshes with the stationary training rack of the stand and rotates to move the carriage in train. The pinion of the elevation power drive meshes with the gear of the elevation segment to rotate the torque tube in elevation.

The missile launcher includes the torque tube assembly, two guide arms, and a guide hydraulic system. The guide arms can extend for outer magazine loading and retract for inner ring loading. Launcher firing is always accomplished from the retracted position; dud jettisoning is always accomplished from the extended position. Each guide arm includes a missile ramming mechanism" Each rammer is a hydraulically operated chain hoist that can be extended into the magazine cells to hoist a missile to the arm. The rammer mechanism includes a hand drive for manual operation in the event of failure of hydraulic pressure.

Each guide arm incorporates a front, center, and rear guide. During loading or unloading, the missiles ride on a continuous rail from the magazine to the guide arm, composed of rails

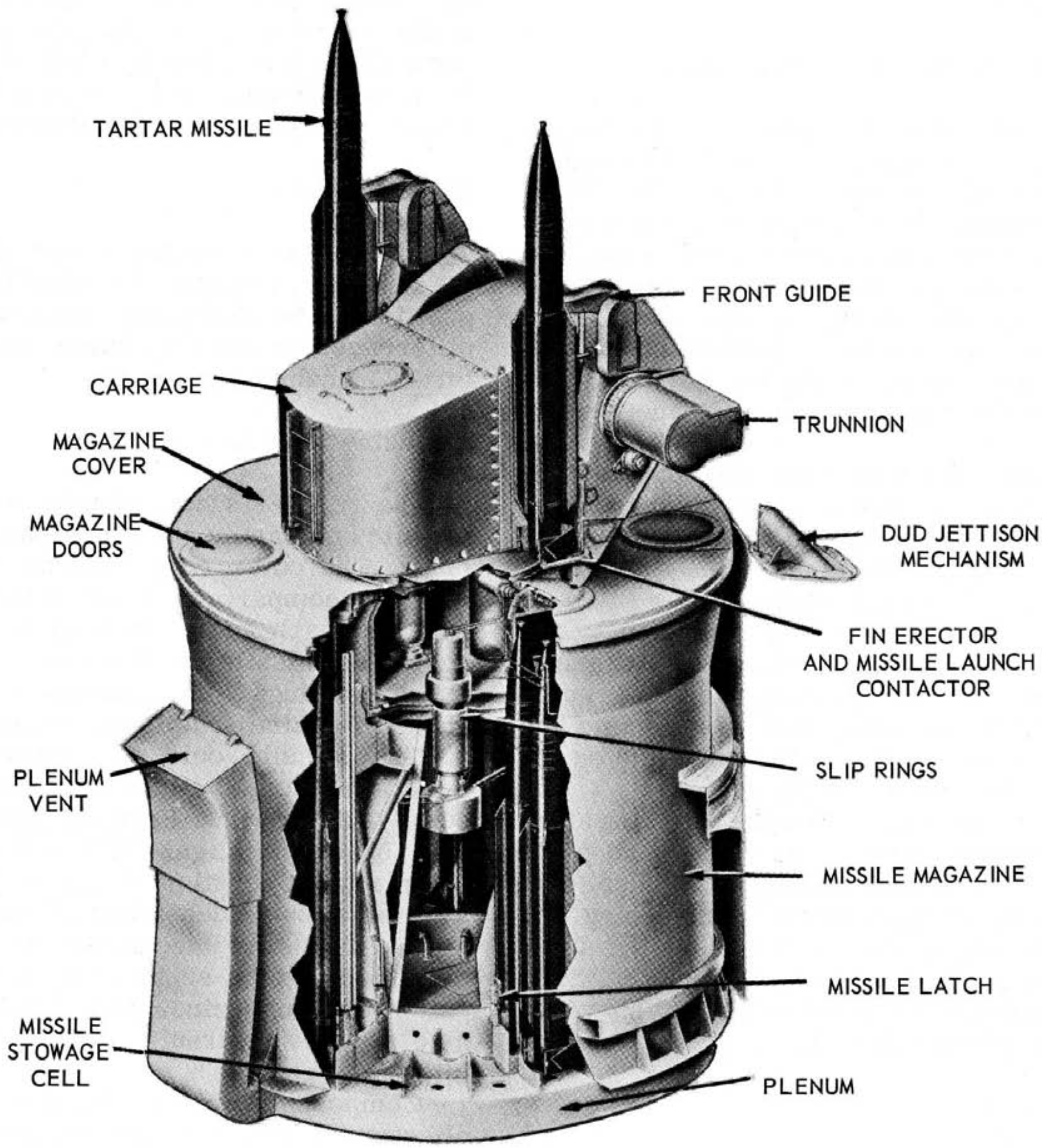

Figure 5-35.—Guided Missile Launching System Mk 11 (Tartar).

in the magazine cell, a segment of rail on the underside of the blast door, and the three guides on the guide arm. The rear guide extends and latches to the blast door when the door is opened. It is extended to latch to the transfer dolly during transfer operations. In automatic loading the rear guide remains extended until the missile is within a few inches of final rammed position. At this point the rear guide retracts and connects an electrical connector from the launcher to the missile. The rear guide incorporates four fin erectors for erecting the missile fins.

The slipring assembly is located on the vertical centerline of the launcher. The assembly transfers electrical power and signals, as well as hydraulic pressure and anti-icing circulating fluid between the rotating launcher and fixed structure of the missile launching system,

You will recognize many of the launcher parts which have the same names as in the Terrier and Talos systems. Some new names here are plenum and plenum vent, magazine cover, and fin erector. They are only on the Tartar system. The plenum and plenum vent are part of the safety system to carry off dangerous fumes in case of an accidental firing in the magazine.

Guided Missile Launcher Mk 116 Mod 0

This is the launcher used with the Mk 13 Tartar launching system. As you have seen in figure 5-2, it has but one guide arm for firing missiles. However, it can fire at a rapid rate. The missile magazine is directly beneath, and it holds 40 missiles, stowed in two concentric circles, called the ready service rings. The ready service rings can be indexed to the position beneath the blast door, ready for hoisting. The launcher can be positioned over either ready service ring.

The launcher assembly consists of the carriage and guide. A base ring and two trunnion supports form the structural units of the carriage (fig. 5-36). The blast door is part of the base ring. It opens only when a missile is being transferred from the magazine to the guide arm or is being put into the magazine. The carriage rotates (trains) and the guide pivots (elevates) to bring the missile into the ordered fire position. The missile is held on the guide arm by the retractable rail.

Mounted on the underside of the base ring are a power unit, cables, piping, and mechanical parts for electrical, hydraulic, and anti-icing functions, Inside the trunnion supports are cables, piping, and connections to supply the guide arm. In the righthand trunnion are the final drive components which include a chain-and-sprocket drive, a pinion, and a sector gear (elevation arc).

Mk 123 Launcher

The Mk 123 Mod 0 launcher is used with the Mk 22 Mod 0 launching system. It has a single guide arm, which is identical to the guide arm of the Mk 13 system. The base ring, on which the launcher is mounted, rotates to position the launcher over the selected missile in its cell. Within the carriage are the train/hoist and elevation power drives, a center column, service platform, train and elevation fluid supply tanks, and the hoist. The trunnion supports are on top of the base ring. The ship's ventilation system is used in the carriage to keep the air circulating.

The train/hoist power drive has a single electric motor-driven hydraulic transmission with separate controls and gear reducers for either training the launcher or driving the hoist chain.

The train/hoist system and the elevation system each have a receiver-regulator with a servoamplifier. Each system has an electric motor coupled to a variable-stroke hydraulic pump (A-end) which drives a fixed-stroke hydraulic motor (B-end). Each system has a power-off brake and associated mechanical drive trains.

MAGAZINES

All Tartar magazines are directly beneath the launcher, and stow the missiles in the vertical position. The following discussion points out differences in the magazines used with the different launching systems.

Magazine Mk 6 Mod 0

The ready-service missile magazine has 42 missile compartments arranged in two concentric rings. The outer ring contains 24 and the inner ring 18 compartments or cells. A set of two rails in each cell fits lugs on the missile to hold the missile in the cell. Latches secure the lower lugs. The individual cells are parts of the magazine and plenum structure.

The missile cells are closed at the top by a rotating cover, fitted with two inner and two outer blast doors. Each diametrically opposite pair of doors aligns with either an inner or outer ring. Operation of the magazine cover is automatic but independent of the launcher. The cover operating mechanism is driven by hydraulic pressure supplied by an auxiliary power unit in the magazine. This auxiliary power unit also supplies hydraulic pressure to operate the missile latches.

Components of the magazine control the application of warmup power to the missiles in the cells. The magazine includes a ventilating system, a sprinkling system to cool overheated missiles, an anti-icing system. and a CO_2 system for fire protection. The magazine has a flame barrier to isolate the missiles, and arrangements for safe collection and exhaust of resulting propellant gases if a missile ignites in its cell. This arrangement consists of the plenum chamber and plenum vent, shown in figure 5-35 and described later in this chapter.

Magazine Mk 8 Mod 0

The construction of the Mk 8 magazine, used in the Mk 13 launching system, is similar to the Mk 6, but is smaller since it serves only one launcher arm. The ready service rings, in two

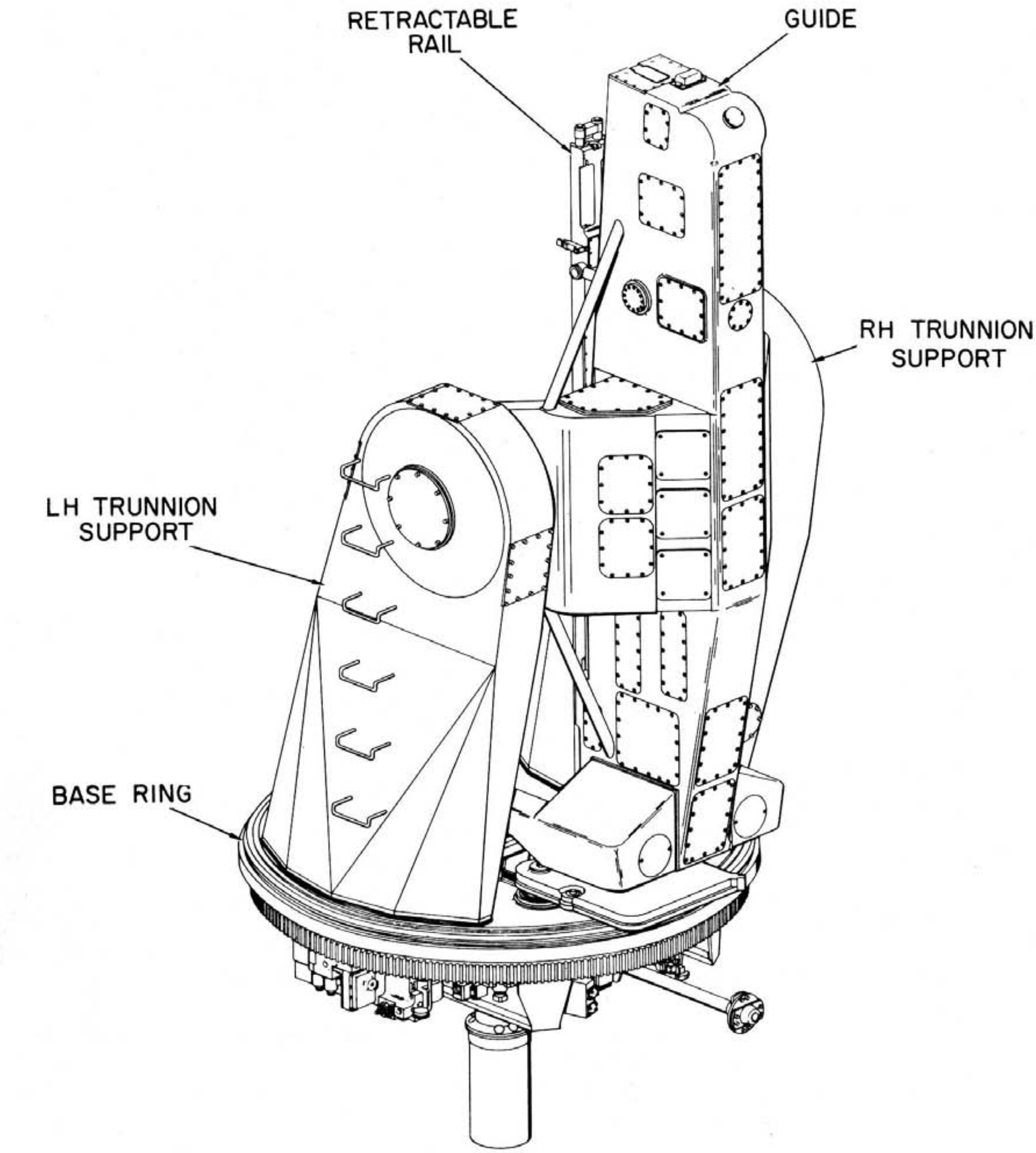

Figure 5-36.—Launcher Mk 116, Mod 0 (Mk 13 Tartar Launching System).

