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Capt. BERTRAND R. BRINLEY
Project Officer, First U. S. Army Amateur Rocket Program

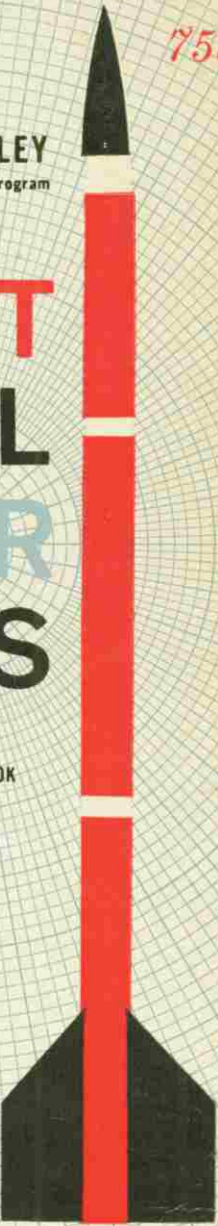
ROCKET MANUAL FOR AMATEURS

THE COMPLETE, AUTHORITATIVE HANDBOOK
FOR SAFE PROCEDURES IN

- DESIGN
- TESTING
- PREPARATION OF FUELS
- FIRING

OF ROCKETS WHICH YOU
CAN MAKE YOURSELF

Foreword by WILLY LEY



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In this book he tells you how to organize your own group for rocket experimentation. He shows you how, for a few dollars, you can design and build rockets that will surpass the best performance of rockets built by pioneer scientists. In step-by-step directions he outlines safe procedures for rocket testing and firing. And in the final chapter he tells how to evaluate accurately the performance of your rocket so that you gain the maximum of information.

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ROCKET MANUAL
For Amateurs

by Capt. Bertrand R. Brinley

Foreword by Willy Ley

Illustrated by Barbara Remington

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FOREWORD

I know in advance of publication that this book will be subjected to strong criticism by some people—and will be hailed by others—with a good chance of being labeled "controversial."

Rocket experimentation by amateurs just happens to be one of the areas where people fail to see eye to eye. Nor is this controversy of whether people should be permitted to do as they please (within reason, of course) or whether Something Should Be Done as new as it looks. Even before the space age was headlined by the beeps from Sputnik No. 1 there were dedicated groups of amateur rocket experimenters who could not only point to successful flights but to an unblemished safety record. They could also tell stories of harassment of various kinds.

But it is true that the problem has assumed major proportions since Sputnik No. 1. For a year or so virtually every youngster wanted to build rockets. And there have been accidents, even fatal ones. The reaction to these accidents took different forms. On the one hand several companies which are in the rocket business issued safety manuals free of charge. So did the Army. Somewhat later the Armed Forces began to assist amateurs actively, as is told in the body of the book by the man who did much of the assisting. On the other hand the large and respected American Rocket Society came out repeatedly against any and all amateur experimentation. And I have had discussions with legislators of various states who favored starting a drive, as if amateur rockets were narcotics, all in the name of safety, of course.

The two arguments most often advanced are (A) it is not safe and (B) the amateurs will not be able to discover something that the professionals have not already done. As for argument (A), the simple fact of life is that it can be highly unsafe but that accidents are always due either to carelessness or simple lack of knowledge. Both of these can be remedied. As regards argument (B), my favorite story is that at one university I saw a medical student dissect a human hand. I could have told him that he would not learn anything that could not be found in medical texts, with fine colored illustrations, and that he had absolutely no chance of making a discovery. My statements would have been perfectly correct, yet have missed the mark by several miles. That student did not lift out the various blood vessels and muscles to find something new for others, he did it for himself, in order to learn and to gain practice.

I might also ask where the professionals came from originally. The young Russian student of engineering, Blagonravov, certainly was not a professional back in 1932 when he built his first rocket. And then there was a group of people on the outskirts of Berlin building rockets. Their names were, in approximate order of age: a high-school teacher called Strache; a man with a degree in engineering but no engineering practice (because of the first World War and the subsequent inflation) called Nebel; a man who had studied mainly zoology and who had thought he would become a geologist, myself; a young man who had begun to study engineering (interrupted by the inflation, too) and who happened to be the only one with machine-shop experience, Klaus Riedel; a high-school graduate who was beginning to study engineering, Wernher von Braun; and finally, a high-school boy who intended to study engineering later on, Helmuth Zoike. This group of rank amateurs built the first German liquid fuel rockets.

Some years earlier, in New England, a physics professor by the name of Robert H. Goddard had also begun to putter around with rockets, to the amazement (and amusement) of quite a number of people who now recall with some regrets that they saw no future in the professor's puttering.

Well, if the first generation of experts had to begin as amateurs, what does anyone expect the next generation to do? Learn how to draw parts with great accuracy without any knowledge of what these parts do, where they fit in and why they exist in the first place?

Just because I was in one of the first groups, a group which had explosions but never an accident to a person, I am more aware of the need for safety than many others who use the word frequently. Yes, safety has to come first and last and every quarter inch in between. But those who want to learn should be permitted to learn—in safety.

WILLY LEY

Chapter I

ORGANIZATION, SAFETY, AND THE SCIENTIFIC METHOD

Before any young man, or group of young men, embarks upon a project as potentially dangerous as rocket experimentation it is advisable, first, to get honest and straightforward answers to some very serious questions. The first question is: WHY DO YOU WANT TO EXPERIMENT WITH ROCKETS? The second question is: WHAT DO YOU HOPE TO ACHIEVE BY IT? And the third question is: ARE YOU WILLING TO MAKE THE SACRIFICES AND TAKE THE ELABORATE PRECAUTIONS NECESSARY TO ENSURE THE SAFETY OF YOURSELF AND OTHERS, AND ARE YOU WILLING TO ABIDE BY THE LAW?

If your answer to the first question is that you are thrilled and fascinated by things that burn and explode, and you love to watch fireworks displays, or you simply want to send a rocket higher than the boy next door, then this book is not written for you, and you had better find something less dangerous to amuse you. You are looking for a *hobby*. And amateur rocket experimentation is not a hobby; it is a serious business.

If you do not understand what is meant by the second question, or you can think of no answer to it other than the fact that it gives you some personal satisfaction to watch a highspeed projectile go zooming off into the air, then this book also is not written for you, and you had better find something more productive to do with your time. Amateur rocket experimentation can be justified only on the basis of its educational value to those participating in it. It is a means of learning more about the sciences and the special technologies of the missile era. And the rocket itself is merely a tool for teaching, perhaps the most useful one man has ever devised.

If your answer to the third question is "No!", or if you do not feel all the precautions recommended in this book are necessary, then you had better devote your time to something that does not have the potential of injuring, or possibly killing, other people. For in amateur rocketry, constant attention to the safety of participants is essential and important above all else.

These three questions must be kept uppermost in the mind of the amateur experimenter if he is to achieve anything in his work, and if he is to live to profit from it. They must guide his every action, and against them he must measure his results.

In this chapter we will consider the methods by which the amateur can achieve the most effective results before getting into the area of actual rocket design and construction. There are three major aspects of amateur rocket activity which deserve careful attention. They are:

ORGANIZATION
SAFETY
SCIENTIFIC METHOD

The amateur experimenter must give careful thought to each of these aspects of his work if he is to achieve anything worthwhile, and if he is to gain community support and assistance. Amateur rocketry is not something that can be engaged in haphazardly, on the spur of the moment, and with no planned program of activity. Neither is it an activity that can be conducted clandestinely—behind the barn or in the cellar—without the knowledge and support of parents and community officials. *Organization* (of both the group and its projects), *safety* and *scientific method* all have as their objective the establishment of a safe and productive working atmosphere. Such an atmosphere is important to any group effort. It is doubly important in the case of an activity as fraught with dangers and physical hazards as amateur rocketry is. Let us first consider the matter of organization.

I ORGANIZING A ROCKET SOCIETY AND A PROGRAM OF EXPERIMENTATION

Amateur rocket experimentation must necessarily be a group effort. Although there are a few examples of outstandingly gifted young people who have worked by themselves and produced very advanced rocket hardware, they are so few that they must be considered unusual. Generally, these individuals are fortunate enough to have more facilities and money at their disposal than the average young person has. But they do not have the facilities to conduct a really far-reaching program of flight testing, and almost without exception they fall short of the achievements of well-organized small groups of experimenters. The most successful amateur rocket groups in the country are almost invariably small organizations of five to ten individuals who share a common interest in advancing their scientific knowledge, and each of whom finds in the study of rocket science a chance to exercise his talents in his own particular specialty, be it chemistry, metallurgy, electronics, mechanical engineering, or even medicine. (This appraisal, of course, excludes those few rather large amateur rocket societies which have been organized for periods of ten to fifteen years, mostly in the Southwest and on the Pacific Coast; but which consist primarily of adults who grew up with rocketry and have continued to pursue it as an avocation.)

The reasons why amateur rocket experimentation seems to flourish best among rather small, but well-organized groups are many. Among them is the fact that rocket experimentation, even on a small scale, costs a certain amount of money. Not a great deal of money, except in the case of very ambitious projects, but enough to be beyond the ability of one or two young men to finance it out of weekly allowances or part-time earnings. Another reason is the fact that rocket design and construction can be a rather complex matter, and the variety of skills required and the depth of knowledge one must acquire in a wide range of subjects almost precludes the possibility of one individual mastering it all by himself. On the other hand, successful amateur rocket groups seem to have discovered that "too many cooks can spoil the broth," and that amateur rocketry can attract a lot of people who are fascinated by the subject, but who do not seem to do any work or make any constructive contribution to the group effort. Frequently, these individuals are people who just love to be members of some organization, but who spend most of their time arguing at great length over obscure and relatively unimportant provisions of the group constitution or by-laws, and who always seem to disagree with the way things are being done. Others among them are simply "dead wood" who are good listeners and enthusiastic supporters of the group, but who never make any concrete contribution in terms of physical work. These persons invariably create friction and jealousies within the group and make it virtually impossible to adopt a unified program of activity and establish clear-cut objectives for research and development work. They are frequently long on ideas (particularly elaborate ones) and talk, but very short on performance. Successful amateur rocket groups have learned to eliminate them from membership at an early stage.

If I were asked to define the *average* or *typical* amateur rocket group in America that is successful in its work and has an intelligently planned program of study and developmental projects under way, I would say that it consists of *seven* bright young men between the ages of 13 and 17, *one* sympathetic and understanding parent or high school teacher who acts as an adult adviser for the group, and *one* engineer or chemist who acts as a technical adviser. This composition of membership does not give the group everything that it needs in order to carry on a full-fledged program of experimentation; but it does represent the organizational nucleus which can obtain for the group the support and assistance it needs from other sources. The fact that this pattern of organization is repeated so frequently throughout the country, and produces results, is evidence enough of its validity.

This does not mean that every group must consist of seven members. Three or four may be the optimum number in many cases. In other cases a group as large as twenty may be able to work effectively together, but this is rather doubtful. In all the thousands of amateur rocket groups I have had a chance to observe and to correspond with, I do not know of one with a membership of more than twenty that has done anything worthwhile.

Composition: The membership of a rocket society should represent as wide a variety of skills and interests as are compatible with the basic purpose of the group. A wide range of knowledge in the basic sciences is needed in order to understand how a rocket functions and to make proper use of it as an experimental vehicle. For this reason successful rocket groups have generally been made up of members whose particular interests are quite different, but whose general interest in the advancement of scientific knowledge about the universe is mutually shared by all other members of the group. Oddly enough, a great many very productive groups are made up of young people of such varied interests that none of them can be said to be interested in *rockets themselves*. Rather, they are interested in only one part of the rocket, or in only one of the many things that rockets can do or be used for. None can properly be described as a *rocket enthusiast*. A typical group may consist of one young man who wants to be a mechanical engineer, one or two others who want to be chemists, another who wants to be a doctor, another who is a radio ham and wants to be an electronics engineer, or just a radio repairman, and another who is only interested in photography. The boy who wants to be an electronics engineer finds in the rocket a chance to further his knowledge of electronic circuitry and telemetering systems and to test his ability to devise practical methods of communicating with the rocket in flight or controlling certain of its actions remotely. The photographer finds an opportunity to test his ability to get good pictures of rocket launchings, or pictures of the earth taken from the rocket in flight, and to test his ingenuity in devising the means of taking such pictures.

Each member of the group similarly finds a challenge in his own particular field represented in the over-all project of getting an efficient rocket into the air and making some use of it while it is there. He contributes from his own special knowledge to the total effort of the group, usually is put in charge of the particular phase of the project in which he happens to be most expert, and assists in other phases of the work as he is able. Thereby each member is able to exercise his own talents in a rewarding fashion, and is able at the same time to gain a considerable knowledge of rocket technology through association with his fellow members. This pattern of functional division of work, according to the individual abilities and interests of the separate members, is followed by nearly every successful amateur rocket society.