concentric circles, hold 40 missiles. In operation, the ready service ring rotates between the outer shell of the magazine and the inner structure to position the missiles at the hoist station for loading into the launcher. Each ring of missiles has a retractable rail just above the ready service ring. During the hoist cycle, the retractable rail extends and serves as a guide for the hoist chain and missile shoes. The magazine power supply, located in the inner structure of the magazine, rotates the ready service ring to the selected position, and drives (raises or lowers) the hoist.

Magazine Mk 9 Mod 0

The magazine for the Mk 22 launching system has a fixed single ring of 16 missiles. Instead of moving the selected missile to position beneath the blast door, the cover (mounting the launcher) is rotated until the blast door is directly above the selected missile, and then the hoist raises it to the launcher.

Associated Equipment

Some of the associated equipment in the launching system for the Tartar missile has been mentioned in the course of the discussion thus far.

WARMUP. - Warmup power is applied to the missiles while in the magazine, so the electronic tubes will be ready to operate when the missile is launched. The main components carrying the warmup power supply to the missile are the warmup contactors and the electrical contact -ring. As each missile is loaded into the magazine during strikedown, a warmup contactor in the cell enters a socket in the missile, establishing the circuit through which power will be applied when the missile is being readied to fire.

PLENUM CHAMBER. - Under the space or cell for each missile in the magazine is a space called the plenum chamber. If a missile should accidentally be ignited while in the magazine, the plenum chamber receives the exhaust gases and conducts them to the plenum vent to escape to the atmosphere. No matter where the missile is stowed, there is always a plenum compartment beneath it. Each compartment has a blow-in plate. Near the top of the magazine are four blowout plates, which release if pressure in the magazine builds up too much.

WATER INJECTOR. - Another system used only in the Tartar launching system is that of injectors. A total of 96 injectors are used, inserted into the base of the stand. Each injector is a standpipe threaded into the base, and a water injection detector nozzle. If a missile were accidentally ignited in the magazine, only the injector located under the missile will actuate to douse the ignited one. There is also a sprinkler system in the magazine to shower down water from above.

DUD JETTISON. - The dud jettison device used with the Mk 11 launching system is similar to that used with Terrier missiles. On the Mk 13 and Mk 22, however, the jettison mechanism is on the launcher arm, and can be operated by remote control from the EP2 panel.

CARBON DIOXIDE SYSTEMS. - An additional means of fire protection provided in the Tartar launching systems is carbon dioxide, supplied by two independent systems. One system protects the area where the missiles are stowed and the other protects the inner or center compartment of the magazine where the power units, receiver-regulators, and electrical units and cables are mounted. The carbon dioxide is supplied from pressurized cylinders of liquid carbon dioxide, secured in an off-mount location. Heat-sensing devices in the magazine detect overheating when a rapid rise in temperature causes the system to activate. Normal changes in temperature do not cause tripping of the actuating levers. Release of the carbon dioxide rapidly vaporizes it and it spreads all through the magazine and reduces the temperature rapidly and smothers any fire.

WARNING. - Although carbon dioxide is not poisonous to breathe, it shuts off all supply of oxygen and quickly smothers all oxygen-breathing life. Observe the precautions posted in and on the magazines wherever carbon dioxide is used.

ANTI-ICING SYSTEMS. -Anti-icing equipment is not unique to the Tartar launching system; Terrier and Talos launchers are similarly equipped to ensure operation of the launcher under low temperature conditions. Pipe lines for the circulation of heated fluid are attached to the launcher and exposed portions of the magazine, such as the blast doors. The anti-icing fluid is pumped from a reservoir tank heated by the ship's steam system.

LAUNCHING SYSTEM CONTROL PANELS

The compactness of the Tartar launching system installation leaves no room for the control panels and therefore they must be mounted nearby. Figure 5-37 shows the location of the control panels for the Mk 11 launching system. The control panels for the Mk 13 and the Mk 22 systems are similarly located in a control station off mount but as near as possible to the launcher and magazine.

Missile Launching System Control Mk 9 Mod 0

The missile launching system control (fig. 5-37) regulates and directs operation of the missile launching system. The power distribution panel (EP1) controls the ship power inputs to

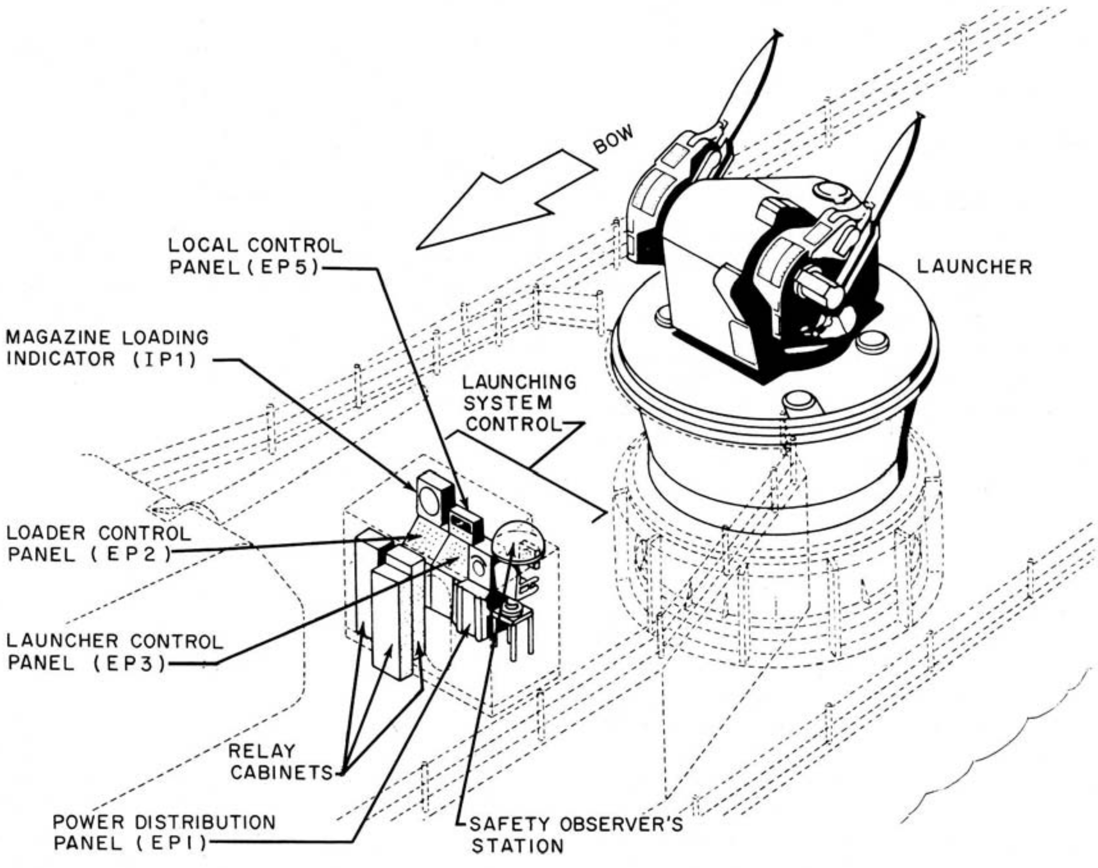

Figure 5-37.—Mk 11 (Tartar) launching system control station.

the missile launching system. The loader control panel (EP2) controls the movement of missiles between the magazine and the launcher guide arm. The launcher control panel (EP3) controls the launcher in loading, unloading, transfer, exercise, firing, and jettisoning. The local control panel (EP5) trains and elevates the launcher manually and displays an error indication to the launching system captain.

The magazine loading indicator (IP1), shows whether cells are loaded, if the warmup power is on, and if the missiles are latched or unlatched in their cells.

Control System Mk 13 Mod 0

The Mk 13 Mod 0 launching system has three remotely located control panels that are the control centers for the electrical circuitry. The EP1 panel is the basic distribution panel for all electrical power for the launching system. It contains circuit breakers, contactors, overload relays, fuses, switches, etc., for the electric motors and the supply circuits.

The EP2 panel is the operation control panel for the launching system and is manned by the launcher captain. It contains the switches and relays to select and control the type of operation, the lights to indicate the phase or sequence of operation, synchros for launcher load, dud jettison, strikedown and checkout positions, and amplifier and error meters for train and elevation.

The EP3 panel is primarily a test panel and is not manned during normal automatic operation. The launcher can be operated in local control from this panel and it contains the switches and jack plugs to perform tests on the launcher train and elevation systems.

Control System Mk 21 Mod 0

The control station of the Mk 22 Tartar launching system also has three control panels: EP1, EP2. and EP3. These have the same functions as the comparable panels in the Mk 13 system.

LAUNCHING SYSTEM FUNCTIONING

Mk 11 Launching System

In automatic operation, the launcher guide arms are elevated to vertical position and the launcher is rotated to position the arms over the selected missile compartments. A chain hoist rammer on each guide arm extracts a missile from the magazine compartment and raises the missile to the arm. On the arm, the folded tail surfaces of the missile open automatically, and connections are made automatically to transfer warmup power and control information to the missile, arm the missile, and complete the firing circuit.

In continuous operation the system is capable of firing a salvo every 20 seconds. Although ordinary operation is automatic, the system can be operated in manual step control. Safety and other interlocks ensure proper sequence of operation. The launcher and magazine require no operating personnel. The launching system control requires three men. Dud jettisoning units. one for each guide arm, are installed adjacent to the launcher. Auxiliary equipment provides for checkout, strikedown, and servicing of the missiles. The system, excluding missiles and auxiliary equipment, weighs approximately 66 tons.

Mk 13 Launching System

Like the Mk 11 launching system, the Mk 13 launching system can be operated in automatic or in step control. Automatic control, with orders coming from the weapons control station, is normally used for firing procedures, while step control is used for exercise, strikedown, and checkout procedures. Automatic control may also be used for unloading the missiles. Except for the fact that there is only one guide on the launcher, the steps in the loading and launching operation match those in the Mk 11 system. It has the same system, unique for the Tartar, for automatic erection of the fins on the missile after it is on the guide. When the missile is to be returned to the magazine, the fins must be folded before it can pass through the blast doors. The fins are folded by sending a crewman out on the launcher to do it; they are not folded automatically.