The Adult Adviser: Ever since amateur rocket activity became a matter of public concern some two years ago the question has been asked, "Who is competent to advise an amateur group interested in rocket experimentation?" The answer is that there are probably only a hundred or so persons in the entire country who could be considered fully qualified to advise an amateur rocket club in every phase of its activities. Obviously this small number of *fully quali-*

fied experts cannot advise every amateur group, and as a practical matter they are not available to advise even one group, because they are certainly among the busiest people in the country today.

Common sense dictates, however, that the adviser to an amateur rocket society need not be an expert in anything. He need only possess mature judgment, "horse sense" and some knowledge of the sources from which he can obtain information and expert advice for the group. It is unrealistic to assume that any one person can give a group all of the technical advice that it needs, or even to assume that the group can get it all from one source. It therefore makes no difference whether the adult adviser has any technical qualifications at all; and it may be better if he has *none*, because he will then be less inclined to assume that he knows something which, in fact, he does not. The president of a large corporation, such as General Motors, is not usually a person who is proficient in any field except management, and it is not necessary that he even know on which side of a car the gas cap is located. His job is to see that the firm has the best technical and production resources and that its operations are productive and profitable. If there is a need for more and better engineers, he directs that they be hired. It is the same with the adult adviser for a rocket group. He can be an interested parent, a high school teacher, a boy scout leader, or anyone competent to lead and supervise the activities of young people. It is only necessary that he have an understanding of the psychology of young people, and sufficient maturity to distinguish between what is foolhardy, and what is not.

The Technical Adviser: A group may or may not have a particular person available to it as a technical adviser. As pointed out earlier, a rocket group must expect to get its technical guidance from a variety of sources, and no one person can be expected to have all the knowledge necessary to give competent advice in the wide variety of technical fields that rocket science encompasses. However, any person trained in one technical field generally has some familiarity with several others and a good grounding in the basic sciences. Most importantly, he is likely to be able to recognize hazards when he sees them, or to know when the group is venturing into an area that is apt to prove dangerous; and he should be reasonably familiar with the sources from which technical information can be obtained. Many groups have enlisted the help of engineers, chemists, or technicians from industry or universities located near them. Such a person is frequently able to give the bulk of the technical advice the group needs, and knows where to get the rest. Even an expert machinist can be of considerable help.

Constitution and Safety Code: Once a group has decided upon the persons who will constitute the original membership of the society, and has found a willing person in whom it has confidence as an adult adviser, the next step that should be taken is to hold an organizational meeting to decide upon the rules under which the group will operate. Most groups draw up some sort of constitution which defines the conditions of membership, provides for the election of officers and the raising of funds, establishes the time and place of meetings, and in general outlines the objectives and the manner in which the club shall operate.

In addition, a safety code is usually written up by a group appointed for the purpose, discussed and voted upon by the membership at large, and adopted as part of the by-laws of the group. Failure to abide by the provisions of the safety code is considered a basis for revocation of membership in most groups.

The safety code is not intended to be a complete listing of safety rules, for such a list would be virtually endless and contain far too much detail to be an effective instrument for enforcing safety discipline and encouraging safety consciousness among the members. The safety code is really more of a code of conduct, outlining the standards of personal conduct which the group feels are important to the safety of the group as a whole, and includes a few of the more important safety rules pertaining to the handling of propellants and the conduct of operations at the launching site.

A sample constitution adopted by a rocket society is reprinted for you here as a model on which you can pattern your own; and a sample safety code follows.

Model Constitution: The framework of the constitution presented here is based upon constitutions adopted by the

White Plains Rocket Society of White Plains, N. Y., the Richland Rocket Society of Richland, Washington, and the Astronautical Research Society of America of Bronx, N. Y. It is intended only as a model on which you may pattern a constitution of your own. Additions or deletions may be necessary in order to adapt it to the particular purposes and composition of your group.

CONSTITUTION

ARTICLE I

Name

This organization shall be known as the............. of ....

ARTICLE II

Purposes

The basic purposes of this society shall be:

a. To conduct experiments, research projects and other educational activities designed to increase the knowledge of its membership in the science of modern rocketry and in the special technologies related to it.

b. To promote and foster the exchange of information with other societies engaged in similar activities.

c. To develop and encourage the establishment of safety procedures among its own membership and to recommend such procedures to all groups and individuals interested in the study of rocket science.

ARTICLE III

Membership

The conditions determining eligibility for membership in the society shall be as follows:

a. Membership shall be open to anyone over the age of .... who exhibits a sincere interest in the purposes and objectives of the organization, and who presents some substantial evidence of accomplishment in the fields of scientific research which the society pursues.

b. A prospective member must submit in writing an application for membership, together with the permission of his parents or a legal guardian.

c. Members must be confirmed by a .... vote of the existing membership of the society.

d. The number of members may not exceed .... unless this number is subsequently changed by amendment of the constitution in the manner herein provided.

e. Any member may have his membership revoked for cause by a . . . . vote of the full membership in regular meeting for violation of any of the conditions of membership established in the By-Laws, or for an infraction of the Safety Code of the society.

ARTICLE IV

Officers

a. The officers of the society shall consist of:
   President
   Vice-President
   Secretary-Treasurer
   Range Safety Officer

b. In addition the society shall select by decision of a majority of the members, an:
   Adult Adviser
   Adult Technical Adviser

ARTICLE V

Meetings

Meetings of the society shall be held weekly or at the call of the President at a place designated by majority vote of the membership at large.

ARTICLE VI

Operations

The society shall conduct such operations as are consonant with its aims and objectives, the abilities of its members and the limitations of its funds and physical facilities, to include:

Research projects
Lecture and film programs
Static firing tests
Launchings
Special study programs

In addition, the society shall adopt and enforce the observance of a strict code of safety which shall govern the activities of all of its members.

ARTICLE VII

Funds

The society shall derive its funds from the assessment of regular dues, special assessments as voted by a . . . . majority of the membership, and from donations it may solicit from business organizations or other agencies at the discretion of the duly elected officers functioning as an Executive Committee.

ARTICLE VIII

Amendments

The constitution of the society may be amended by a .... vote of the full membership, to be taken not earlier than the second regular meeting to follow the submission of proposed amendments.

BY-LAWS

(The by-laws to the constitution should cover in detail such subjects as: the duties of officers; the conduct of elections and voting procedures; the amount and method of assessment of dues; the conditions for impeachment of officers or members; and provision for their amendment.)

Model Safety Code: The safety code presented here is representative of the type of code established by many rocket societies throughout the country, as a guide for the conduct of their operations and as a means of controlling the activities of their members. As explained in the text, the safety code is not intended to be a complete listing of the safety precautions that should be taken in every phase of rocket experimentation. Such a list would be far too detailed to represent an effective code. Rather, it is intended to set standards of safe conduct for the group and to cover only the major precautions which should be observed.

Failure to abide by the provisions of the safety code is considered a basis for revocation of membership in most groups.

SAFETY CODE

I All members of the .... agree to conduct themselves in a manner which will best insure the safety of themselves and others, and to observe the specific safety precautions recommended by the Safety Officer and adopted by the group.

II All devices must be fired or tested only in the presence of a qualified expert, and all devices and procedures must be tested for safety by an expert and approved by the Safety Officer before they are adopted for use.

III Permission of parents must be obtained by all persons attending a launching or static firing.

IV The testing or firing of any device will only be done with the knowledge and consent of the local governing authorities, and after the officers of the society have determined that the conditions of the test satisfy the requirements of state and federal agencies exercising jurisdiction over the transportation and handling of explosives and the use of air space.

V No device will be fired, either statically or in flight test, except by means of a foolproof electrical device which can be operated from a safe distance.

VI At static firings and launchings all persons must be adequately protected by protective wearing apparel recommended by the Safety Officer, and must stay within the bunkers and revetted areas designated by the Range Officer. Adequate fire-fighting facilities must be available, and emergency first-aid equipment must be on hand with a person who possesses a Red Cross certificate in first aid.

VII No member will be permitted to experiment with propellant combinations independently of projects assigned and supervised by the society Technical Adviser, nor will he be allowed to keep fuel or oxidants at his home. Violations of this provision of the code will result in immediate dismissal from the society.

VIII Rockets will be flight tested only at the approved launching site of the society, and only on dates designated by the Range Officer after proper clearances hand with a person who possesses a Red Cross certifi-

IX No visitors will be permitted at the launching site except by the invitation of the society, and upon the understanding that they will abide by the regulations of the society governing launching operations.

Seeking Sponsorship: Sponsorship by other agencies and organizations can be extremely important to an amateur rocket society, whether it takes the form of outright financial assistance, donations of materials, or just plain moral support. To the embryo rocket society which demonstrates a seriousness of purpose, a due regard for the safety of its members and the general public, and an ability to produce well-designed hardware, such support and assistance is not difficult to come by. For one thing, rockets make news and young people interested in science attract public attention these days. Most any organization likes to be associated with things which attract attention and get space in the newspapers. Time and time again it has been demonstrated that once an ambitious young rocket group has a few initial successes and gets itself talked about in the newspapers, offers of help and assistance come pouring in from all sides. Also, nearly every person is impressed by young people who demonstrate the initiative and the enterprise to do something that is not expected of them in the normal course of events. Professional people, particularly, seem to have an irresistible urge to help, guide, and advise young men and women who exhibit talent.

There are a great many organizations and business enterprises in any community who have resources and facilities that can be of immense help to a group of struggling young scientists—the problem is to convince them that such an investment is worthwhile, and that the group concerned deserves help. As an example, I know of one rocket society in a small community that had a very difficult time getting any sort of assistance until, by dint of hard labor and persistence, it managed to put together a five-foot rocket which was successfully fired to a height of one mile on an Army range. The resultant newspaper publicity so thrilled the town that within two weeks the group was deluged with offers of material and assistance. The local telephone company made them a present of two miles of communication wire and twenty telephones. The Chamber of Commerce offered to sponsor the group's activities. The town council invited them to present a proposal for the establishment of a launching site on the outskirts of town. A local machine shop offered to machine their nozzles and nose cones free of charge, and to train members of the group in the operation of a metal lathe. The school board made the facilities of the school shop available to the group and offered the school as a meeting place. Several near-by industries offered free materials, parts and technical advice. In no time at all, the group had a dozen technical consultants available to it.

All of this stemmed from just one thing—solid evidence of achievement and a little publicity about it in the newspapers. This pattern has been repeated in the cases of hundreds of other small amateur groups throughout the country. One secret of success in getting community recognition seems to be to get the ear of a sympathetic newspaper man. Reporters readily sense the human interest value in the familiar story of budding young scientists struggling to obtain the assistance that they need, and trying to convince the world of the merit of their work. In innumerable cases a local reporter proves to be the key man in getting community organizations and business establishments interested in helping amateur rocket groups, simply because it means rich story material for him and his newspaper.

Another technique that has proved effective in enlisting community support is to arrange for presentations or demonstrations by the most articulate members of the group before luncheon meetings of such community service organizations as Kiwanis, Rotary, Elks, Lions or the Junior Chamber of Commerce, or a local American Legion Post. Have your adult adviser or your group president get in touch with the Program Chairman for any such organization and offer to present a half-hour talk and demonstration explaining the group's work at one of the regular weekly luncheon meetings. Such opportunities are easy to arrange because the average Program Chairman is continually scratching his head for new ideas, and forty-eight weeks of the year he finds himself buttonholing some speaker at the last minute to fill in the ever-present vacancy in his schedule. You will be surprised at how impressed and responsive such an audience of business men can be when they listen to a group of young men explain the intricacies of a scientific project that is completely over the head of the average listener.

Once you have made an initial impression with such a presentation, however, follow it up immediately. Don't let the idea cool off. Contact the key members of that organization the very next day (or the members who seemed to be most impressed with your presentation), and suggest to them that they appoint a committee to meet with officers of your club to discuss the details of a program of support for the club's projects. The members of such organizations as Kiwanis, Rotary, etc., are usually very influential men in the business and political community. Many of them know the Mayor, the Chief of Police and the Fire Chief by their first names and have been friends with them for years. Their voices carry a lot of weight and city officials generally have confidence in their judgment. A proposal to city officials coming from them will get a much more sympathetic hearing than if it were to come directly from the spokesmen of your own club. Such men also are well-acquainted with the industrial and business firms in the area; they know what each of them makes or sells, and they know what facilities they have. Moreover, their own organization usually includes the prominent officials of such firms in its membership. Most service organizations are created to foster and promote within the community projects and activities very similar to yours. Take advantage of them.

The same sort of an approach can be used in the case of large industrial firms in your area that happen to have a sizeable staff of engineers and technicians, or which manufacture equipment or material that is useful to your group. With a little imagination and some aggressiveness on your part, you can get the help you need, providing you impress the people you approach with the seriousness of your group and the fact that your work has a scientific and educational purpose. Nobody can be expected to be interested in helping a group of young men to set off fireworks. But they *will* be interested if you can point to some achievement your group has been responsible for (such as a well-designed and constructed piece of hardware, or a testing device that has an obvious scientific purpose) and they feel that you intend to continue with your projects and have not just been smitten with a fad.

Seeking Technical Help and Advice: Technical help and advice is available to the average group from a great many more sources than you may realize. One of the best is a university, particularly a technical one. In this day and age there is scarcely a town or village in the country that is not within driving distance of a seat of higher learning. Have your adult adviser contact the head of the physics department, the chemistry department or the mechanical engineering department at any such institution. You may be surprised at the willingness of professional educators to devote time and effort to the education of the young for no reasons other than the joy of doing it and the deep sense of dedication that most teachers have. Bear in mind, always, that such people are busy and have their own schedules and obligations to abide by. If the members of your group are polite, studious, unobtrusive, and willing to listen, you will get much farther with educators than if you badger them with inconsequential questions at inconvenient times. Do not call such a person on the phone, or go to see him, the moment that some idea or knotty problem occurs to you. And do not permit the members of your group to do it. Arrange for regular meetings with anyone from whom you seek technical advice (at *their* convenience, not yours) and save all your questions and problems for that time. You will be amazed at how often a really hot idea looks like a crazy pipe dream after you have thought it over for a week, and how often a complicated problem is not a problem at all when you have devoted sufficient thought of your own to it. It is a good rule in life never to open your mouth the first time that an idea occurs to you. Think it over for awhile and consider it from every angle. After you have thought about it for a few hours, or a few days, and it still seems to be a good idea, then it is time enough to talk it over with someone else. You can save yourself and your group a lot of embarrassment this way; and you will earn a reputation as a sober thinker, rather than a blabbermouth.

In addition to colleges and universities there is a host of other sources for technical help. We have already mentioned industries as one prime source, and it is not necessary that they be right next door. You can always get a certain amount of help by corresponding with any firm. You can also arrange to travel once a month, or once a week, to some near-by city where a large industry happens to be located, if you really want the help and advice you are seeking. You can also find out where the nearest chapter of the American Society of Mechanical Engineers, or the American Rocket Society is located and arrange to have your group occasionally attend monthly meetings as guests.

You can also take a long, hard look around you within your own community. Maybe a retired engineer or physicist lives right next door to you. (I know of an eighty-five-year-old Polish physicist who is the principal adviser to an amateur group in the Hudson River Valley, and he is tickled to death to be able to keep his hand in the profession to which he devoted his life.) There is no village in the country that cannot reach a TV repairman on the telephone. Yours can tell you a great deal about electronic circuitry. If you have hot air heating in your house, the man who installed it can show you how to work with sheet metal, and will probably let you use his bending brakes and dies to form the flanges on your fins. The next time your mother calls the plumber, strike up a conversation with him. He knows a lot about working with metal tubing, tapping holes, and threading pipe ends. Your local telephone company has a lot of engineers and technicians on its staff. So does the city water department, the department of power and light and the gas company. Any large garage has drills, metal saws, tapping and grinding equipment, and the people who know how to use them; and every town of 15,000 to 20,000 people has at least one machine shop.

And finally, of course, there are the many installations of the armed forces scattered throughout the country. Each of the uniformed services has been authorized by the Department of Defense to lend technical assistance and to furnish other types of support to deserving groups of amateur scientists. The Army's policy in this respect is by far the most liberal and the most far-reaching. If you happen to live somewhere near an Army technical installation, or a large post that has tremendous open land areas and no air-traffic problem, you probably will be able to get a great deal of technical supervision and maybe even a chance to static test or launch your rockets. Bear this in mind about military installations, however. They are not all the same. All of them do not have the same facilities, the same categories of personnel, nor are they engaged in the same type of activity. Some are merely large troop training centers, some are technical arsenals or research centers, some are personnel processing centers, some are record centers, etc., etc. If you happen to live within a few miles of Fort Sill, Oklahoma, you are lucky. The Army Ordnance Missile School is located there and your group can get what amounts to a complete course in rocket science over a period of time, and a chance to fire its rockets. But if you happen to live next door to the Army Personnel Records Center in St. Louis or the Army Finance and Accounting Center in Indianapolis, you can get no help at all, unless you are interested in how the payroll is made up for a missile battery. Do not blame the commanders of military installations if they refuse to give you help. They are authorized to help you, but only *if* (and it is a big "if") they have the facilities and qualified technical personnel to do it, and only *if* such help does not interfere with the accomplishment of their basic mission. Naturally, the commander of Fort Mason, California cannot permit you to launch a rocket on his post, which is right in the middle of the city of San Francisco; but he would probably be willing to tell you how far it is from San Francisco to Tokyo, because it is his business to ship military personnel to the Far East.

II SAFETY

If your group wants to be on hand to greet the first man to return to earth from the moon, or to play some part in getting him there and back, the first requirement is to stay alive long enough to do it. And if you want to shake his hand or pat him on the back, you can do a much better job of it with five fingers than you can with a severed stump. Rocket experimentation can be a frightfully dangerous business, and there is no sense in risking your future happiness and well-being in an ill-conceived and badly-executed attempt to show your friends and neighbors how smart you are.

Throughout the entire course of your group's program of experimentation the idea of personal safety and the avoidance of injury must be uppermost in everyone's mind. The ends of safety must be served first: the advancement of science and of knowledge comes second.

In the field of rocket experimentation there are three important facts of life which all amateurs must know and recognize. If you cannot appreciate the importance of these three things, you have no right to be experimenting with rockets and endangering the lives and property of other people.

1. A ROCKET PROPELLANT IS ONLY A HAIR'S BREADTH AWAY FROM BEING AN EXPLOSIVE COMPOUND. UNDER THE PROPER CONDITIONS OF HEAT AND PRESSURE IT *IS* AN EXPLOSIVE COMPOUND.

2. THERE IS NO ESSENTIAL DIFFERENCE BETWEEN A ROCKET AND A BOMB, EXCEPT THAT THE ROCKET HAS A HOLE IN ONE END (AND THIS HOLE CAN BECOME BLOCKED).

3. A ROCKET IS A FREE-FLIGHT PROJECTILE. IT FLIES FAST ENOUGH TO KILL.

Safety is largely a matter of your mental approach to the operation you have in mind. Get in the habit of thinking of your rocket as a BOMB. Make up your mind that *it is going to explode,* and then you will find yourself taking certain precautions by instinct that you might not otherwise think of.

Also, *remember this*: most accidents happen when people are doing something that they have done a thousand times before, like stepping into the bathtub, holding a match to the gas jet of a stove, or backing a car out of a driveway. Familiarity breeds contempt; and it is just because we are so familiar with what we are doing that we become contemptuous of it and insensible to its hazards. When we are approaching a new and unfamiliar task, or doing something for the first time, we are naturally cautious.

This is why the Army establishes strict, "by-the-number" routines for every hazardous operation, particularly on firing ranges and in munitions dumps. Violation of the routine is a basis for severe disciplinary action, whether an accident results, or not. You must take the same attitude in all the work your group undertakes. The routine that is designed to prevent accidents must be followed faithfully, no matter how unnecessary it may seem, or how boring it is to follow it.

A third thing to keep always in mind about safety is the fact that even though you may not always be able to prevent an explosion, you can almost certainly prevent yourself from being injured by it. Proper protective clothing and equipment, shockproof shelters and barricades, and plenty of distance are the essential ingredients of personnel protection. After all, it is not the explosion that is so dangerous. It is being exposed to it that hurts. If you can cut down the time and degree of exposure, you can similarly reduce the likelihood of injury. In many lines of work explosions are a common thing. They occur frequently in propellant manufacture and research, in munitions plants, chemical plants and ordnance arsenals. In the case of blasting operations, and certain new metal forming techniques, they are deliberate. Seldom is anyone hurt in such explosions, because: they stay as far away as possible, they take cover behind barricades, they are wearing protective gear, and they are following the prescribed routine. If you can make certain that the members of your group observe the same sensible precautions, no one will be injured, no matter how many of your rockets explode.

Safety Rules: Throughout this book safety rules and warnings of hazards appear in virtually every chapter under the subject headings to which they apply. For the general guidance of your group, and because they apply to virtually any type of hazardous activity, a list of basic rules to follow is included here. You might want to copy this list and post it in the place where you hold your meetings.

PERSONAL AND GROUP SAFETY PRACTICES

1. *Safety rules are for you*

   NEVER take the attitude that safety rules are only for the other person. Safety rules are established by experts who invariably take the same precautions themselves. In the field of rocketry, safety rules are the result of painstaking research, trial and error, and costly mishaps.

2. *Research your project before you start building hardware*

   Remember that your work is *experimental* in nature. Before attempting any experiment, be sure to check and recheck reference data available to you from schools, libraries, industry, and government.

3. *Never work alone*

Two heads are always better than one. Your chances of serious injury are reduced proportionately by the number of capable assistants you have. There must always be someone available to help in event of a disabling, crippling, or blinding accident. Experienced sportsmen observe this basic rule of survival; as a junior rocketeer, you must obey it.

4. *Don't hide your activities*

Though you may think they'll cramp your style or hinder your activities, let your parents, teachers, and local authorities know what you are doing. They are wiser and more experienced than you, and will encourage you, provided you observe and implement all safety precautions.

5. *Get an adult supervisor*

Under no circumstances should you build a rocket, mix rocket fuel, load a rocket, or attempt to launch it without guidance and supervision by an adult. Look around . . . you'll find some adult who is interested in your project, whether he is a parent, teacher, official, brother, or neighbor. Your supervisor may not be an expert in anything but common sense, but don't work without him.

6. *Safety lies in orderliness and neatness*

Be neat. Keep your working area free from trash, dust, and scraps of metal and material. Don't work in your basement or attic unless it is clean, has good heating, good lighting, and good ventilation.

7. *Be prepared for emergencies*

Make sure adequate fire prevention measures are available. Face shields, gloves, and a first aid kit should be on hand, as well as a telephone in event of fire, explosion, or major physical injury. Check for open flames, exposed electrical heating, exposed wires, poor electrical fittings and switches. DO NOT SMOKE AT ANY TIME while building, fueling, testing, or launching.

8. *Listen to advice*

Don't be a martyr to science. Disregarding sound advice from others may cause you to lose your life. At least consider the merits of other plans, approaches, and ideas.

9. *Organize your work before starting*

When your research is completed and double-checked, decide on a plan of action. Organize your plan and develop a step-by-step checklist. Integrate all safety precautions into your checklist. Go over all phases of your plans at least twice before starting, to make sure you haven't overlooked anything. As an additional check, ask your supervisor to review your plans. Finally, make certain you follow your outline.

10. *Consider the safety of others*

Remember that you are responsible for the safety and welfare of those around you. This holds true whether you are in the laboratory, workshop, in transit, or at the launching site. Carelessness on your part may well result in death or injury to the innocent.

11. *Prepare for the worst*

It is characteristic of youthful optimism to think only of what will happen if everything goes right. Get in the habit of thinking about what will happen *if everything goes wrong*. You'd be surprised how many weaknesses and hazards you may discover in your plan by this simple switch in mental approach.

III SAFETY THROUGH SCIENTIFIC PROCEDURE

Adopt a scientific mental approach: There is much that you can do to ensure the safety of yourself and others by simply adopting an intelligent and scientific approach to your project. The suggestions which follow do not represent specific precautions to be taken against specific hazards; but rather constitute a summary outline of a procedure you can follow in order to eliminate as much guesswork as possible in the development of your rocket.

All scientists and development engineers follow similar patterns in their work. Even in the automobile industry, where there is over fifty years of accumulated know-how in the production of millions of vehicles, each new model is the result of this same careful, painstaking process—which may start as much as three years before the new model appears in dealers' showrooms.

Professionals work this way in order to avoid costly mistakes. They attempt to predict, calculate, or prove the performance characteristics of every mechanism or device under development before the item itself is produced. You can save yourself time, money and possible grief by learning to work in the same manner.

Plan your working procedure: You do not necessarily have to follow every step in this procedure. On the other hand, there may be steps you will want to add. The point is to establish for yourself an orderly working procedure which will ensure an end product from which most of the "bugs" have been eliminated in the design and testing process.

1. RESEARCH

Do all the research you can. Do it continuously during the development of your project. Research is often the first proving ground of the feasibility of an idea. You may discover someone has already done exactly what you propose to do and can give you valuable, time-saving data. Of more importance, someone may have already demonstrated that it is impossible to do it, and save you time.

2. EXPERIMENTAL DESIGN

This is the first phase of actual design work. Get your idea on paper as early as possible. By just making a drawing, you can uncover faults and weaknesses in a design, and bring to light design and construction problems which may require further research to solve.

Even at this early stage, professional designers frequently have scale models constructed of wood or other material, to help them determine basic shapes, proportions, aerodynamic characteristics, etc.

3. PRELIMINARY DESIGN

After you have decided upon the general characteristics of your rocket and computed its theoretical performance, etc., you are ready to make detail drawings of the complete rocket and component parts. These drawings should be complete; but remember that they are only "preliminary." You may change your mind about some details or develop better ideas in the very process of making the drawings. You will make further changes after you have built test models of various components and have a chance to correct errors.

4. BUILDING YOUR FULL-SCALE MOCK-UP

The next step is to build a full-scale mock-up of your rocket from your preliminary designs. This can be done from cardboard, wood, or any other easily workable material. Engineers use mock-ups to determine: (1) whether their design ideas have allowed sufficient clearance for all parts to fit in place (without "interference"), (2) whether the parts can be assembled in the sequence planned, and (3) whether special fabrication problems will be involved, etc.