Mk 22 Launching System

A major difference between the Mk 13 and the Mk 22 is that the magazine structure of the Mk 22 is nonrotating, and the launcher is the rotating part. The launcher is positioned over the cell of the selected missile, which is then hoisted to the guide, and the launcher trains and elevates to the position ordered by the weapons control station. Operation can be automatic from the weapons control station or in step control from the control panels near the launcher, The launcher is activated from the EP1 power panel, and then it can be operated in automatic or step control.

SAFETY

The primary reason for the vast amount of information available on the subject of safety precautions is simply the desire to prevent accidents. Research has shown that a majority of all accidents come about through sheer carelessness. Not only is there a loss of time involved in an accident, but also there is an accompanying loss of either equipment, material, or, in the extreme case, life itself. Aside from these important considerations, there is a vast amount of money wasted in replacing damaged equipment, making investigations, paying for hospitalization or funerals, and for man-hours not worked during convalescence. These are but a few of the problems faced every day by the Navy because personnel fail to heed the posted and required safety precautions.

Practical safety features are incorporated into Navy equipment to eliminate potential hazards to personnel. Since familiarity with equipment leads to carelessness, observation of all safety notices and rules is mandatory. NO RELAXATION OF VIGILANCE SHALL EVER BE PERMITTED,

All personnel taking part in and observing operation of power equipment shall remain alert, keep clear of moving parts, and be thoroughly familiar with the safety precautions applicable to that equipment. At no time will skylarking be allowed in the vicinity of operating power equipment.

The following summary of safety precautions is intended to be general in nature but their importance should not be misunderstood.

Do not service or adjust live equipment without the presence of another person capable of rendering first aid.

Never measure potentials over 600 volts by means of flexible test leads.

Do not tamper with interlocks or any other equipment safety feature.

If possible, use only one hand when working on live circuits.

Never use electrical or electronic equipment known to be in poor condition.

Do not allow unqualified personnel to operate the control panels. Trainees or other persons undergoing instructions shall operate only under the strict supervision of a qualified and responsible operator.

Except for General Quarters, always sound the train warning bell and get an all-clear signal before training and/or elevating the launcher (before each time the equipment is to be moved); likewise sound the loading horn before moving any of the feeder components (before each time equipment is to be moved).

Whenever any motion of a power drive unit is capable of inflicting injury to personnel or material, not continuously visible to the person controlling such motion, the officer or petty officer authorizing the unit to be moved by power shall insure a safety watch. The safety watch shall be omitted in general quarters, but must be maintained in areas where such injury is possible, both inside and outside the unit being moved. There shall be telephone or other effective voice communication established and maintained between the station controlling the unit and the safety watch.

Do not enter the train circle when the launcher train motor is running.

Do not load a live round for a nonfiring exercise.

Be sure that all personnel are located in safe areas before proceeding with such operations as extending or retracting a loader chain (when loaded), opening or closing either the blast doors or magazine doors, indexing a ready service ring, and transferring missile-boosters.

Do not enter a magazine while loading or unloading procedures are under way.

Be thoroughly familiar with all posted safety precautions and those listed in the OP pertaining to the equipment to which you are assigned.

SUMMARY

As you study the different missile systems you will notice that many of the mechanisms and the electrical and electronic components are the same and operate in the same manner. Not that knowing one system means you know them all, for there are differences, but by making comparisons and noting the ways in which systems are different, you will find it easier to understand the operation of the several systems.

CHAPTER 6

A TYPICAL GUN AND MISSILE WEAPONS SYSTEM

This chapter will give you a brief overview of a typical gun and missile weapons system. The system described here is made up of elements that have been taken from Terrier and Tartar system. It illustrates the typical composition and functioning of gun and/or missile weapons systems (not including all weapons, such as depth charges, bombs, etc.). And it will provide the background that will lead to a better understanding of the system you have aboard ship.

WEAPONS SYSTEM CONCEPT

You have already studied the fundamental fire control problem. Now you will study some of the equipment used to solve that problem.

The effective use of any weapon requires that a destructive device (containing an explosive) be delivered to a target-usually a moving target. To deliver the weapon accurately, we must know both the location and the velocity of the target. Most targets now travel faster than sound, and must therefore be engaged at great distances. Against such targets, a weapon is most effective when it is used as part of a weapons system. A weapons system is the combination of a weapon (or multiple weapons) and the equipment used to bring their destructive power against an enemy.

A weapons system includes:

1. Units that detect, locate, and identify the target.

2. Units that direct or aim a delivery unit.

3. Units that deliver or initiate delivery of the weapon to the target.

4. Units that will destroy the target when in contact with it or near it. These units are usually termed weapons. Figure 6-1 illustrates these units and groups of units that make up a weapons system.

DETECTING UNITS

The first steps in using a weapons system and solving the fire control problem are to detect, locate, and identify the target. Initial contact with a surface or airborne target may be visual, or it may be made by radar. It is difficult to detect a target visually at long range, or even at short range when visibility is poor. For that reason, targets are usually detected by search radar. Search radars, as you know, keep a large volume of space around your ship under continuous watch. They give the ship fairly accurate information about the target's position, even when the target is hidden by fog or darkness. To determine a target's position we must know its range, its direction from the ship, and, for an airborne target, its elevation. Radar gives all three of these coordinates. (Radar has certain disadvantages, too. For example, it can be detected by an enemy at about four times the range at which it can pick up an enemy target.)

Optical devices are used as a supplementary source of information on slow-moving targets at relatively short range. They are useless against missiles or jet aircraft, which must be engaged while they are still beyond the range of optical instruments.

After we have detected and located a target, we must identify it. How can we identify a target that may be several hundred miles from our ship? The answer lies in a device called IFF (Identification, Friend or Foe). See Figure 6-1. Radar alone cannot tell the difference between friendly or enemy targets. But the IFF equipment can challenge an unidentified target, and determine from the answer whether the target is friendly. The equipment consists of two major units - the challenging unit which asks the question, "friend or foe," and the transponder which answers the question. IFF equipment is used in conjunction with search radar, and sometimes fire control radar. Briefly, this is how it works. To challenge a target you press a switch attached

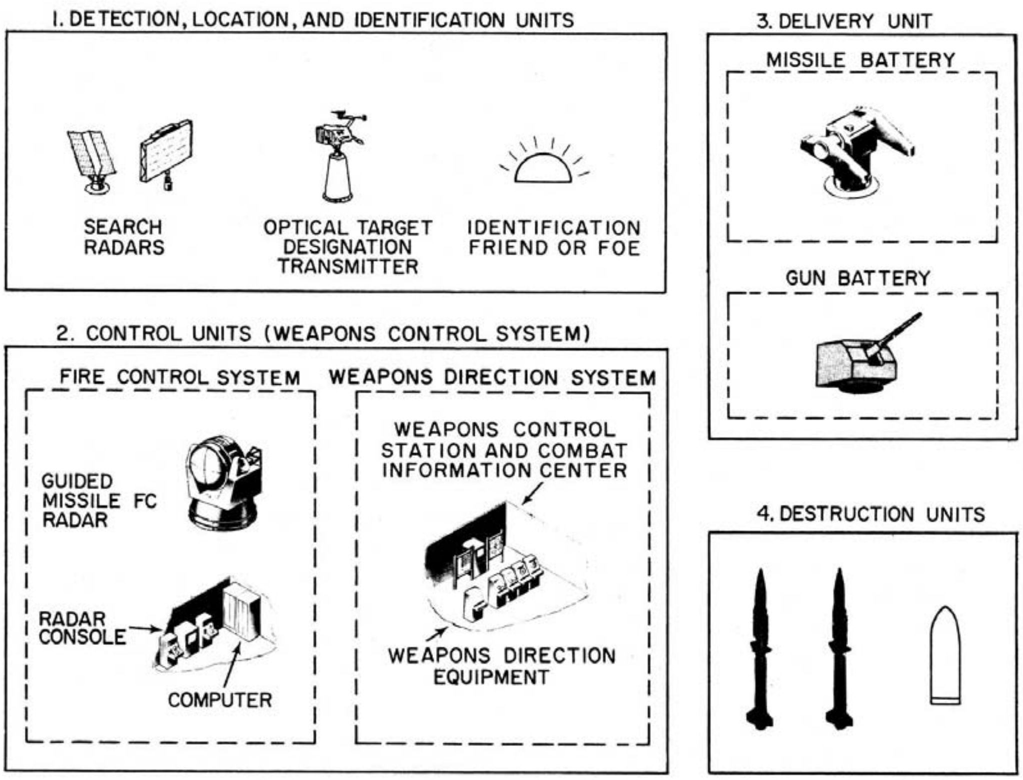

Figure 6-1.—Basic composition of a gun and missile weapons system.

to the radar. The transmitter will then send out a pulse of low power radio energy toward the target. If the target is friendly it will carry a transponder, which consists of a receiver and a transmitter. When the receiver picks up a challenge, it causes the transmitter to send out an answering pulse or pulses. The answer is usually a coded message. It is picked up by the challenging unit's receiver and sent to the indicator of the search radar. An enemy target will not know the code and therefore will not be able to answer the challenge.

CONTROL UNITS

Control units in a weapons system develop, compute, relay, and introduce data into a delivery unit, a weapon, or both. They direct, control, or guide the weapon (destructive device) to the target, and cause it to function in the desired way. These units form the heart of the weapons system. Note (fig. 6-1) that there are two groups of units in the control unit: Fire control system, and weapons direction system. These will be discussed in more detail later.

Types of Control Units

The devices that perform the control functions include:

DATA TRANSMISSION SYSTEMS that send target position information developed by the detecting units to the rest of the weapons system, and convey other data among the components of the weapons system. Examples are synchro, resolver, and potentiometer circuits.

COMPUTER DEVICES to process the input data from the detecting units and other sources, and put out the aiming and program instructions that cause the weapon to reach its target. Examples are rangekeepers and computers.

DISPLAY UNITS that display information at various locations on the ship. These are generally electronic or optical devices.

DIRECTING DEVICES which, with the aid of detecting devices, establish target location to a finer degree than the detecting devices alone. Directing devices can also function to directly or indirectly control missile flight. Examples are gun and missile directors, and radar sets.

REFERENCE DEVICES such as stable elements, which establish reference planes and lines to stabilize lines of fire, lines of sight, and other references. These units are gyroscopically controlled.

DELIVERY UNITS

Broadly speaking, delivery units launch or project destructive units toward the target. Examples are guns, missile and rocket launchers, torpedo tubes, and depth charge projectors. Don't think of these devices as weapons. The term WEAPON is properly applied to the destructive unit that is launched or projected. Thus a guided missile launcher is not, strictly speaking, a weapon; the missile itself is the weapon.

To be employed effectively against their targets, all weapons must either be aimed at their targets or must be programmed during flight. They may require both aiming and programming. Programming is the process of setting automatic equipment to perform operations in a predetermined step-by-step manner. Aiming and programming are done at or before the time of launching, either by or through the delivery device. This function is characteristic of all delivery devices, even the simplest. Aiming the destructive device (weapon) at the target may be done simply by positioning the delivery device (a gun barrel or launcher guide arm, for example). Or it may be done without aiming the delivery device, by placing program instructions in the weapon. Some missiles are programmed to start searching for the target after the launching phase is over. Examples of other programmed functions that could be performed in the weapon are ignition of propulsion units and arming of the warhead after a designated number of seconds of flight.

Types of Delivery Devices

Guns direct (aim) the projectiles by positioning the gun barrels, and the propulsion energy is provided by the propellant charge, which may be a separate component as in bag guns and semi-fixed ammunition, or enclosed in the powder case which is crimped to the projectile.

MISSILE LAUNCHERS retain and position missiles during the initial part of the launching phase, and, by means of attachments to the launcher, feed steering, vertical reference, and program information into the missile up to the instant of launch. Of course there are other types of delivery devices, such as torpedo tubes, depth charge and thrown weapon projectors, and rocket launchers. But guns, and missile and rocket launchers are most important to you as a GMM. You will be required to understand their function in the weapons system. The GMGs are responsible for operation of depth charge and thrown weapon projectors, rocket launchers, and the Basic Point Defense Surface Missile System. When you are ready for E-8 you will need to know about those also, so do not evade learning about them as you go along. Use your opportunities for learning.

DESTRUCTIVE UNITS

The end purpose of detection units, delivery units, and control units is to cause the destruction unit to intercept or pass near the target. It is then the function of the destruction unit to destroy or inflict maximum damage on the target. Except for projectiles used in small arms, and some of those used in calibers up to 40-mm, weapons and projectiles used in combat are loaded with explosives, and equipped with devices to set off their explosion at the proper time. For some weapons and projectiles, the proper time is the instant the weapon makes physical contact with the target. For those designed to penetrate targets protected by armor or concrete, the proper time is after penetration. Still others are intended to explode when they reach the vicinity of the target.

In some special types, the explosive is intended only to rupture the container so the contents can be disseminated in the area selected. Examples of these are various types of gas bombs (lethal or merely disabling), biological warheads, and various chemical warheads. In these types, the explosive is not the destructive force.

BASIC WEAPON COMPONENTS

All weapons and projectiles have these components.

1. A CONTAINER or BODY which houses the internal components. The body may have such other functions as piercing armor, breaking up into high velocity fragments when the weapon or projectile explodes, or improving the weapon's ballistic characteristics by means of fins or streamlining.
2. A DETONATING DEVICE (called a fuze, exploder, detonator, etc.) which initiates explosion at the proper time, and includes safety devices to prevent premature explosion.

3. A PAYLOAD which is the "reason for being" of the weapon or projectile. The payload usually consists of high explosive or nuclear material. Exceptions were mentioned above as special types.

Weapons of some types have their own propulsion systems. The outstanding examples are guided missiles, torpedoes, and rockets. With the exception of rockets, weapons that have a propulsion system also contain guidance and control systems.

To summarize the weapons system concept, we can say that any weapons system contains four major functional components, which are interrelated to make up the system as a whole (fig. 6-1).

REPRESENTATIVE SHIPBOARD WEAPONS SYSTEM

The equipments making up each of the four categories of functional components are enclosed in separate blocks (fig. 6-1). We will introduce and discuss the four groups of equipments in the order in which they operate to solve the fire control problem.

TARGET DETECTION, LOCATION, AND IDENTIFICATION UNITS

The first contact with an airborne target is usually made by air search radar. These radars are designed to keep a large aerial volume under nearly continuous observation. Jet aircraft travel at high speed, and may launch guided missiles against our ships from a great distance. This requires that our radar search be carried out to long range. To cover the necessary area, search radar uses a wide beam. In addition, most search radar antennas rotate as they search. Targets detected during this scanning process show up on the radar's target display indicators as alternately fading and brightening spots. It is difficult to determine target range, course, and speed from these spots. All of these factors limit the accuracy with which search radar can provide information about target position. For target information of the required accuracy, we must depend on fire control radars. We will discuss these radars later in this chapter.

After the search radar has detected a target and determined its approximate location, the next step in the development of the fire control problem is to identify the target. The problem of recognizing and identifying a friend or foe is as old as warfare. Passwords, flag hoist signals, and even the uniforms we wear are identification devices that have been developed through the years.

In modern warfare the identification problem is urgent. Radar systems present targets in the form of spots or spikes (called echoes) on a radar screen; but friendly and enemy targets look alike on the screen. Furthermore, high speed planes and guided missiles give us very little time to solve this problem. And when friendly fighter aircraft pursue enemy planes to within gun range of our ships, the identification problem is acute.

The safety of ships in a task force is another phase of this problem. If the enemy were able to use our identification system, he could make deadly approaches before his presence were known. In the past, enemy planes have actually followed our fighters to their mother ship and discovered the location of the carrier and her escorts. In such an instance the destruction of the enemy planes is vital, so that the location of the fleet will not be revealed.

Before we leave the subject of the major equipments that fall in the category of detection, location, and identification units, we want to emphasize that solution of the fundamental fire control problem begins with detection of a target. The next step is to locate it. And the final step in this initial phase is to identify it as friend or foe. These three steps combine to form the first phase in the functioning of a weapon system. At this point you should begin to see that you must think in terms of a complete weapons system in order to understand the functioning of each individual component in the system.

In the discussion above we have considered only air targets. Surface targets and underwater targets must also be detected and identified, and their location determined. A search radar is used to scan the area for surface targets; sonar is used for the detection of underwater targets.

Now let's consider the CONTROL UNITS in group (2) (fig. 6-1). These are not the control panels we described in chapter 5, which control only the missile launching system.

CONTROL UNITS IN A WEAPONS SYSTEM (THE WEAPONS CONTROL SYSTEM)

Once the air search radar detects and roughly locates the target, and the IFF equipment has determined whether it is a friend or foe, the target information from these sources is sent to the equipments that we have called control units. These units include fire control radars, computers, weapon direction equipment, stable elements, and many other mechanical, electrical, and electronic instruments.

Traditionally, the systems of equipment used for the control of a particular battery of guns, torpedoes, or other conventional weapons, have been known as fire control systems. But the complexity of guided missiles has required the introduction of new fire control instruments, and new terms of describe them. In the following paragraphs we will define some of these terms.

All of the units that are enclosed by the solid line in block (2) of figure 6-1 form a WEAPONS CONTROL SYSTEM. A weapons control system is defined as a group of interconnected and interrelated instruments that are used to control the delivery of effective fire on selected targets. The system is composed of a WEAPONS DIRECTION SYSTEM and one or more Fire Control Systems. It includes all the equipment necessary to control target assignment for guns, missiles, and ASW weapons.

Weapons Direction System

Any WEAPONS SYSTEM begins to function as a system as soon as a target is detected. A FIRE CONTROL SYSTEM however, begins its functioning by determining target position with all possible precision, so that a line of fire can be established. Before a fire control system can establish a line of fire, certain preliminary processes must take place within the weapons system. These processes are:

1. Detection of a target by search radar or other devices.
2. Identification of the target by IFF or other devices.
3. Evaluation of the target.
4. Designation of the target to a fire control system.
5. Acquisition of the target by a fire control system.

The weapons direction system coordinates and monitors the operations of the missile launching system and the fire control systems.

The target position and identification information obtained during the first two processes is sent to the CIC (Combat Information Center), and to the WCS (Weapons Control Station, Fig. 5-7). These two organizations of equipment and personnel may be in the same compartment or in separate locations (fig. 5-8). Here, we will consider them to be in the same compartment. This compartment also contains the units that make up part of the Weapons Direction System (WDS). This particular group of equipments is known collectively as Weapons Direction Equipment (WDE). The WDE, and minor units that support its function, make up the Weapons Direction System of a ship.

The purpose of the WDS is to perform those functions that are required during three phases of a tactical situation. During the first phase, the equipment provides electronic means for the display of targets detected by search radars, and it provides devices for selecting and initially tracking the targets that show up on the displays. These displays are similar to the PPIs that you are familiar with or have read about in Basic Electronics, NavPers 10087-B. Targets show up as bright pips or dots on the face of the scope.

As the tactical situation develops, and the targets get closer, the system provides means for evaluating the situation and assigning a fire control system or systems to acquire and track designated targets. This is the second phase in the tactical situation. The third and last phase requires that weapons be assigned by the WDS to the fire control system that is tracking the target. Before weapons are assigned, the tactical situation must be reevaluated.

EVALUATION. - So far in this discussion, we have introduced three new terms: evaluation, designation, and acquisition.

In fire control, evaluation is concerned with these questions.

1. What does the target intend to do? Is it going to pass close to the ship for observing, or is it going to launch an attack?
2. How threatening to the ship's safety is the target? If its obvious intent is to attack, how much time does the ship have to launch a counterattack? And what weapons should the ship use to repulse the target?
3. What kind of attack is the target capable of launching? If the target carries missiles, the ship must launch weapons that will reach the target before it can launch its missiles.

There are other factors involved in evaluating a tactical situation, but these sample questions should give you some idea of what the term "evaluate" means.

The equipment in the weapons direction system I presents a complete visual picture of the tactical situation, It displays all the targets that have been detected by the search radars. Each target must be evaluated with respect to the overall defense picture. The process of target evaluation is performed by ship's personnel with the help of equipment in the WDS, Decisions are made to bring the ship's weapons to bear on the most threatening targets. These selected targets must be assigned to the appropriate fire control systems. The assignment process includes two functions - designation and acquisition.

DESIGNATION. This is the step taken to assign the tracking element (director, radar, radar set) of a fire control system to a particular target. On the basis of target evaluation and the availability of fire control systems (some of which may be disabled, or busy with other targets), decision is made to assign a fire control system to the target. This is usually done by pressing a button to activate circuitry that transmits target position information from the weapons direction system to the antenna positioning circuits of a radar set, or the power drives of a director. These units automatically move the radar antenna to the position designated by the WDS. If the designation data is inaccurate the radar set must search for the target.

The searching process may last for a fraction of a second or longer, depending on the accuracy of the designation information and other factors. Once the fire control radar has found the target and starts to track, it can be said that it has acquired the target.

ACQUISITION. Acquisition by the tracking device is the process of accepting a designation from the WDS equipment which acquired the target, and starting to track it. A target is acquired when the radar has "gated" it, or the crosshairs in the director sights are on it.

In the preceding discussion we indicated that the WDS was further subdivided into the weapons direction equipment, and other equipment related to the overall function of the weapons direction system.

Fire Control Systems

A ship may have several fire control systems, depending on the number and type of weapons aboard. It may also have more than one missile or gun fire control system, or a combination of both. In addition, the ship may also have an underwater battery fire control system.

Missile fire control systems include directors, radars, and computers. The major functions of these components include tracking of the designated target, transmission of the target data to the weapons direction system, aiming of the launcher, and guidance of the missile to the target.

The GMM does not operate the fire control equipment but he needs to have some knowledge of what is taking place so he can cooperate intelligently with the FTs.

DELIVERY UNITS

Chapter 5 described the delivery units (launchers) for Terrier, Talos, Tartar, and Standard missiles. The launchers for Asroc Launching Group Mk 16 which incorporates the Asroc Launcher Mk 112, is the responsibility of GMTs and is not described in this text. Shipboard gun systems may include 3-inch, 5-inch, and 8-inch guns. These are the concern of the GMGs, but you need to know about them when your chance comes to make E-7 or E-8.

DESTRUCTION UNITS

A typical weapons system has gun projectiles and one type of missile; larger ships have more than one size and type of projectiles and two or more types of missiles. The different missile rounds of the Navy are described in other chapters of this text; other naval ordnance is described in Basic Military Requirements, NavPers 10054-C, with which you should be familiar.