5. TEST MODELS & WORKING SCALE MODELS

It is important, in most cases, to construct actual working models of some components to determine whether they will perform as expected when subjected to certain tests. These models can be either full-scale or smaller, as long as the materials used and the proportions conform to the actual design. With rockets, it is most important to construct a small-scale working model of the rocket engine, which can be tested safely, and to actually construct and test various working parts, such as parachute ejection mechanisms, receivers and transmitters, firing devices, etc. When your rocket is several hundred feet in the air, it is too late to try to determine whether all the parts will actually work. Once a working model has passed all its tests, it is a simple matter then to make it any size you want, as long as the dimensions remain proportionately the same. Remember that such things as temperature, humidity, acceleration, etc., can have an effect on the performance of working parts. Take these into consideration in your tests.

6. Final Design

By the time you have completed steps 4 and 5 you will have discovered many things about your design requiring improvement or change. You will discover further things that will change your design when you actually start final construction. These are called "production changes." But it is time now to make your final design drawings incorporating all of the lessons you have learned from your tests. These are the drawings from which you will build your final product. Make them good. Make them accurate.

7. Prototype Construction

The "prototype" is the first full-scale completely operational model of a product to be produced from the final engineering design. If you are intending to build more than one rocket from the same plans, then the first one you build is the prototype. Succeeding ones are production models.

Construct the prototype carefully and painstakingly. A good design can be ruined by faulty workmanship. Don't use a part, or a type of construction, that has not passed your tests.

Remember that the prototype is still an experimental vehicle. It is normal for many design changes to be made after its performance has been analyzed. Don't be stubborn about changing a pet idea after actual performance tests have demonstrated that it will not work.

If you follow the preceding steps, or a similar pattern, you can be confident that you have "developed" a rocket—not just built one. Its chances of successful performance will be much greater. And—the safety of yourself and others will be that much more certain.

IV AMATEUR ROCKETRY AND THE LAW

Before your group reaches the stage of actual propellant preparation, static testing, or the launching of rockets, there is one more important aspect of your activity which must be given very careful consideration and thoroughly checked out, and that is the *legality* of what you are doing.

We all must live with the law; and most of us try to abide by the laws of society and support them, because we recognize that it is the only way to maintain order and still have the freedom to do the things that we want to do. As an amateur scientist who hopes some day to work in the nation's space program, you cannot afford to run afoul of the law, and neither would you want to.

Appendix A on page 332 contains a summary of current state laws applicable to amateur rocketry as a guide for you. The actual texts of the laws can be obtained from your town clerk or by writing to the legislative assembly of your state. Bear in mind that by the time you read this book the list shown in Appendix A may no longer be complete or up-to-date. Its real purpose is to emphasize to you that such laws do exist, and to furnish you with the official designation of the laws with which you should be familiar.

Very few states have, so far, enacted legislation aimed specifically at amateur rocket activity. Those which have generally recognize the fact that there are educational values to be considered which must be given equal weight with considerations of public safety. In several instances, no public law has been passed, but some official or state commission has been given the authority to establish *regulations* governing amateur rocket experimentation. These regulations, of course, have the full effect of law as long as the courts uphold their legality. In the states of California and Connecticut it is the State Fire Marshal who has been given this authority. In the state of Washington it is the State Aeronautics Commission. In the state of Vermont the State Department of Education and the Bureau of Aeronautics jointly share the authority. The latter case is significant. Vermont is the only state in the country in which the educational value of amateur rocketry has been so formally recognized that the Department of Education has been granted partial authority over it. The state of Washington is equally cognizant of this. The state of Connecticut has probably taken the most restrictive and prohibitive attitude of all, and the state of South Carolina is not far behind.

Whatever the laws in your particular state may be, you must abide by them, and adapt your program to their provisions—unless you can arrange to do your work in some neighboring state which may have more liberal laws. And, in addition, you must abide by the ordinances of your own community, which in many cases may prohibit such activity altogether. As far as federal law is concerned, there are only two agencies which exercise jurisdiction in any area which amateur rocket activity might invade. One is the Civil Aeronautics Administration and the other is the Interstate Commerce Commission. The former is concerned with anything that is projected into airspace above an altitude of 500 feet, *anywhere in the country,* and any activity or building that takes place within five miles of an airport. Permission must be obtained from a Regional Administrator of this agency for *each* rocket launching. It is a good idea to contact the Regional Administrator in your area (he is usually located at some prominent airport) and have a frank talk with him about your plans. The Interstate Commerce Commission is concerned with regulating the transportation of explosives and inflammables on highways, bridges and tunnels, and establishes classification ratings for all types of chemical substances. If you intend to transport any kind of rocket propellant on any public highway, or across a state line, you had better let the ICC know about it, as well as state and local police all along the route you intend to follow.

For groups who do any type of radio telemetering, the approval of a third federal agency is required. This is the Federal Communications Commission. This agency is responsible for control of the airwaves and allots the frequencies and channels for all types of transmission for whatever purpose. Certain bands are assigned to amateurs and to commercial users of radio, such as taxi companies, police departments, etc. You must make certain that you are operating within the regulations of this agency if you intend to do any type of radio transmission.

The most important legal hurdle for any group, however, is to obtain the permission of its own local police and fire departments. These authorities come first in the line of authority, and their permission must be obtained regardless of what the provisions of state laws and federal regulations may be. You might be complying with every state and federal law on the books and still be fined $100 by a local judge for violating a city ordinance. The sensible thing to do is to have a conference with the Chief of Police and the Fire Chief in your town *before* you attempt any experimentation involving propellants. Show them what you want to do and the area in which you want to do it. If they say "No," suggest another area, and ask them what they want *you* to do in order to earn their approval. Most such officials are reasonable men, and they will try to make it possible for any citizen to do what he wants if a way can be found to do it within the law and if it will not infringe on the rights of others. Remember that if you have an accident or create a public nuisance of any sort, you will not only put the officials on the spot who co-operated with you, but will probably destroy your chances of continuing your experimentation.

Most existing state and local laws applying to rocket experimentation are those currently in effect to control the use of fireworks, and storage and handling of explosives and blasting operations. In nearly every instance, provision is made in the law for permits to be issued to qualified persons and agencies which will authorize them to conduct such operations under certain specific conditions. Find out what you need to do to get such a permit for your group, and have your adult adviser obtain it. Don't take a chance with the law.

Chapter 2

BASIC ROCKET DESIGN

Paradoxically, the most modern type of motive power—the rocket—is at the same time the simplest and the oldest motor known to man. It has been in use for seven centuries, perhaps even longer. Yet only during the past twenty years has man been able to put it to effective use and to develop it toward its full potential. Its basic elements are disarmingly simple. But to make these elements work together efficiently, and to develop propellants which will make the rocket a practical and useful vehicle has stretched the limits of man's technical resources and pushed the frontiers of his knowledge of the basic sciences outward.

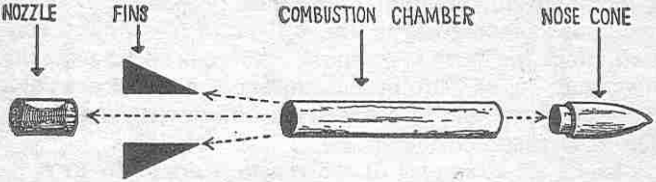
Development of the rocket to the gigantic dimensions of the missile we see today—capable of traveling distances of 5,000 to 6,000 miles over the earth's surface, and probing many times this distance into outer space—has been largely a matter of developing fuels, structural materials and thrust chamber designs which can make more efficient use of the rather simple principle of the rocket motor. No new scientific discoveries have been necessary in order to achieve this. Rather, it has been a question of waiting until the arts of metallurgy, chemistry and thermodynamics were better understood by man. This is typical of all technological development. Great scientific discoveries of one age are frequently not exploited for many generations—or even centuries—until mankind has acquired the companion knowledge and developed the tools which are required to make effective use of them. The steam engine—conceived in principle by Isaac Newton—lay dormant for two hundred years until a Welsh miner decided it was practical to lay steel rails on which a steam locomotive could run, and until engineers developed methods of manufacturing boilers, pistons, rods and valves that were sufficiently strong to withstand the pressures and stresses placed on them.

The principle of rocket propulsion is based on Newton's third law of motion which states that for every action there is an equal and opposite reaction produced—normally in an opposite direction. In simple terms this means that if you lift an object weighing fifty pounds a distance of one foot you are also exerting fifty-foot pounds of pressure on the earth. And, theoretically, the earth should move in the opposite direction a distance proportional to its weight as compared with the weight of the object you lifted. Since the earth is so massive, there is no measurable movement on its part in this instance; but there would be if you were able to catapult an object weighing many billions of tons into the air.

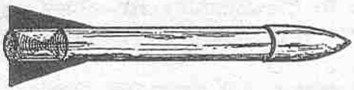
The classic examples of the *reaction principle,* as it is called, are the firing of a gun, and the escaping of air from a balloon. When a gun is fired it recoils, or kicks back, in a direction opposite to that which the bullet took. When air escapes from a balloon, the balloon flies off in a direction opposite to the escaping air. Since rocket motors work on the same principle they are often referred to as *reaction motors.*

In the rocket motor, hot gases are produced by means of rapidly burning some chemical substance (liquid or solid) which is called a propellant. A propellant generally consists of a fuel (or reducer) and an oxidizer (or oxidant). Neither will burn satisfactorily by itself, but in combination they create a chemical reaction which produces heat, and gas products which have mass and weight. The heat generated by this reaction creates a pressure within whatever vessel is being used. This pressure acts to drive the gas products out of the vessel, through any opening that is provided. In a pistol, the chamber in which the burning of the gun powder takes place is the cartridge casing. The opening provided for the escape of the gas products is the muzzle of the barrel. In a rocket it is very much the same. The main body of the rocket motor is called the *combustion chamber.* The escape port is generally called the *nozzle.*

A combustion chamber and a nozzle together constitute a complete rocket motor—in its simplest form. But even for simple rockets two other things are required in order to give the rocket direction and stability in flight. These are: a nose cone, and fins. In Illustration *1* these four basic elements of a simple rocket are shown. The only items which must be added to this assembly to make it fly are the propellant (fuel, plus oxidizer) and a means of igniting it. Illustration *2* shows all the essential parts, with dimensions, of a basic rocket which you can build as a beginning project.



EXPLODED VIEW of SIMPLE ROCKET

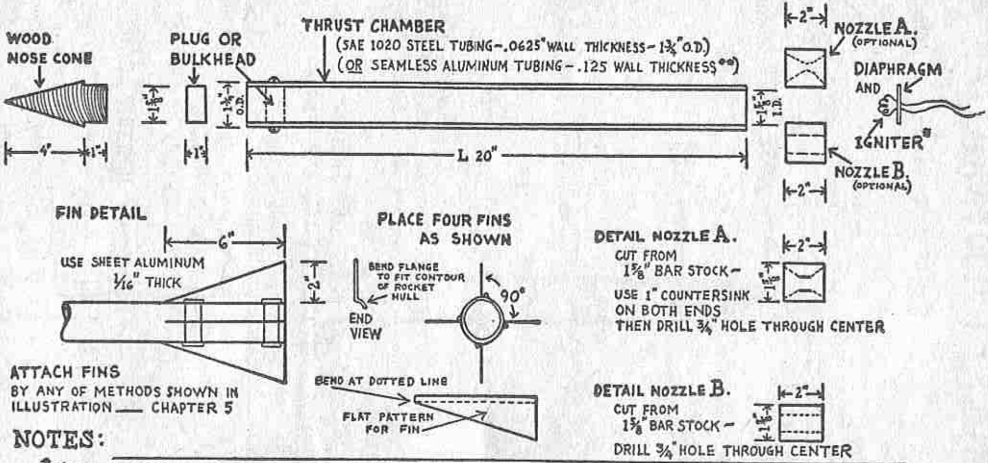


ROCKET ASSEMBLED

ILLUSTRATION NO. 1

Before you begin the construction of a rocket, however, it is advisable to consider some elementary principles of rocket operation, and some of the factors which can cause a rocket to become an extremely dangerous "weapon" capable of causing death or injury.

A rocket achieves its forward motion by expelling, or exhausting, hot gas particles from a nozzle. This *motion* of gases toward the rear causes the rocket body to move forward, as a *reaction*. The gases *do not push* against anything. It is simply their *velocity* as they move rearward, multiplied by their mass, that determines how much force, or *thrust*, is imparted to the rocket. Naturally, it is desirable to have as much gas as possible (mass) ejected from the nozzle as rapidly as possible (velocity) in order to get a high degree of thrust. To achieve this, it is necessary to burn a substance in the rocket chamber which will create a large volume of gas rapidly and produce enough pressure to drive the gases out of the chamber at a high rate of speed. The substance must not burn so rapidly that it amounts to an explosion, however; and neither must it



A BASIC ROCKET FOR BEGINNERS

NOTES:

* 1 FOR DETAIL OF DIAPHRAGM-IGNITER ASSEMBLY SEE ILLUSTRATION ___ CHAPTER 5.