In the following articles we shall describe the units that make up the weapons direction system.

TYPICAL WEAPONS DIRECTION EQUIPMENT

Some of the major tasks performed by the weapons direction equipment (WDE) are director-to-target assignment, launcher-to-director assignment, salvo select, missile warmup, missile firing, and emergency and dud firing. The WDE is the link between the search radars and the fire control system.

It is worth repeating that the weapons direction equipment includes displays and controls for the evaluation of target data, and for the selection and engagement of targets so as to ensure the most effective use of the gun and missile batteries. A typical WDE consists of one or more Target Selection and Tracking consoles, a Director Assignment console, a Weapon Assignment console, and the necessary cabinets to house power supplies and computer units.

TARGET SELECTION AND TRACKING CONSOLE

Figure 6-2A shows a typical target selection and tracking console. Regardless of the mark or modification, they all have the same general shape. The console is used for selecting and tracking targets detected by search radars. The principal indicator on a console of this type is a PPI (Plan Position Indicator) fig. 6-2B), that displays the bearing and slant range of all targets picked up by a selected search radar. The primary controls are a pantograph arm for selecting and tracking targets, and pushbuttons for assigning target-to-tracking channels. Other controls are provided for selecting various search radars for the PPI display, for selecting certain range scales, and for inserting target position and rate of movement data into the tracking channels.

Targets are displayed on the scope as radar video (pips). To select a target and assign it to a tracking channel, you position the pantograph sighting ring (fig. 6-2B) over the target pip and then press a channel button. Pressing the button gains electrical access to that channel, and simultaneously causes an identifying channel letter to appear next to the target pip. Successive corrections of pantograph position develop target course and speed data that are inserted into the tracking channels.

DIRECTOR ASSIGNMENT CONSOLE

The primary purpose of this console is to provide the information display and controls required to assign fire control systems to the targets being tracked by the target selection and tracking console operator, when it is determined that a specific target or targets should be engaged. Figure 6-3 shows the panel layout of the director assignment console for our basic WDE. Two plots are provided on the face of the console - a plan plot on the left, and a multipurpose plot on the right.

The plan plot (fig. 6-3A) Shows three range rings, and indicates true bearing with north at the top. Each target being tracked by that target selection and tracking console operator appears on

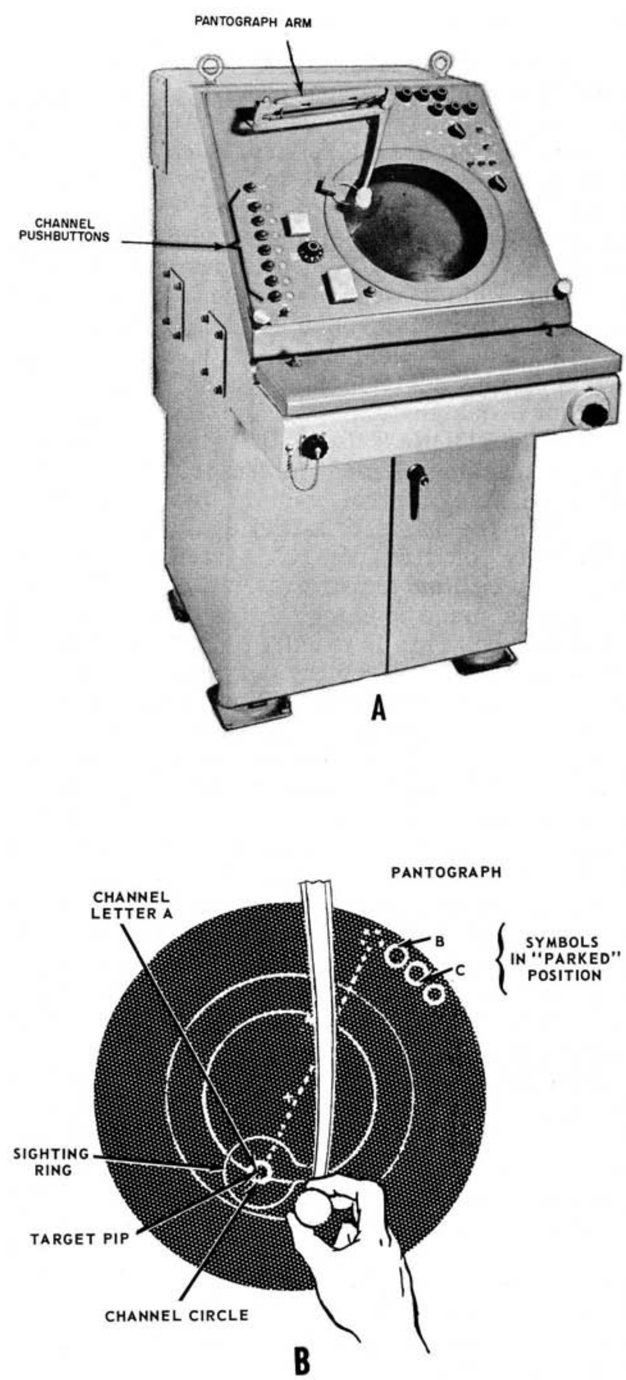

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Figure 6-2.—Typical weapons direction equipment: A. Target selection and tracking console; B. Plan Position Indicator (PPI) display on console.

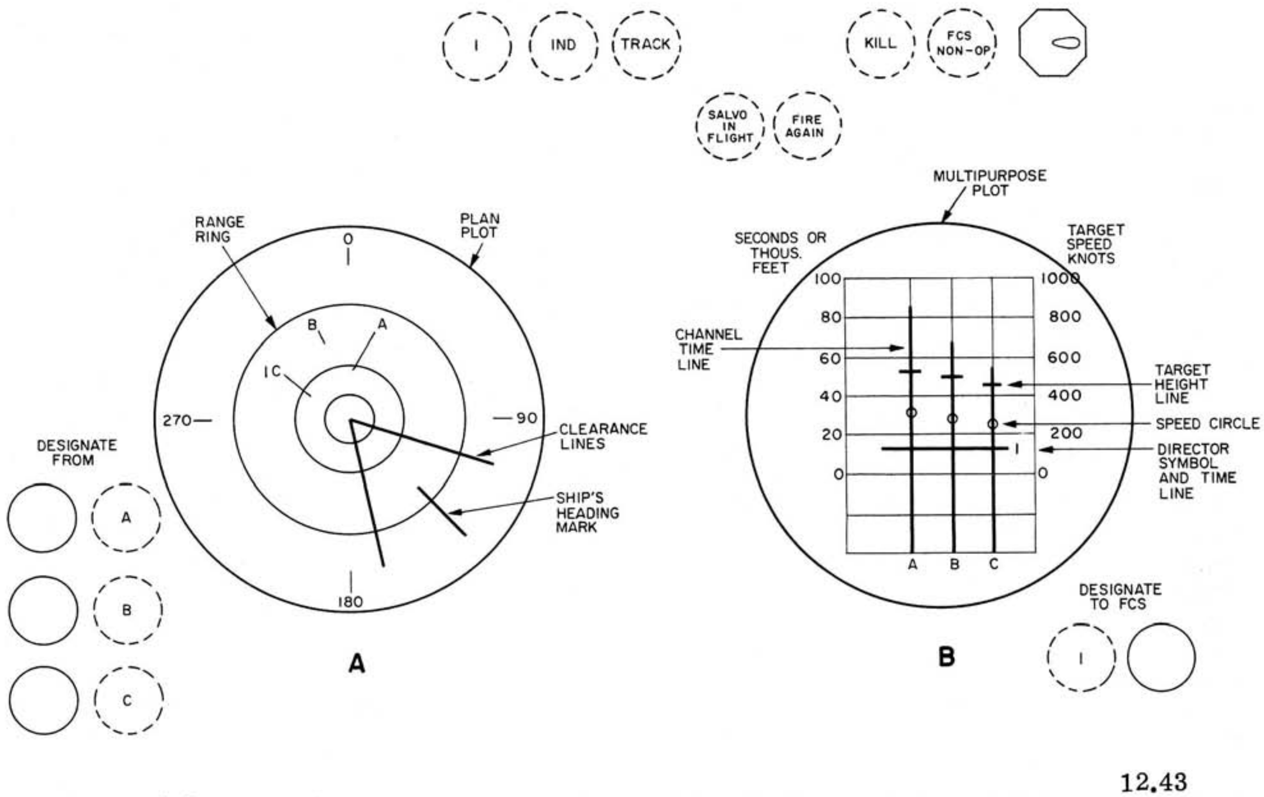

Figure 6-3.—Director assignment console display: A. Plan plot; B. Multipurpose plot.

the display as a letter, corresponding to the tracking channel from which it originates. The figure shows that tracking channels A, B, and C are tracking three separate search radar targets. The straight line associated with target A indicates the course and speed of this target. The number 1 indicates the position of the radar set in the basic fire control system. If the weapons control system had more than one fire control system, these additional system s would have associated numerals. A ship's heading marker, and radial clearance lines on either side of it, are presented electronically and rotate when the ship changes course. The sector between the two clearance lines indicates the region into which we may not launch missiles because of danger of striking the ship's superstructure.

The multipurpose plot (fig. 6-3B) is used primarily for making time comparisons. These comparisons help the operator to decide which of several targets to designate to a director, and to plan the future handling of targets that cannot be assigned immediately. Once the radar set acquires the target and begins to track it, the fire control system is busy solving the missile fire control problem. During this time the operator, with the aid of the information displayed on the plot, can decide which target is next in line for assignment to a tracking radar set.

The multipurpose plot is also used to indicate the speed and height of targets that are being tracked by the tracking channels. As you can see in figure 6-3B, it is divided into three vertical lines - each line representing a tracking channel. All changes in indications take place vertically, and you can read the values indicated as you would read a thermometer.

The vertical lines show, for each target, the time within which the radar set must be assigned and a missile fired in order to intercept the target before it can reach its Estimated Weapon Release Range (EWRR). The EWRR will vary, depending on the type of payload the enemy is carrying and on how accurately you guess what the payload is. This estimate range is manually inserted into the DAC and affects the length of the channel time line. The director symbol and time line (fig. 6-3B) comes into play only after the director is assigned. As this line decreases to zero level, it indicates the time left in which you have to make a target intercept at the maximum effective range of your system before he (the target) reaches the release range of his weapon. (For example, if you guess that the target's payload is an air-to-surface beam-rider missile, the EWRR might be on the order of 25,000 yards. At the left of the plot you can read how much time you have to assign the radar set so that it can acquire the target, track it, solve the problem, and load and fire a missile salvo, and have the missiles intercept the target before the target can release its missiles. This points up the need for quick evaluation. In conjunction with the plan plot, the multipurpose plot provides the necessary information to speed up this process. It relieves the human operator of the necessity of remembering how much average time each component in the weapon system requires to perform its function under varying conditions.

The scale used to measure assignment time is also used with the height line. The height line is a short horizontal bar which moves up and down the vertical channel line as target altitude changes (fig. 6-3B). In this case the number represents thousands of feet. To the right of the display is a target speed scale (marked knots) which is used in conjunction with the speed circle. The speed circle rides up and down to indicate target speed.

The long horizontal line shown in this plot represents busy time for the radar set. When the radar set is not acquiring or tracking, the time line and director symbol number rest at zero time. But when the radar set is assigned a target, the time line and symbol move up to indicate the time during which the set will be busy with that target; they slowly move down as time elapses. After a missile salvo is launched, the line and symbol continue to move downward until they reach zero. The missile should then have intercepted the target, and the radar set is ready to be assigned a new target.

Above the two display plots is a field of lamps relating to the gun and missile fire control system. The lamp with the numeral 1 in it is called the BUSY lamp. (If our basic weapon control system had more than one fire control system, each of them would be represented by a different lamp and number.) The BUSY lamp is sighted whenever the radar set is assigned a target. The IND lamp is lighted when the radar set is operating INDependently of the weapon direction equipment, as in tracking drill or radar calibration exercises. The TRACK lamp indicates that the assigned target is gated and is being tracked. The KILL lamp lights when a target has been destroyed. The observation of the kill is usually visual.

The FCS NON-OP lamp indicates that some part of the fire control system is not in operation. When missiles are launched, the SALVO-IN-FLIGHT lamp lights. If another salvo is ordered to be fired, the FIRE-AGAIN lamp lights to indicate that this order has been sent to the weapon assignment console, but that the salvo has not yet been fired.

The pushbuttons at the lower left labeled DESIGNATE FROM, and the pushbutton at the lower right labeled DESIGNATE TO FCS, are used in making assignments of the radar set to one of the three tracking channels, A, B, or C. The operator makes the assignments by simultaneously pressing the selected' 'designate from" button and the "designate to FCS" button until both lights function. This process connects the radar set to the selected tracking channel and slews the radar set automatically onto the target. At this time the radar repeat-back symbol moves until it is superimposed on the track channel symbol. This indicates to the director assignment console operator that the radar is tracking the proper target.

WEAPONS ASSIGNMENT CONSOLE

The Weapons Assignment Console (WAC), is designed to operate with the fire control system and launcher. It displays data from the fire control system, giving the target's present and predicted intercept positions, and information from the computer indicating whether or not missile intercept is possible. It also has a summary display of launcher information.

The missile firing key is located on the weapon assignment console. Decision of whether or not to fire is made from this station. The target may be out of range, for example, and this information would be shown on the console.

The console has a cathode-ray tube display showing a horizontal plot and true bearing, with own ship's position in the center. Around this plot is a fixed bearing ring. Radial lines from the center to the edge of the plot, generated electronically, indicate launcher unclear areas caused by ship's heading. These lines rotate with changes in ship's heading. This display is similar to the plan plot of the director assignment console (fig. 6-3A).

The other indications on the cathode-ray tube display appear only while the fire control system is tracking a target. These indications are:

1. An "X" indicating target present position.
2. A small circle indicating target future position at the predicted point of intercept.
3. A large circle about the center, which indicates the maximum range the missile can reach at the target's predicted altitude at intercept.
4. A thermometer type display at the left hand edge of the plot, giving the target's predicted altitude at intercept (H).

LOCATION AND OPERATION OF CONSOLES

Directors, gun mounts, and missile launchers are mounted on the deck; search radars are above the deck. Normally, missile directors are not manned and have no optical tracking equipment. Full radar control is the only type of operation possible. There are no provisions for local operation in the director although the radar operator can position the director from the radar console. In both gun and missile directors, the optics and radar antenna are stabilized to a varying degree. Target data are transmitted to the computer.

Optics are used chiefly for gunfire control. Gunsights, gunsight telescopes, lead-computing sights, and optical rangefinders are examples.

Figure 5-8 shows the shipboard location of missile system components on three types of ships, CAG, CLG, and DLG. The search radars, high up on the ship's superstructure, scan the surrounding sea and sky for targets for all types of weapons. They transmit target data to the weapon direction equipment where the signals appear on the scopes, to be interpreted by the operators. The computer converts the radar signals for presentation on the PPI-scope (fig. 6-2).

In case of casualty to the primary search radar, a secondary source of target information may be available from other search radars. (Not all ships have a secondary source.)

If there are multiple targets, which is likely to be the case in an attack, the threat of each target must be evaluated. With today's supersonic planes, missiles, and swift ships and submarines, the time to make decisions is very limited, and a weapon director must be assigned very quickly to the most threatening target. The technicians and officers in CIC study the target's indications and movements even before the target video signals show on the weapon direction equipment, A target tracking radar is quickly assigned to pinpoint the location of the target, determine its speed, and height (for air targets). This information enables the weapons officer to determine which weapon is best suited to engage the target, and a director is assigned, either a gun director or a missile director. The positions of the targets in the tracking channels are transmitted continuously to the director assignment console. The console operator evaluates the targets on the basis of this information and assigns a fire control system. The weapon assignment console has charge of launcher assignment and selection of the missile. This time of missile firing is very important since we must strike for missile intercept before the target reaches its release point, and releases its own missile. This means that loading time must be precisely controlled. Each GMM must do his job with speed and precision.

Missiles must have a certain warmup period before being fired; but it must not be too long, or the electronic balance will be upset by the heat generated within the missile. This means that the missile cannot be energized well in advance of the expected launch. The WAC operator must make a decision as to when to begin warmup.

A TYPICAL FIRE CONTROL SYSTEM

Gunfire control systems are adequately covered in the preceding chapters. In chapter 2 we discussed basic gun fire control principles and the elements of gun fire control systems; therefore these systems and equipments will not be discussed in detail here. In this section we will discuss only the equipments that make up the fire control system of a typical guided missile ship.

Look again at figure 6-1. We have assumed that the fire control system shown in the illustration is capable of controlling gun and missile batteries at the same time. This is a valid assumption because there are systems of this type in the fleet - Tartar, for example.

The fundamental fire control problem contains three basic elements - a line of sight, a prediction angle, and a line of fire. The line of sight is established optically or by radar, using a director or a radar set. A fire control computer produces the prediction angle in the form of gun and missile orders. These orders are transmitted to the guns and missile launchers to position these equipments along their respective lines of fire. The above statements indicate that there are two basic equipments needed to solve the fire control problem when guns and missiles are used as weapons. These two equipments are a director and a computer. You might add another instrument - the stable elements, but its function is sometimes performed by a device included in the director. So we can say that a complete fire control system contains a director, a computer, and a stable element which mayor may not be a separate unit. When separate, the computer and the stable element (fig. 6-4) always operate as a pair. Directors, gun mounts, and missile launchers, mounted on the deck, measure their position with respect to the deck plane. Ship's roll and pitch are independent of target position, and therefore affect all measurement of target's position and motion. Stabilization is needed to keep the line of sight on target and the line of fire on an aiming point in space. Corrections are needed by the computer for LOS and LOF.

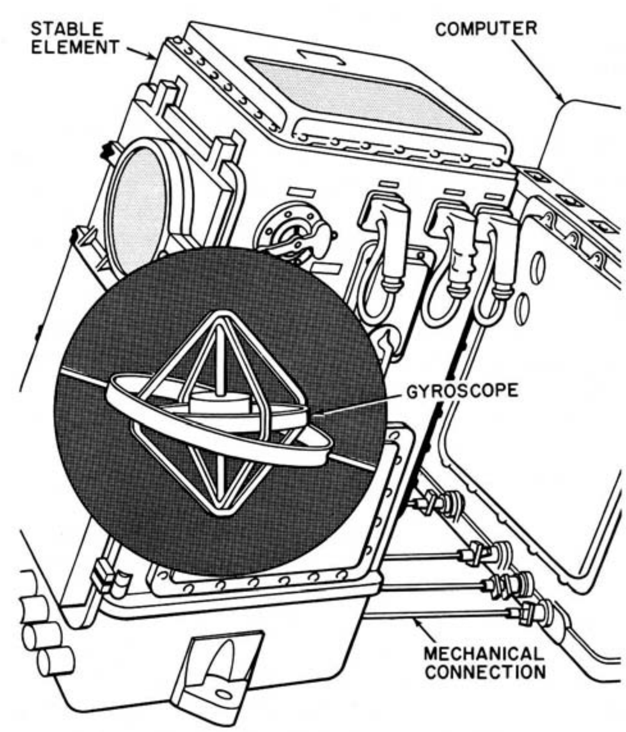

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Figure 6-4.—The stable element is a gyroscopic device.

FUNCTIONS AND PROBLEMS OF FIRE CONTROL

Any combined gun and missile fire control system has four primary basic functions: to acquire and track targets; to develop launcher, gun, and missile orders; to guide missiles to the target; and, in some instances, to detonate the missile warhead.

Secondary functions of the system are to provide target information such as target speed, target course, range to the target, and system and weapon status information to the display units of the weapon direction system. This information is used to evaluate the tactical situation and to aid in the fire control system and weapon assignment

The Director or Radar Set

The director or radar set is the eyes of the fire control system. It can search for, detect, acquire, and track a target; and it can "capture" and guide a missile. At this point let's stop and consider the terms "director" and "radar set." There may be some confusion in your mind as to their exact meaning. The equipments perform the same functions in the weapon system, but they have different physical arrangements. A director contains a radar and/or optics for tracking and ranging, and it is usually manned (in gun or gun/missile fire control). A radar set has no optical tracking device or rangefinder. It is not manned in the sense that a man is located inside the antenna supporting structure. True, there is an operator in the radar control room; but his primary function is to monitor the equipment and make sure it is functioning properly.

In the rest of this chapter we will use the term "radar set," rather than director, because that name has been given to the newer equipments that perform the same function as a director.

The radar set described here, and illustrated in figure 6-1, is an automatic-tracking gunfire control and missile guidance radar. It receives target designation data from the weapon direction equipment, and uses this information to acquire and track a designated target. If guns alone are used to fire on the target, the radar set tracks the target to provide information needed to solve the gunfire control problem. If guided missiles are used, the radar not only tracks the target but transmits radar signals to capture the missile and guide it to the target (if it is a beam- rider or a command guidance missile).

Of course, as we have mentioned before, the radar set performs all these functions simultaneously if guns and missiles are used at the same time. Also, it can operate as a search radar if circumstances require.

The radar set can transmit simultaneously, on a common nutation axis (fig. 4-3), three distinct beams of radar energy-the tracking, capture, and guidance beams. A narrow tracking beam first acquires and tracks the target automatically. The wide angle capture beam captures the missile after launch, and holds it until it enters the narrow guidance beam (fig. 4-19) that guides it to the target. The capture and guidance beams are transmitted simultaneously; the missile distinguishes between the two because they are coded differently.

The radar set consists of two major groups of equipment: an antenna group, and a control and power group. The antenna group, which is located above deck, consists of a pedestal upon which are mounted the antenna and the necessary electrical and mechanical components required to stabilize and position the antenna. Housed inside the mechanical structure of the antenna group are the transmitting, receiving, and associated microwave circuits. Here, too, are located the gyroscopes that space-stabilize the antenna, and thus the radar beams, to compensate for the roll and pitch of the ship.

The control and power equipment group is located belowdecks in a compartment usually called the radar room. This room contains the radar consoles used to operate, monitor, and control the radar set. Also located in the radar room are the cabinets containing the power supplies that provide the operating voltages for the various units in the radar set.

Typical Gun and Missile Computer

The typical gun and guided missile fire control computer described here is an electromechanical type designed to operate automatically. No operating personnel are needed. It is located in the ship's plotting room, and is used with the radar set described previously. The computer is a dual ballistic computer. In other words, it solves the gun and missile fire control problems simultaneously.

The computer has three basic ways of operating. It can operate when designation is desired; then, after the radar set has acquired the designated target, the computer aids the radar set in tracking it. As soon as the guns and/or missiles have destroyed the target, the computer shifts to the air-ready method of operation. These different methods of operating are called modes. The various modes of computer operation can be briefly described as follows:

AIR-READY MODE.-In this mode the computer is energized, but is receiving no information. It generates orders only to put the radar set, launcher, and guns in predetermined air-ready positions. For example, the air-ready position of the radar set may be at zero° of train and 45° of elevation; the launcher air-ready position may be at 180° of train and zero° of elevation.