** 2 DO NOT USE ALUMINUM TUBING IF NOZZLE IS USED — USE STEEL ONLY.

3 ROCKET CAN BE FIRED WITHOUT NOZZLE IF DESIRED.

4 NOZZLES SHOWN ARE NOT DESIGNED FOR HIGH PERFORMANCE, BUT FOR EASE OF FABRICATION FOR BEGINNING GROUPS. FOR MORE EFFICIENT NOZZLE DESIGN SEE CHAPTER 4.

5 USE HEAVY METAL SCREWS 3/16" TO 1/4" IN DIAMETER TO FASTEN FOREWARD BULKHEAD AND NOZZLE TO ROCKET BODY — 4 SCREWS EQUALLY SPACED. BRAZE ENTIRE PERIMETER TO PREVENT ESCAPE OF GAS PRESSURE.

ILLUSTRATION No. 2

BASIC ROCKET ASSEMBLED

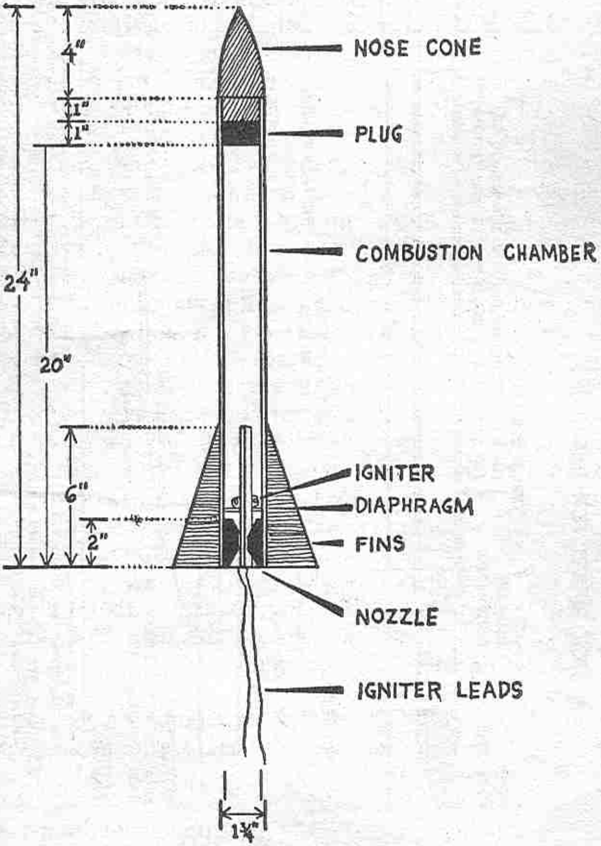


ILLUSTRATION NO. 3

be allowed to create so high a pressure in the chamber that it will crack the chamber casing before the gases can be expelled. Preventing this from happening, of course, is a matter of engineering design; and this design must achieve a balance among a great variety of factors, any one of which can cause a failure of the system if it is not properly controlled. The most important of these factors are: the burning temperature of the propellant substance, the burning rate (i.e., how much of it is burned in one second), the size of the combustion chamber, the composition and thickness of the chamber wall, the diameter of the nozzle throat, and the length of the nozzle.

The propellant substance burned in the rocket motor chamber may be either solid or liquid; and if solid, it may either be in the form of a cast grain or a tightly packed powder. Nearly all amateur rockets employ a solid propellant, and 95% of these are in powder form (usually a mixture of a zinc dust and powdered sulfur). Powders, of course, are readily mixed and relatively easy to load, which accounts for their widespread use. They have serious disadvantages, however, in that it is very difficult to control the density to which they are packed, and virtually impossible to predict with any accuracy how rapidly they will burn. Generally speaking they tend to burn unevenly (frequently due to excess air being trapped among the particles) and this uneven burning may disturb the aerodynamic balance of the rocket, causing it to travel erratically and zoom off in unpredictable directions. Also, powders tend to burn *all at once,* rather than gradually, creating a very high pressure for a very short period of time. If this condition occurs, the rocket is likely to explode.

These eventualities (and many others that will be discussed later) must be guarded against. It is therefore advisable that amateur rockets:

a. Be *overbuilt* from the standpoint of the size and strength of materials used so as to provide as wide a margin of safety as possible.

b. Be launched, or tested, only under conditions which will ensure the absolute safety of all participants, and which allow for the fact that the rocket may:

explode while being loaded.

explode on the launching stand.
rise ten feet in the air and explode.
rise only a short distance and then fall to earth still spitting out chunks of burning propellant.
do a complete loop and plunge back to earth under full thrust.
rise normally a short distance, then keel over and fly horizontally in any direction of the compass.

These, and many other odd things can happen when you start to experiment in a field where even the professionals don't know all the answers. If you don't believe it, read this description of an amateur rocket launching from the records of a West Coast society that has been conducting rocket experiments for approximately fifteen years:

"After having risen only 20 feet and then going back down to about 4 feet, it continued to fly for about half a mile, setting fire to the sage brush as it went, at a speed close to 350 miles an hour."

Amateurs must understand that the rockets they design and build are what the military calls "free flight" rockets. In other words, there is no means of guiding or controlling the flight of the rocket once it has left the launcher—except, perhaps, the wishful thinking of those who designed it and the prayers of the spectators. (Even if a very advanced amateur group were to build a guidance system into a rocket, it could not be considered reliable enough to permit the assumption that it would go where it was intended to go.) For this reason, amateur groups must never launch even small rockets except in areas where there is no human habitation of any description *in any direction* for a distance greater than the maximum range of the rockets being fired. And they must also have the permission of the local authorities who have fire and police jurisdiction in that area. How to calculate the size of the clear, or *safe*, area that you need is covered in Chapters 8 and 9, together with many other aspects of safe launching operations.

The basic rocket shown in Illustration *2* is, of course, elementary both in concept and design. It is intended as a beginning project for the individual rocketeer or newly-organized group. It is not designed for high performance, but rather with a view to reasonable safety and ease of fabrication. If desired, the rocket can be made and test-fired without a nozzle as long as a diaphragm or some other type of retainer is used to hold the propellant in place initially. For beginning groups it is probably better to follow this procedure initially, and then to construct similar rockets with nozzles in order to compare performance.

The Nozzle: The two nozzles shown in the illustration are likewise not high-performance designs. They are "rule-of-thumb" designs which are relatively easy to fabricate and which have a generous safety allowance in the ratio of combustion chamber diameter to nozzle throat diameter. The ratio used is close to 2 to 1. Generally, amateur rocket groups have found that nozzles function with fair efficiency, and explosions do not occur, if this ratio never exceeds 3 to 1. (I.e., a rocket with a chamber inside diameter of 1½ inches should have a nozzle with a throat *no smaller* than ½ inch in diameter.) This ratio is based purely on experience, after many hundreds of rocket launchings, and not on engineering principles. It cannot be substantiated by calculation that this is an optimum ratio. It seems to give satisfactory results, however, providing other design factors are not out of balance. In Chapter 4 you will learn more about the factors that determine correct nozzle design and you will find there a thorough exposition of the calculations necessary to determine the proper nozzle dimensions.

Each of the nozzles shown in Illustration 2 can be made with a minimum of machining, a drill press being the only machine tool necessary for the drilling and countersinking. The finished nozzle should be as smooth as it is possible to make it, however, and it should be a tight press fit in the end of the rocket chamber. The sharp edges at either end of the throat section should be filed smooth and slightly rounded to prevent unburned propellant from accumulating at this point and possibly causing the nozzle to clog. A clogged nozzle means that an explosion will result unless the chamber walls are unusually strong.

The nozzle is attached to the body of the rocket with four machine screws of at least $\frac{3}{16}$ of an inch diameter placed equi-distant from each other around the circumference of the tubing. Get an engineer or a machinist to check the shear strength of the screws you are using. A machinist's or engineer's handbook will tell you. Make sure that the combined shear strength of the four screws is far in excess of the expected chamber pressure. Otherwise the nozzle may be blown out of the end of the rocket. Assume that the maximum chamber pressure developed by this rocket will be in the neighborhood of 600 to 700 pounds per square inch, and that the nozzle cross-sectional area exposed to this pressure is approximately 1.6 square inches. Make sure that you do not drill completely through the nozzle nor into the rocket chamber at any point when using screws for attachment.

An alternate method of attaching the nozzle, if you can get the work done, is to thread the entire length of the nozzle and an equal distance inside the rocket tube. Naturally, this is a more convenient method of attachment and it simplifies loading and insertion of the diaphragm. But if you use this method you must be extremely careful that propellant particles do not become stuck in the threads. Even a small amount can cause an explosion when the threads are tightened.

Care must be exercised to insure that the nozzle throat aperture is correctly aligned with the center line of the rocket body. When drilling and counter-sinking make certain that the drill is precisely centered and the angle of attack is exactly parallel to the outer surface of the nozzle. Even the slightest deviation from true center will cause the rocket to veer off sideways in flight.

The metal used for the nozzle should be the hardest, most heat-resistant type obtainable, consistent with machining requirements. SAE 1020, low carbon steel is satisfactory for low-performance rockets, but a chrome-molybdenum alloy is better. Get an engineer or metallurgist to advise you on this, if possible.

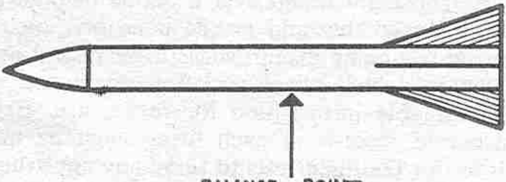
The Rocket Body: The rocket body should be of *seamless* steel tubing (SAE 1020) preferably, although aluminum is permissible for smaller rockets where a high-performance nozzle is not used. If you use steel, the wall thickness should be approximately 0.625 inches for a rocket of 1¾ inches outside diameter. A wall thickness of .125 is recommended for aluminum tubing, although $\frac{3}{32}$'s of an inch may be satisfactory. Care should be exercised in drilling holes to ensure that they are perpendicular to the surface and not canted.

The forward bulkhead, or plug, is cut from bar stock of 1⅝ inches diameter, and like the nozzle, should be a tight press fit in the rocket body. Attach the bulkhead with four of the same size machine screws used on the nozzle. To prevent leakage of pressure around the perimeter of the bulkhead, it may be brazed. But if you prefer to accomplish the loading of the propellant through this end of the rocket, so that the nozzle may be brazed in place, you can fit a tight rubber seal into the rocket body between the bulkhead and the nose cone. In this case, it is desirable to fasten the nose cone in place with screws, also, in order to hold the rubber seal tightly against the bulkhead.

The Nose Cone: The nose cone is made of wood and may either be turned on a lathe or whittled to shape. It, too, should be a tight press fit in the rocket body, but this is not important if the bulkhead is brazed in place. The nose cone can perform a useful function in balancing the rocket properly. It is desirable that the rocket be in balance when suspended at a point somewhere around its midpoint. Definitely, the center of gravity must be forward of the center of the fins.

ILLUSTRATION NO. 4

Aerodynamic Balance



BALANCE POINT
OR CENTER OF GRAVITY
SHOULD BE NEAR MIDPOINT OF ROCKET HULL,
BUT DEFINITELY FORWARD OF FIN SURFACES.

Balance your rocket, loaded with sand or some substance of the same approximate weight as the propellant. If it is nose-heavy, you can compensate by hollowing out the nose cone. If it is tail-heavy, you can insert lead weights in the nose cone to adjust the balance forward.

The Fins: The fins of the rocket should be made of 1/16th inch thick sheet aluminum. They may be attached to the rocket hull with band-type clamps, spot welding, or brazing. At the nozzle end, advantage may be taken of the screws which attach the nozzle to the hull, to also hold the fins in place. Do not attempt to place screws elsewhere on the rocket hull, however. For details of methods of fin attachment consult Illustration 24 in Chapter 5. To bend the flanges to the proper contour, take your parts to any tinsmith or a firm that installs hot air heating systems. They have the bending brakes to do a neat job for you.

The fins for this rocket have been designed according to a formula used by some amateur groups which is discussed in detail in Chapter 5. As you will see, after reading that chapter, there is no established method of calculating fin size and shape, even for professional rockets, without recourse to automatic computers—a procedure obviously beyond the capabilities of any amateur group. In the final analysis, fins must be flight tested by the trial and error method before a satisfactory configuration for any given rocket can be determined. Generally speaking, amateur groups tend to equip their rockets with much larger fins than are necessary. Many small rockets are successfully flown with no fins at all.

For a beginning project it is recommended that the small rocket shown here (or one similar to it) be fabricated in some quantity and flight tested over a period of time with different fin arrangements and nozzle conformations. By this means, the beginning group learns a great deal about the many factors which affect rocket performance, and accumulates valuable information for future use. Extensive and accurate records of each firing must be maintained in order for the flight tests to serve any constructive purpose. In Chapter 10 you will find a sample flight test data sheet and further guidance on this subject.

Diaphragm and Igniter: The diaphragm and igniter assembly shown in Illustration 2 is shown in detail in Chapter 5, Illustration 28. The diaphragm itself should fit snugly into the rocket body in order to perform its function and should be made of some easily workable and brittle material such as plastic or brass. The function of the diaphragm is to prevent the escape of gas from the burning propellant until enough pressure has built up to ensure thorough burning of the propellant and sufficient thrust to lift the rocket off the launcher. A rocket without a diaphragm may simply burn slowly on the launcher until all the propellant is consumed without having developed sufficient pressure for lift-off.

The diaphragm is designed to burst at high pressure and be ejected from the nozzle in small particles. For this reason they are sometimes called *burst diaphragms.* Naturally, the type and thickness of material used is of considerable importance. Here again, experimentation is necessary in order to determine just the right material and thickness required for a particular rocket. If the diaphragm is too strong, or melts into a tight ball which clogs the nozzle, a rupture of the rocket casing may result. Although copper has been used for this purpose, it is not recommended because of its tendency to melt rather than burst. Brittle plastics and brass are most widely used.

The igniter most generally used is a simple nichrome wire from any heating element and it is connected to a power source by wire leads. *All rockets must be fired remotely* from a safe distance. You will find directions in Chapter 8 for a safe firing set-up and the construction of a reliable firing circuit.

Propellant: This rocket is designed to burn a mixture of zinc dust and powdered sulfur mixed in the proportion of *3* parts zinc to *1* part sulfur by weight. This is a very commonly used amateur propellant and has been used successfully in a variety of proportions. You will find a thorough discussion of it in Chapter 3 with directions for mixing it in a theoretically optimum proportion; but since so many groups have used the 3 to 1 ratio with satisfactory results it is recommended that you conduct your early experiments with this simple mixture. Follow the safety directions in Chapter 3 for mixing, loading and compacting.

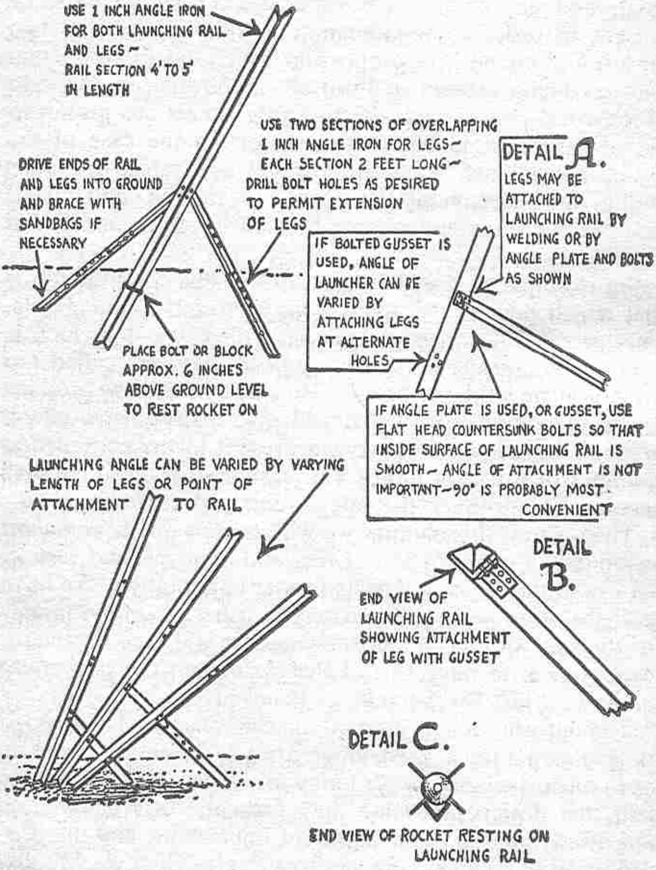
Launching the Rocket: Naturally, you should not attempt to launch even this small rocket without the permission of authorities in your community, and without having read all of the chapters in this book dealing with organization and safety, layout of a launching site and safe firing procedures. It is also a good idea to establish a program for static testing your rockets (as explained in Chapter 7) before any actual launchings are attempted. Usually, if your rocket has been correctly designed and built, it can be re-used for a flight test after a successful static firing. If the rocket fails in a static firing you would not want to have risked it in a free flight test anyway, so nothing has been wasted.

Any one of a number of different launching rack designs is suitable for launching this type of rocket. And as your group progresses you will undoubtedly want to design one to your own particular requirements. Further information on launching mechanisms is given in Chapter 8, but for the present the simple launching rail shown in Illustration *5* will prove satisfactory.

The performance of a given rocket design will vary widely according to the type of propellant mixture used, the density to which the propellant is packed, the type-burst diaphragm used, the accuracy of nozzle construction, and even temperature and humidity conditions at the time of firing. In addition, there is a host of other factors too involved to discuss here which can cause performance variations in apparently identical rockets fired under identical conditions. It is by direct comparison of test results, careful observation, and close examination of recovered rocket hulls that the average amateur group learns most about the mysterious factors it is trying to control. Rockets of the size and type detailed in Illustration *2* are capable of reaching altitudes between 1,000 and 1,500 feet using the zinc and sulfur propellant. A more refined nozzle design may double or triple this altitude. But do not be disappointed if the rocket you build does not approach these figures. The challenge is not met by achieving a record altitude. It is met *by learning how* to achieve that altitude. It is virtually axiomatic of rocket experimentation that much more is learned from failure than success. No one on earth can positively say what caused a rocket to perform perfectly—except that "nothing seemed to go wrong." But the causes of failures can frequently be pin-pointed—and when one has been explained, something has been learned.

ILLUSTRATION NO. 5

Tripod Type Launcher for Basic Rocket Described in Illustration No. 2



Chapter 3

ROCKET PROPELLANTS

What the amateur usually refers to as the *fuel* for his rocket is more properly described as the *propellant*. Professionals make a clear distinction between the two terms which is generally ignored in popular usage. Propellants consist of two things: a fuel (or reducer) which will not burn by itself; and an oxidizer (or other agent) which must be present in order for combustion to take place. The two are usually mixed in a proportion which ensures sufficient oxidizer being present to burn all of the fuel. In the case of the solid propellants, the two ingredients are premixed and usually cast in the rocket motor. In the case of the liquid propellants, they are carried separately in tanks within the airframe of the rocket or missile, and mixed only at the moment of combustion in the combustion chamber.

An example of a widely-used propellant combination is that which powers the Army's NIKE ground-to-air missile. This propellant consists of a fuel called JPL-4 (which is really a high-grade kerosene), and an oxidizer called red fuming nitric acid (or RFNA). Both are needed to produce a rate of combustion which will give a propulsive effect, because there is no free oxygen present in the combustion chamber of a rocket motor (at least, not in the quantities necessary to produce the rate of combustion required).

Throughout this chapter we will use the word *propellant* to indicate a combination of fuel and oxidizer, and restrict the use of the word *fuel* to its proper connotation. We have used the word *fuel* rather loosely in other chapters, mostly for the sake of convenience; because it is a little awkward, for instance, to have to call the *fueling pit* the *propellant loading pit* just for the sake of being precise.

The information presented in this chapter is intended to give you first a brief summary of the more common types of propellants in use today in the professional missile field, the design problems they present, their advantages and disadvantages, their apparent limitations, and the general trend of development in propellants. Then we will discuss the relatively few propellants that are used by amateur groups, and deal in specific detail only with the zinc and sulfur combination which is the most widely-used amateur propellant, and the one with which the most consistent results are obtained.

I TYPES OF PROPELLANTS

Although research is being undertaken toward the development of more advanced types of propellant systems, there are only two principal types of propellants in general use today. They fall into two broad classifications: those called liquid propellants, and those called solid propellants. As far as modern rocketry is concerned, the liquid propellants have been used more widely, experimented with for a greater period of time, and are capable of a higher level of performance. The solid propellants have only recently come into favor (after having been virtually forgotten), there are fewer of them, much less development work has been done on them, and to date they have not achieved the high-energy yields of the liquids. If you have been doing much reading on the subject you have probably become aware of a continuing controversy among missile scientists and development engineers as to whether the liquid propellants or the solid propellants possess the greater development potential, and on which of them research should be concentrated. This controversy is silly and pointless for several reasons; but most important among them are the fact that neither liquid nor solid propellants as we know them are likely to be the ultimate means of propulsion, and the fact that both liquids and solids have their proper place in a wide variety of uses. Neither one of them can be expected to usurp the field.

In the liquid propellant classification there are two major subdivisions: the *bipropellants* and the *monopropellants.* The bipropellants consist of a fuel and an oxidizer which are stored separately within the missile and are fed independently to the combustion chamber where they are mixed only at the instant of combustion (e.g., gasoline and liquid oxygen). This is necessary because certain combinations of fuel and oxidizer are self-igniting when mixed (e.g., aniline and nitric acid) and cannot be brought into contact with each other until the moment that combustion is desired. Other combinations, while they do not ignite spontaneously, nevertheless form highly unstable compounds when brought into contact with each other and are consequently very dangerous to handle and can explode without warning. As an example, the widely-used combination of alcohol and liquid oxygen, if not ignited upon contact, forms gelatinous globules which have *100 times* the explosive force of an equivalent weight of TNT. When this circumstance occurs in the laboratory, through a failure of ignition or for some other reason, all work must cease and the area must be cleared until the liquid oxygen has had a chance to evaporate. Evaporation of the oxygen takes from forty-five minutes to an hour.

Monopropellants are fluids which contain both a fuel and an oxidizing agent, either as a single chemical such as *nitromethane,* or as a mixture such as *ammonia* and *nitrous oxide*. These are stored and fed into the combustion chamber as a single fluid, thus eliminating the need for an additional tank, extra plumbing and extra storage and handling equipment, as well as mixing valves and complicated injectors. Another monopropellant which has been used is hydrogen peroxide (80% conc.) but it has a very low specific impulse compared with other liquid propellants.

Among the solid propellants you will also hear two types mentioned—*double-base* and *single-base*. But all solid propellants do not fall into one of these two categories, so that these are not comprehensive classifications. At present, many of the leading solid propellants in use are based on the nitric esters nitrocellulose and nitroglycerine. Those which contain only nitrocellulose are called *single-base;* those which contain both are called *double-base*. Obviously, there are many solid propellants which contain neither of these ingredients, so the terms do not apply to the entire field of solids.

LIQUID PROPELLANTS

A table showing the composition of the more common types of liquid propellants is included in Illustration *8* at the end of this chapter. You will note that virtually all of them consist of some type of oxidizing agent and a fuel of the hydro-carbon family which is easily oxidized. The chart also shows the *specific impulse* rating for many combinations and the flame temperature produced during combustion. We will discuss the meaning of the term *specific* *impulse* and how it is calculated later in the chapter. For the present it is only necessary to know that it is a measurement of the ability of a propellant to produce thrust and it is expressed in seconds. The higher the value shown for specific impulse, the more powerful is the propellant. In the case of the liquid propellants the term *specific thrust* rather than *specific impulse* is sometimes used. This is because the measurement means something slightly different in reference to liquids, since it takes into account the rate of flow of the propellant into the combustion chamber. However, the two terms are equivalent in all respects except the method of calculation, and *specific impulse* has come to be more widely used regardless of the type of propellant being considered.

Although some amateur groups have experimented with liquid propellants, and some have actually constructed liquid-propelled rockets of acceptable design, the engineering problems involved and the hazards of working with liquid chemicals are such that serious experimentation in this field is beyond the capacity of all but a tiny percentage of the most advanced amateurs. It is not within the scope of this volume, nor is it considered advisable by the author, to present sufficient data on liquid propellants and liquid motor systems to enable the amateur scientist to undertake actual construction. It has been emphasized throughout this book that no experimentation involving the use of propellants should be attempted by the amateur without thoroughly qualified professional supervision. Particularly is this true of the liquid propellant field, where the dangers are the greatest. Unfortunately, a great many popular magazines and popular texts on rocketry carry disarmingly simple illustrations of liquid rocket motor systems which encourage the amateur in the mistaken belief that he can design and build one. These diagramatic representations of liquid motors and feed systems are intentionally oversimplified in order to enable the lay reader to grasp the fundamental principles involved. They are not intended to be design drawings and a successful motor could never be built with such drawings as the only guide, primarily because all design information relating to fuel flow control, method of ignition, methods of valve control, corrosion problems and a host of other engineering considerations has been eliminated from the diagram. Similar diagrams have been included in this book purely for the purpose of illustrating the basic elements of a liquid motor and the principles of its operation.

The liquid propellants possess certain very definite advantages, as opposed to the solids, but also pose certain design problems and storage and handling problems which render them less desirable from a standpoint of utility. Their chief advantages are:

Higher energy yield. (Considered as a group, liquids are approximately 50% more powerful than available solid propellants.)

They are readily available, and in most cases can be produced in large quantities.

Combustion temperatures are generally lower, as are combustion pressures, thus making possible lighter motor wall construction.

Fuel flow rate (and consequently combustion rate) can be controlled directly, making possible a wider range of performance for a given propellant.

They are relatively unaffected by changes in temperature, humidity and pressure and can be stored for indefinite periods of time if stored properly.