DESIGNATION MODE. - The computer goes into this mode of operation when it receives a "director assigned" signal from the director assignment console of the WDE. The computer directs the radar set to the designated target position so that the radar line of sight will point at the target. It also sends a search program to the radar set. The search program causes the radar beams to move in a preset pattern about the designated target position. The radar searches for the target, and when the target is gated the computer automatically goes into the track mode of operation.

TRACK MODE. - When the radar set acquires the target in range, bearing, and elevation, the track mode starts. The radar set then transmits an on-target signal to the computer. The computer sends signals to the radar set that cause it to drive at a rate that will keep it locked on the target. The computer determines the proper lead angles for the launcher and guns, and transmits these quantities to them in the form of electrical signals. These signals drive the guns and launcher to the proper aiming positions.

Before the missiles are launched, the computer determines and transmits to the missiles quantities that move the missile gyros to their proper positions. The computer also transmits, to the various display consoles of the WDE, tactical data such as present target position, future target position, and missile time to target intercept (time of flight).

DELIVERY UNITS IN A TYPICAL WEAPONS SYSTEM

The delivery units of a typical weapons system are the gun mounts and the missile launcher. This section sums up operation of a typical

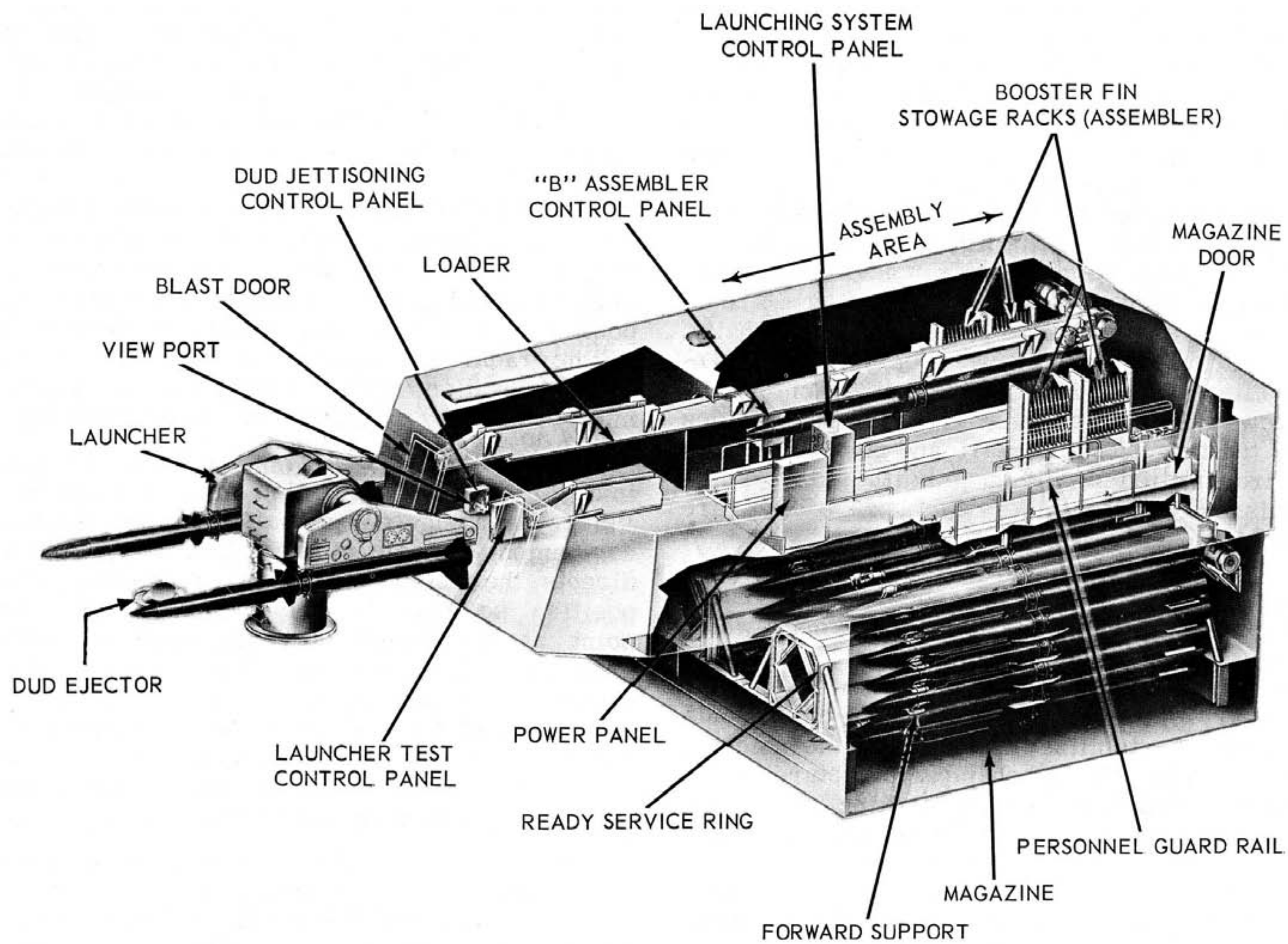

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Figure 6-5.—Typical Terrier missile launching system Mk 10 Mods 0 to 6.

missile launcher and the equipments associated with it. Guns are covered in Military Requirements for PO 3&2, NavPers 10056-B, and Seaman, NavPers 10120-E.

Guided Missile Launching System

The guided missile launcher shown in figure 6-5 is part of a group of equipments that are known collectively as a Guided Missile Launching System. A guided missile launching system has three major components:

1. Guided missile launcher
2. Guided missile launcher feeder
3. Guided missile launching system control

The primary purpose of a guided missile launching system is to stow missiles until needed and then supply them to a launcher for firing. Its secondary function is to remove unfired missiles from the launcher and return them to the missile stowage area (or jettisoning them in case of dangerous misfire or a dud). In missile replenishment, too, the launching system equipment is used to strike the missiles below to the magazine, or to bring them up for unloading.

GUIDED MISSILE LAUNCHER. - All Navy missiles that are launched from ships (not including submarines) use short rail launchers. (These launchers are commonly called Zero Length launchers.) This type has one or two, usually two, launcher arms (or rails). The launcher shown in figure 6-5 is the dual-rail type. It receives and secures two complete missiles - one on each launcher arm... The launcher automatically trains and elevates in response to synchro signals (missile launcher orders) from the fire control computer. Through electrical connections on the launcher arms, the missiles (except Standard) receive warmup power before launch. Warmup power is used to bring the missile gyros up to speed, and to warm up the vacuum tubes, without taking power from the missile power supplies. Preflight information is also supplied to the weapon through contactors in the launcher arms, and the firing circuit is connected through the launcher to the missile's internal firing circuitry. The launcher can automatically return to a predetermined fixed position in which a new missile can be loaded on the launcher arm, or an unfired missile can be returned to stowage.

GUIDED MISSILE LAUNCHER FEEDER. - The purpose of this group of equipments is to stow guided missiles and their boosters in magazines, to remove them from the magazines, and to load them on the launcher arms. There are several types of feeders, but they all have these two purposes. The feeder described here is the most common type. The other systems are similar in operating principles.

The feeder consists of three functional groups of equipment - the magazine, the loader, and the assembler. Figure 6-5 shows the magazine area. The main piece of equipment in the area is the ready-service ring, in which the missile-booster combinations are stowed. The ring can rotate like the magazine of an automatic revolver. This rotating motion of the ring is called "indexing." The ring is indexed to position a missile round so that it can be placed under the loader. The loader provides a means for removing the missile rounds from the ring and loading them onto the launcher rails. Figure 6-5 shows one loader rail. Usually there are two of them. Continuous grooves in the rails function as tracks to support the booster shoes during loading operations. The booster shoes are T-shaped and horseshoe-shaped lugs. The rails of the launcher arms are also grooved to receive these lugs. During the loading or unloading operation, the launcher is positioned so that the loader rail and launcher rail form one continuous track. Missiles are loaded onto or unloaded from the launcher by a loader chain that is guided by a track in the loader rail. A hook, or pawl, attached to the chain, engages the rear shoe of the booster.

The third group of equipments that make up the feeder is called the assembler. The assembler is essentially a set of racks for stowage of the aerodynamic surfaces (booster fins and missile wings). The wings and fins are mounted on the booster and missile manually, by men assigned to perform this operation.

GUIDED MISSILE LAUNCHING SYSTEM CONTROL. - This equipment group includes the panels used to operate the missile launching system. The power panels contain circuit breakers, overload relays, and other electrical components required by the various power drives that control the movement of the launcher, rammer, and ready-service ring. Other panels contain operating controls that are used to start the system and control its operation. These panels normally respond to orders from the WDE. For example, the WDE may send an order to ALERT the missile launching system. An ALERT light on a panel flashes, indicating to the operator that WDE wants the missile launching system's equipment put into operation. The orders transmitted from the WDE to the missile launching system are of interest to the GMM, for he must learn to operate the control panel at any station in the launching system.

Types Of Orders. - The MISSILE SELECT order is transmitted from the WDE to the launching system to indicate the type of missile to be loaded on the launcher. There are several types of Terrier missiles. All of these types may be loaded together in a single magazine. This is called mixed loading. When the launching system has selected the type of missiles called for by the WDE, it sends back a signal indicating that the order has been carried out.

The LOAD order tells the launching system to start loading a missile or missiles. A load order may be "continuous," "single," or "hold." A "continuous" order causes missiles to be continuously supplied to the launcher. This operation is similar to "rapid or continuous fire" in conventional gunnery. The "single" order causes one missile per arm to be loaded on the launcher. The "hold" order holds the launching system in a ready-to-load condition.

When the launching system receives the UNLOAD order, it unloads any missiles that may be left on the launcher arms, returning the missiles to the magazine. In some mods, this can be done in automatic operation; in others it must be done in step operation.

The INTENT-TO-LAUNCH (ITL) is similar to the conventional "commence fire" order in one respect- it is transmitted by closing a firing key. But, while the gun firing circuit is completed almost instantly when the key is closed, there is a slight delay before a missile firing circuit is completed. This delay is necessary to establish certain operating conditions in the missile, and in other equipments in the weapons system. Before the missile can be fired, it must indicate that it is ready to be launched. This indication, "missile-ready-to-fire," is sent through the launching system control circuits back to the WDE. Almost every piece of equipment in the weapons system affects the operation of the firing circuit, either directly or indirectly.

Gun Battery

There are a number of situations in which a missile is not the best weapon. The target may be too close, or it may be too small to be worth expending a costly missile to destroy it. The search radars locate the targets, and the tracking radars (or directors) track the target and pinpoint its location. From the information shown on the display scopes in CIC, the weapons officer must decide what weapon to use against each target and must transmit his orders so action will be taken at once. Multiple targets may require the use of several kinds of weapons simultaneously. Radars can search and track more than one target at a time, and certain computers are capable of solving gun and missile fire control problems simultaneously.

DESTRUCTION UNITS IN A TYPICAL WEAPONS SYSTEM

As we mentioned earlier in this chapter, our typical weapons system is designed to control two weapons, the gun (projectile) and a homing or a beam-rider missile. These weapons have been discussed in this book, or in the books in the reading list. In addition to surface-launched weapons, there are air-launched and underwater-launched weapons. These are not discussed in this book, but you have been given basic descriptions in Seaman, NavPers 10120-E, and Military Requirements for PO 3&2, NavPers 10056-B.