Their chief disadvantages are:

They require elaborate plumbing systems—which more than compensate for the weight saving realized by light motor wall construction—and which are of such intricacy that "temperamental" mechanical failures plague most liquid systems.

Many of the chemicals used are highly corrosive, requiring the use of expensive and hard-to-obtain materials for storage tanks, valves, fittings, seals, tubing and a host of other items.

Many are likewise extremely toxic, representing a hazard to personnel and requiring very costly storage and handling procedures.

Fueling time and the logistical problems involved in their transportation and storage render them almost useless for a great many applications.

Their low density creates a bulk displacement problem which is reflected not only in the size of storage and transportation facilities required, but in the size and weight of the airframe of the missiles in which they are used.

All things considered, it would appear that the single most important advantage of the liquid propellants is their higher energy yield (as evidenced by their specific impulse ratings). But considerable progress has been made toward reducing this advantage by development of increasingly more powerful solid propellants within the last few years. It must also be considered that the advantage of the liquids in terms of specific impulse is not a true measure of comparative performance of the two types of propellants in their ultimate employment within the airframe of a missile. Specific impulse is a measure of performance in terms of *pounds* of propellant consumed. In view of the lower density, and consequently greater bulk of the liquids, one must take into account the greater size and weight of the airframe required to accommodate them. This factor appreciably reduces the advantage of superior thrust since a given number of pounds of a liquid propellant must lift a greater weight of airframe than would an equivalent number of pounds of a solid propellant. This means that even if solid propellants never achieve the high energy output of the liquids, they may very soon reach the point where they *outperform* them in terms of payload delivered.

As examples, it can be cited that the satellite launching vehicles currently in use in this country have already abandoned liquid motors except for the first, or *booster,* stage of the missile. And the Army medium-and long-range artillery missiles CORPORAL and REDSTONE (both liquid propelled) are being replaced by the smaller, lighter solid rockets SERGEANT and PERSHING. In both cases the new solid types, roughly two-thirds the size and weight of their predecessors, will deliver the same size warhead the same distance with a lower impulse propellant, simply because of the weight saving in the carrier airframe. Naturally, they have other advantages also, which are important to the military; but are seldom taken into account by persons interested in arguing over the relative merits of propellants. These are: immensely simplified handling and firing procedures, zero fueling time, reduction in the amount and complexity of supporting apparatus, and a significant reduction in the size (and training) of the crew required to service and fire the weapon.

Combustion Performance of Liquid Propellants: Liquid propellants of the bipropellant type are fed into the combustion chamber of a rocket motor under pressure from tanks in which the fuel and oxidizer are stored separately. Usually some type of inert gas (such as nitrogen) is used as the pressurizer to force the fluids from their storage tanks to the injector which sprays them into the combustion chamber. In other cases, turbo-pumps are used to pump the fluids and these pumps are actuated by some type of gas generating substance such as hydrogen peroxide or a slow-burning cordite charge. You will learn more about these systems in the chapter on Motor Systems. In the case of the monopropellants, of course, the feed system is simpler because only one fluid is involved, but the methods used are the same.

Generally the fluid is sprayed around the walls of the combustion chamber in a helical pattern: this serves to cool the walls of the chamber, and also increases the chances of complete combustion by creating a fine, misty spray of fuel and oxidizer. As previously mentioned, ignition must be almost instantaneous or very dangerous, highly explosive, compounds may form. What happens from this point until the moment that hot exhaust gases are ejected from the nozzle exit is not completely understood and is still the subject of much research and development work; for many compounds may be formed, broken up and re-formed before the eventual exhaust product is produced, and several types of shock waves develop which contribute to what is called *combustion instability* and which inhibit the smooth flow of exhaust gases to the exit. Stated simply, however, the burning propellant produces hot gases which press against the walls of the chamber and seek to escape through the one exit provided by the nozzle. When sufficient temperature and pressure are produced to create a high enough velocity of exhaust gases escaping through the nozzle, *thrust* is developed and the rocket is propelled forward.

How much thrust is developed is dependent upon the inter-relationship of a combination of factors involving the design of the injection system, the design of the combustion chamber, the properties of the particular propellant combination, and the design of the nozzle (the chief function of which is to accelerate the exhaust gases to the optimum velocity obtainable). As far as the propellant itself is concerned, the most important factor affecting thrust is the relationship between the flame temperature of the burning propellant and the molecular weight of the exhaust products. The higher the temperature within the combustion chamber, and the lower the molecular weight of the particles ejected through the nozzle, the higher the velocity of the exhaust stream will be. And the higher the exhaust velocity is, the greater the thrust.

The exhaust products ejected from the nozzle of a rocket motor may consist of a variety of compounds of the basic elements which go to make up the fuel and the oxidizer, and in many cases they cannot be isolated and identified before they are converted to other compounds by changes in temperature and pressure during the exhaust process. For this reason it is impossible, at the present stage of technological progress in rocket science, for researchers to make a complete chemical analysis of the products of combustion that are formed in the combustion chamber and flow through the nozzle of the rocket. However, the bulk of the exhaust products can be identified as they emerge from the nozzle exit. These products represent matter with measurable mass, weight and chemical composition.

The molecular weight of any substance is the sum of the products of the atomic weights of each element in the compound multiplied by the number of atoms of that element in one molecule.

$$\text{Molecular weight} = \text{atomic weight} \times \text{no. of atoms}$$

This weight is expressed in pounds (merely as a standard of measurement, for this standard bears no relationship to the *actual* weight of a molecule).* As an example, the molecular weight of water (H_2O) would be calculated as follows:

$$M\,(H_2O) = (1 \times 2) + (16 \times 1)$$
$$M = 18 \text{ lbs.}$$

This does not mean that a molecule of water weighs

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* If the weight is expressed in grams it is referred to as the gram-molecular weight of the substance.

eighteen pounds; but it does mean that eighteen pounds of water consists of sixteen pounds of oxygen and two pounds of hydrogen. And it means, further, that the distribution of weight among the elements in any given quantity of matter is based upon the atomic weights of those elements and the number of atoms of each that are contained in one molecule of the substance. In the case of water, the equation above illustrates that each molecule of water contains two atoms of hydrogen with an atomic weight of 1, and one atom of oxygen with an atomic weight of 16.

Wherever the combination of low molecular weight and high flame temperature exists, the specific impulse is high. Where flame temperature is low, or molecular weight is high, the specific impulse rating is correspondingly low. In other words, some correlation exists between the molecular weight of the propellant, the flame temperature, and the specific impulse obtained. Bear in mind, however, that the molecular weight that is important here is the molecular weight of the *exhaust products*—not that of the original propellant combination.

The specific impulse (or specific thrust) of a propellant is probably the most important and most frequently used index of its efficiency. We will consider it again when we deal with amateur rocket propellants. There are a number of different ways of computing it, depending on the type of data that you start with, and it might be well to present one of the formulas used for liquid propellants while we are discussing them. Assuming that you do not know the total amount of thrust developed by the propellant, or the exhaust velocity, but you do know certain other basic data concerning the propellant and the motor in which it is to be used, you may find the specific impulse by the following formula:

$$I_{SP} = \sqrt{\frac{2}{k-1}\,\frac{RT_c}{M_w g}\left[1-\left(\frac{P_e}{P_c}\right)^{\frac{k-1}{k}}\right]}$$

where: g = acceleration of gravity
k = specific heat ratio (the ratio between the amount of heat required to raise the tem-

perature of one pound of a substance 1 degree centigrade when it is under constant pressure, and the amount required when it is held at constant volume: $\frac{C_p}{C_v}$)

R = universal gas constant (1544)
T_c = combustion temperature (absolute)
M_w = mean molecular weight
P_c = combustion chamber pressure
P_e = nozzle exit pressure

This is a fairly complicated formula, but by studying it closely you can see that specific impulse is related to the performance of a propellant *in a particular rocket motor.* In other words, a propellant combination does not have a specific impulse of its own, entirely independent of any motor system. Rather, it may produce quite a range of values for specific impulse depending on the design of the motor system in which it is burnt; for such values as combustion chamber pressure and nozzle exit pressure will vary with each motor design. The values for specific impulse shown in the table (Illustration 8) are the highest obtainable for each propellant combination, and assume that the motor involved is of optimum design permitting a maximum acceleration of the expanding gases through the nozzle.

There are several ways of defining what is meant by the term *specific impulse,* because it represents a relationship involving many factors which are under constant change during the process of combustion and ejection. One way of expressing the meaning of the term is to say that it represents *the rate of change of momentum* of the gases, or the rate of acceleration of the gases through the nozzle. This definition is fairly good; but we are not only concerned with acceleration of the gas particles. We are also concerned with the rate at which the gases *expand* as they leave the nozzle. The two things are interrelated, of course, and it might be said that one follows the other logically. However, the ability of a gas to expand is largely a property of the gas itself, whereas the acceleration of the particles through the throat of a nozzle is partially affected by the design of the nozzle and the combustion chamber.

Nevertheless, there is a simple and direct relationship between specific impulse (or thrust) and the exhaust velocity; and if the exhaust velocity of a particular motor and propellant combination is known, then the specific impulse can be calculated by use of a very simple equation:

$$I_{sp} = \frac{v_e}{g}$$

where: g = the acceleration of gravity
v_e = the exhaust velocity

The presence of the term *g* in this equation should indicate to you that specific impulse is not just a measure of velocity, but of *the rate of change in velocity*—since *g* is a measure of acceleration in terms of feet/second/second. This means, then, that *thrust* is not a matter of the velocity of the gases escaping from the nozzle exit, but is determined by the *rapidity* with which they reach that velocity. Thrust is accounted for by the fact that the gas particles in the combustion chamber initially have a zero velocity, but rapidly reach a very high velocity on their way to the nozzle exit. *Thrust* takes place between the combustion chamber and the nozzle exit; not *at* the nozzle exit. By the time the expanding gases reach the exit they have done their work. No matter what their velocity is at that point they can have no further effect on the movement of the rocket. From this point it is only important that they be allowed to dissipate themselves as rapidly as possible, and reach atmospheric pressure as rapidly as possible, so as to make room for the gases which are following behind them. (Failure of the gases to reach atmospheric pressure shortly after their escape from the nozzle would create a *back-pressure* which would slow down the movement of succeeding gas particles through the nozzle.) If the gas particles within the combustion chamber had a high velocity to begin with (assuming it were possible to create this condition), and they experienced no increase in velocity on their way to the nozzle exit; then no thrust would be produced at all, no matter how great the velocity was. Similarly, if the difference in velocity between combustion chamber and nozzle exit were very small, there would be no appreciable thrust.

You can demonstrate to yourself the principle that is involved in creating thrust by sitting in a swing and conducting two experiments. First, extend one leg in front of you very slowly to the limit of its reach. The swing will not move. Secondly, kick the leg out in front of you as fast as you can. The swing will be propelled backward a short distance. In both cases you have performed the same amount of work by moving the same leg the same distance. But in only one instance did a reaction take place in the swing. Does this mean that Newton's law of reaction does not always apply? No! It simply means that in the first instance the reaction was not of a high enough order to move the swing. In other words, no *thrust* was produced. In the second instance considerable velocity has been added to the movement of the leg, and the rapidity with which that velocity is reached (the rate of acceleration) will determine the size of the reaction produced in the swing. In the first instance the impulse of the leg is very low. In the second instance it is very high. Impulse is the measurement of the speed with which a given velocity is reached.

Corrosive and Toxic Effects of Liquids: Before we leave the subject of the liquid propellants it might be well to review briefly the hazardous properties of some of the chemical substances widely used in propellant combinations in order to emphasize to the reader the dangers which lie in wait for the amateur who is foolhardy enough to attempt to experiment with them. Generally speaking, amateur rocket enthusiasts simply have no conception of the extraordinary precautions which have to be observed by commercial firms, professional laboratories and the military services in the transportation, storage and handling of these substances, nor of the elaborateness of the equipment and the high degree of training of the personnel used to employ them effectively. The destructive properties of these substances affect both materials exposed to them and personnel who have to handle them, in most cases. Their effect on materials is called *corrosive action* and, generally speaking, they tend to decompose certain materials or change their physical properties. Their reaction on the human body is described as a *toxic effect* and is usually manifested in the form of burns, blisters, rashes, or in extreme cases, decomposition.

Liquid Oxygen: There is no such thing as a *safe* oxidizer, but of those presently available, liquid oxygen is the least harmful because it is nontoxic. It does not give off poisonous or otherwise injurious fumes. If spilled on the skin, it evaporates rapidly and does no harm. However, prolonged contact with it will cause severe frostbite in the member exposed, because of the extremely low temperature, and it reduces the temperature of pipes, tubing and containers to the point that they cannot be touched with the bare hand without the skin sticking. Because liquid oxygen boils at minus 183 degrees centigrade, it must be kept in vacuum insulated containers, or containers insulated with glass wool. The loss during transfer from one container to another is extreme, and the overall loss from time of manufacture to actual use runs as high as 50%. The chief danger of liquid oxygen is the fire and explosion hazard it represents. Porous organic materials exposed to it may absorb sufficient oxygen to render them highly inflammable or even explosive. The vapor given off by liquid oxygen tends to form pockets of gaseous oxygen in unventilated areas, and the presence of this gas creates a serious fire hazard. Pure oxygen lowers the ignition point of all materials with which it comes in contact and makes them burn so fiercely that even metals become combustible in its presence. Liquid oxygen also makes most metals extremely brittle. A steel pipe can be broken with a light tap from a hammer after its temperature has been reduced by contact with it.