WEAPONS SYSTEM FUNCTIONING

To provide a brief review of what you have studied so far in this chapter, we will list the principal steps or phases a typical weapons system goes through to accomplish its mission. The mission, of course, is to destroy the enemy or a practice target. The principal steps, in chronological order, are:

1. TARGET DETECTION. Search radars detect targets at long ranges, to allow time for the weapons system to go into action and complete its function.
2. TARGET SELECTION- From the information supplied by the search radars, the weapons direction system selects the targets that appear hostile, and that require missile and/or projectile interception, and inserts them into tracking channels. Target selection and tracking is performed by personnel assigned to the target selection and tracking console-a unit of the weapons direction equipment.
3. SEARCH RADAR TARGET TRACKING. The tracking channels (computing circuits) continuously track selected search radar targets to generate target rate of movement. This data appears as a symbol (letter) on the face of a large cathode-ray tube (scope). When the tracking channel has computed the correct target course, speed, and rate, the symbol on the scope will remain superimposed on the target echo supplied by the search radar. This computed target position and rate data are used for evaluation of the tactical situation presented to the ship, and for transmission to other units in the WDS - especially the director assignment console. Each target that is being tracked is assigned a different symbol to prevent confusion.
4. EVALUATION. The weapon system evaluates the threat of various targets, decides which should be engaged by guns and which by missiles, and decides which targets should be given the priority. The evaluation is performed by personnel, but they are aided in this process by the displayed information on the various consoles in the WDE and CIC.
5. DIRECTOR ASSIGNMENT. A radar set is assigned to the target having the highest priority. When a radar set is assigned, this implies that a fire control system has been included in the assignment.
6. ACQUISITION., The assigned radar set (fire control system) gets on the target.
7. TRACKING. The fire control radar tracks the target to provide precise target position and rate data. The computer associated with the tracking radar operates on the data from the radar set to provide the solution to the fire control problem. The computer answers are

supplied to the guns and launcher as synchro signals to position these units in train and elevation.

8. REEVALUATION AND WEAPON ASSIGNMENT. The target that is engaged by the fire control system is reevaluated with respect to the tactical situation (this may have changed), availability of the launcher or gun, and the range limitations of the weapons.

9. LOADING. Missiles are loaded on the launcher, and the guns are prepared for firing.

10. LAUNCHER SYNCHRONIZATION OF MISSILE ORDER INPUTS. Synchro transmitters and receivers are inherently "self-positioning" or synchronizing. A synchro system is used to transmit a training order from the director to the launcher. The synchro transmitter, mounted on the director and geared to it, transmits the movement and position of the director. The dial of the synchro receiver in the launching equipment constantly indicates the director's position. The launcher will train to match the receiver dial. The synchros are connected electrically, but the launcher is moved in train and elevation by hydraulic power. The synchros actuate hydraulic pilot valves that actuate and control the hydraulic system.

The launcher is capable of unlimited train (unless located in a position where this is not possible). The guide rails may be elevated between -10° and +90° with respect to the deck (for Tartar systems) though the maximum angle of fire is 85°. "Stow" and "load" positions for Terrier Mk 10 systems both are between 1° and 3° (varies with Mod) elevation and 180° train, but Tartar systems load and stow at 90° elevation, Latches secure the launcher in the required load or stow position.

An ever-present problem is the limitation placed upon firing arcs by the ship's superstructure. The launchers guns are electrically cut out if they are aimed at any part of the ship. The mechanical actuator is the nonpointing zone cam, The cutout area is referred to as the blind zone for the weapon. An aft gun or launcher cannot fire dead ahead at low elevation angles, and a forward gun or launcher is cut out directly aft, except where the gun or the launcher guide can be elevated above the firing cutout zone.

Synchronizing networks or circuits may use relays, diodes (semiconductor and vacuum tubes), and gas tubes (thyratron or neon). The purpose of the synchronizing circuit is to prevent overspeeding of the drive where large changes are necessary. If a large error signal is allowed to drive the equipment at an excessive speed, and there is a radical change of target speed or direction, the inertia of the moving heavy equipment could be so great as to drive past synchronism. The time required for the launcher to synchronize is about 5 seconds. Upon assignment, the loaded launcher synchronizes in train and elevation with the launcher orders generated by the computer. The Launcher Status Console operator supervises missile and launcher readiness, noting that the launcher is synchronized and that missiles are warmed up and ready to fire. The sequence of operations is similar for all surface launched missiles. After the missile is on the guide arm and the blast doors are closed, the launcher train and elevation latches retract. The launcher starts to synchronize to the director and synchronizes to the firing position. The salvo firing circuit is closed and the missile is activated. The arming tool winds and retracts, the guide arm contactor retracts and the booster is ignited.

The missile clears the guide arm rails. Then the missile on the other guide arm is fired. If the order is for continuous firing, other missiles are brought up from the magazine, the wings and fins attached, and warmup applied. As soon as both guide rails are empty, the launcher synchronizes to load position, and the cycle is repeated.

11. LAUNCHING AND FIRING. The missiles are launched at the proper time and in the proper direction. The guns are loaded and fired.

12. MISSILE GUIDANCE. The fire control radar guides each missile to the target being tracked. Gun projectiles, of course, receive no guidance.

13. TERMINAL PHASE. When a missile or projectile approaches to within lethal range of the target, a VT fuze detonates its destructive charges. This is the "moment of truth" for the weapons system.

INTERSYSTEM COMMUNICATIONS

All the information gleaned by radars and computed by computers is of no value if it is not available to decision-making personnel. The information must be available instantly to officers, petty officers, and other men who have the knowledge and competence to interpret and apply it. A complicated network of communications, with duplicate equipment to take over in case of failure or damage, is necessary to keep data transmission a continuing process. Figure 6-6 is a simplified schematic of the flow of data in

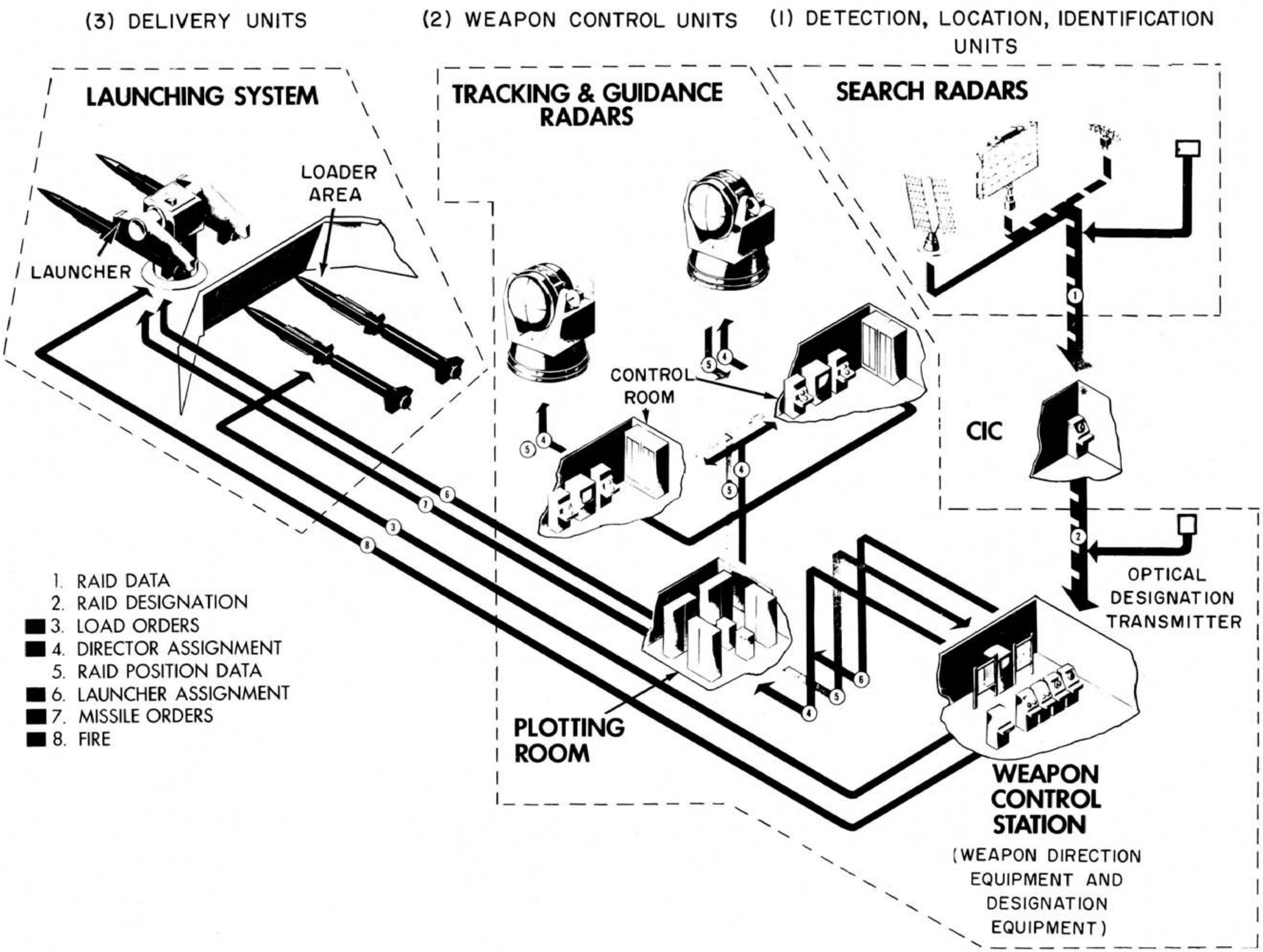

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Figure 6-6. – Flow of data and orders in Terrier weapon system: simplified schematic.

Gene Slover's US Navy Pages

Phil Hays' Talos Missile Page

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a Terrier weapon system. Let's follow through on the flow of data in a typical weapon system.

The search radars in figure 6-6 include a surface search radar (AN/SPS-10), a primary search radar with pencil-beam for long-range scanning (AN/SPS-26), and a fan-beam radar for long-range aircraft detection (AN/SPS-29). Targets not identified by the radars are challenged by IFF. Results are relayed to CIC, the Pilot House, and the Weapons Control Station, where they are displayed on scopes. IFF is normally controlled from CIC. By switching at the radar distribution switchboard, the radars can be connected directly to the target tracking consoles. The optical designation transmitter is used if there is failure of the search radars or if the target is too low for detection by search radars.

The designation equipment has a target selection and tracking console in WCS and another in CIC. From the information displayed on the PPI-scope, CIC assigns tracking channels for the targets in the order of their apparent threat. Telephone communications are available for all personnel in the system. so decisions and changes can be given verbally to supplement (or replace) pushbutton signals.

The operator of the Director Assignment Console (in WCS), on the basis of information from the tracking radars and director displayed on his console, assigns a missile launcher or a gun system +.0 a particular target.

The operator of the Weapons Assignment Console (in WCS), studying the display of information on his scope, selects the missile rail to be loaded, the method of loading (single or continuous), pushes the button that initiates warmup power to the missile, selects the number of missiles to be fired per salvo, and assigns the launcher to a fire control system. He can also cancel the launcher assignment.

At the control panel in the launcher system, the operator watches the succession of lights and, if anything is wrong, he immediately notifies CIC. It may be necessary to select another missile or even assign another launcher; the target does not wait for repairs to be made.

The whole operation takes less time than it takes to tell about it. Each man must be master of his job.