Hydrogen Peroxide: The fumes of hydrogen peroxide are mildly toxic, and the liquid itself, if spilled on the skin, causes irritation. White patches will form, and unless the liquid is washed off immediately severe itching results and peeling of the skin follows. If the fumes are inhaled they irritate the mucous membranes of the nose and throat, causing coughing and excessive nasal and throat secretion. Damaging effects to the eyes may not be apparent until long after the exposure. Severe skin burns can result from prolonged exposure. Hydrogen peroxide may cause spontaneous combustion of porous organic substances if spilled on them. Pumps, tubes, tanks and other handling apparatus must be tightly sealed to prevent leakage of the fluid, and special outer protective clothing and eye-shields must be worn by personnel exposed to it.

Nitric Acid: White fuming nitric acid and red fuming nitric acid are both highly corrosive and extremely toxic. Gas masks must be worn by personnel handling them. Contact with the liquid causes severe skin burns, but the fumes are even more dangerous, causing irritation of the eyes, nose and throat, with resultant violent coughing, a choking burning sensation in the chest, headache and vomiting. Symptoms may not appear until long after exposure, by which time damage to internal tissues and organs may be so advanced as to be beyond treatment. Concentrated nitric acid (95% or over) will eat through virtually any metal, so that only pure aluminum can be used for containers. If the acid becomes diluted through exposure to a damp atmosphere it will even corrode aluminum, and it is very difficult to prevent its dilution because of its hygroscopic nature.

Ethyl Alcohol: This substance is like water in its appearance but causes severe irritation to the eyes and upper respiratory tract if its vapors are inhaled. Its effect on the skin is relatively mild, but prolonged contact will cause some irritation. It is not as poisonous as some other forms of alcohol if taken internally, but is nevertheless highly intoxicating and injurious to the stomach. It acts as a solvent on most organic materials and is a moderate fire risk.

Furfuryl Alcohol: This is a yellow liquid with a brine-like odor and a bitter taste. It is poisonous if taken internally, or even if absorbed through the skin. It causes irritation to both skin and eyes. Concentrations of its vapor will cause irritation to the throat and lungs.

Methyl Alcohol: This is a highly poisonous substance, colorless like water and with a smell similar to ethyl alcohol. It is harmful whether taken internally, absorbed through the skin or breathed through the lungs. It evaporates quickly and is highly flammable. Even in small amounts it will cause headache, nausea, vomiting and irritation of the mucous membranes. Larger amounts cause dizziness, staggering, severe cramps, blindness, convulsions and coma. Even a small amount taken internally may cause death. Personnel should not be exposed to it in unventilated areas, and respiratory equipment is a must when working with it.

Hydrazine: This is a colorless, alkaline, fuming liquid, which may be odorless or have the odor of ammonia. It is flammable, highly explosive and corrosive. It is poisonous by breathing, by skin contact and if taken internally. Intense skin burns result from contact with the liquid. The vapors will cause immediate and violent irritation of the nose and throat, and itching, burning and swelling of the eyes. Prolonged exposure may cause blindness. A gas mask must be worn when working with it.

Hydrocarbon Fuels: Virtually all of the hydrocarbons (gasoline, kerosene, heptane, butane, octane, pentane, etc.) give off large amounts of vapors which are heavier than air and tend to collect in low places. These vapors are instantly ignitable if exposed to a spark or flame, and are poisonous by inhalation or absorption through the skin. Prolonged exposure to the fluid can even cause deadening of the tissues of the skin.

The foregoing does not include all of the fuels and oxidizers used in liquid propellants; but it does cover the more common ones, and those having the more dangerous toxic properties. A review of the list should convince anyone that these are not substances which can be treated lightly nor handled carelessly. No amateur should experiment with any of them, either singly or in combination, and they should not be stored or handled in populated areas where other people may be exposed to their hazards. Highly trained professional personnel whose jobs require them to handle these substances wear and use elaborate protective equipment and must submit to almost daily physical examinations to determine whether they are suffering from delayed or cumulative effects of exposure.

SOLID PROPELLANTS

The more commonly known solid propellants, and the substances of which they are composed, are shown in the table in Illustration 8. As we have seen in our discussion of the liquids, the solid propellants have generally lower ratings of specific impulse and burn at higher temperatures. Many of them are extremely dangerous to compound because they are based on, or contain, explosives that have been familiar to us for many years. Even though the propellant in its final form may be perfectly stable and not sensitive to shock, friction or heat, the process of compounding it can be fraught with danger. Most solid propellants must be mixed in a molten state and cast into the rocket chamber, or compacted under pressures of many, many tons in order to achieve the density required. The equipment required to do this, and do it with any degree of safety, is so costly and elaborate as to be beyond the means of any amateur group. The hydraulic presses and dies necessary for this type of work can run into the hundreds of thousands of dollars.

When one considers the vast resources, in terms of money, equipment, laboratories and research technicians, presently devoted to the development of solid propellants in this country and elsewhere in the world, it is utterly foolish to entertain the notion that some brilliant young genius working odd hours in a basement or attic might hit upon a formula that has eluded the best brains in the field. He is much more likely to blow off an arm and set his house on fire. The substances used in rocket propellants are simply not the type of thing one mixes on the kitchen stove. It is therefore wiser, and safer, for the amateur to *avoid all experimentation* with fuels and to not even attempt to mix fuels which require melting or extreme pressures to compound with an oxidizer. The zinc and sulfur combination, which has been used widely by amateurs, and which is considered in detail in this chapter, will send a rocket to altitudes far beyond the ability of the average amateur group to track it. In view of this, it seems pointless to experiment with other compounds which are more difficult and dangerous to handle.

The solid propellants possess certain very definite advantages which make them attractive to users, particularly the military services who must always be concerned with the problems of transportation and supply in distant combat areas, and the equally important problems of servicing, maintenance, and the training of personnel. The simplicity of solid propellants (which are either prepackaged or cast directly into the rocket motor, and do not require the elaborate plumbing and control mechanisms that the liquids do) gives them a practical advantage of prime importance. For military purposes, a great deal of performance can be sacrificed in favor of simplified handling, training and logistical requirements. Among the advantages of the solid propellants are:

- Low toxicity—which reduces handling problems and hazard to personnel, and eliminates the need for much protective clothing and equipment.
- High density—which means less bulk and a consequent saving in storage space and size and weight savings in the rocket airframe.
- Ease of handling—rocket and propellant can be shipped as one unit, fueling equipment, time-consuming fueling process and elaborate countdown procedure are eliminated or reduced to a significant degree.
- Lower cost—Pound for pound the solids cost less and are less expensive to handle. There is no loss through evaporation or spillage.
- Ease of ignition—complicated and temperamental ignition systems are not required.

There are also certain disadvantages to the solid propellants, as compared to the liquids. They are:

- Lower performance—Pound for pound the solids generally give lower thrust.
- Decomposition—Whereas most liquids can be stored for indefinite periods of time (as long as they are in the proper type container), many solids tend to decompose or *age* in storage, with resultant changes in chemical structure.
- Cracking—Cracks sometimes occur in cast grains, either through aging or mishandling. What is called *thermal cracking* may occur during the burning process. The presence of these cracks increases the burning surface, and consequently the temperatures and pressures created, and can cause a violent explosion.

DANGERS AND HAZARDS OF THE SOLID PROPELLANTS

As in the case of the liquids, there are very definite dangers and hazards involved in the preparation and use of solid propellants which the amateur should be aware of, and which should convince any thoughtful person that experimentation with them is foolhardy. The amateur who ignores these hazards, or treats them lightly, is inviting disaster. A few of the more common hazardous materials, and the dangers they represent are listed here for your information:

Black Powder: This is the oldest known explosive mixture and also the most unstable. It is so unpredictable and tricky to handle that it is no longer used professionally for any serious purpose. A mixture of potassium nitrate, charcoal and sulfur, it explodes readily when subjected to heat, friction, shock or an igniting spark. Small amounts of it may be used successfully as an igniter for a more stable propellant or as an explosive charge to separate stages or eject a parachute device. No more than a few ounces of it should ever be mixed.

Match heads: These have been widely used by a great many thoughtless amateurs and juvenile "firebugs" who are interested only in seeing something explode. The friction match is obviously a highly unstable thing invented to make it easy for the housewife to start a fire. One of them does not represent much danger. But *three* match heads have been known to propel a quarter-inch bolt with enough force to send it crashing through a window and chip a concrete wall. A pound of match heads has sufficient power to blow off an arm or a leg. A container full of match heads can explode if merely shaken.

Nitroglycerine and nitrocellulose: These are used as the principal base of a great many solid propellants, but should not be handled by amateurs under any circumstances. They have a toxic effect on the human body, causing headache, nausea, vomiting and in extreme cases of exposure even convulsions and decomposition of tissue. Both are extremely sensitive to shock, friction and heat (particularly nitroglycerine), and are among the most powerful explosives known.

Chlorates and perchlorates: These should not be used by amateurs under any circumstances. The most readily available chlorates, sodium chlorate and potassium chlorate, are so friction sensitive that they will detonate when ground or rubbed in a mortar. They are not used even in professional propellants for this reason. The *perchlorates* are more stable, but are still dangerous.

Potassium permanganate: This compound has appealed to many amateurs because of its availability and its ready burning. Many have had the bright idea of using it in CO_2 cartridges and Jetex units with disastrous results. It is so friction sensitive that the slightest grinding will set it off. In one case, a young rocket enthusiast had his left hand blown off when he tried to use a nail to enlarge the nozzle aperture of a cartridge he had loaded with potassium permanganate.

Powdered metal: Virtually any powdered metal is dangerous if it is allowed to form a dust in the air. Iron, magnesium, nickel and aluminum will produce an explosive mixture with air when they are being poured from one container to another or when shaken. Some metals, such as magnesium, will ignite spontaneously when in the form of dust in the air, even though no igniting spark is present.

Generally speaking, this is true of any substance which is in powder form, whether it is classed as a combustible or not. Flour mills and cement plants have been known to explode without warning, sometimes completely demolishing a plant. On a recent television stunt program the production staff had the brilliant idea of tossing a bag of flour on a man who was impersonating a firecracker just as his wife was asked to light the fuse protruding from his head. The idea was to increase the "comic" effect; but instead, a violent flash explosion took place which gave both the man and his wife serious burns.

In addition to the dust hazard presented by finely divided metals, many of them become very shock sensitive when mixed with an oxidizer.

Spontaneous combustibles: Certain substances will ignite spontaneously when exposed to air. Among these are yellow phosphorus, metallic sodium and metallic potassium. Naturally, these materials should never be handled by amateurs. They scatter particles as they burn, and these particles will burn deep holes into flesh.

The foregoing is not intended to be a complete listing of all of the hazards one may encounter in working with solid rocket propellants. It is simply a guide to some of the more frequent and evident dangers. To ensure maximum safety in preparing and handling *any* propellant combination, it is recommended that the reader pay careful attention to the safety rules listed at the end of this chapter.

PROPELLANT GRAIN SHAPES AND METHODS OF FORMING

Most solid propellants are either cast or molded into a solid bar which is the exact shape and size of the combustion chamber of the motor in which they are to be used. This solid bar, consisting of a mixture of fuel and oxidizer, is called a propellant *charge* or *grain*, with the latter term being more widely used. In some cases the propellant mixture, in a molten or putty-like state, is poured directly into the combustion chamber and allowed to harden under conditions which will allow it to form a firm bond with the rocket chamber walls. This is called a *bonded grain*. In other cases, the mixture may be cast, or formed under pressure, to the exact dimensions of the combustion chamber in a mold designed for that purpose, and then is inserted into the motor when it is ready for use. In still other instances, propellant combinations may be cast or formed into cylinders or "bar stock," the approximate size of the motor chamber. The bar is then "machined" to fit any one of a variety of motor chambers by sawing, grinding or extruding it to the desired dimensions. This method may be used when it is desired to produce a propellant grain for use in a variety of rocket motors of roughly similar dimensions; but, naturally, it is only practical in the case of propellants which are not sensitive to shock, friction or pressure.

Propellant grains produced by these methods fall into three general classifications according to their burning characteristics. These are: *neutral-burning*, *regressive-burning*, and *progressive-burning*. Cross-sectional and longitudinal views of grain designs within each of these classifications are shown in Illustration 6.

Neutral-burning types are those in which the area of the burning surface remains more-or-less constant throughout the burning process. The amount of propellant consumed during any given period of time likewise remains constant, as does the burning pressure.

Regressive-burning charges are those in which the area of the burning surface *decreases* during the burning process, with a consequent drop in the amount of propellant burned per time period and a constantly decreasing pressure.

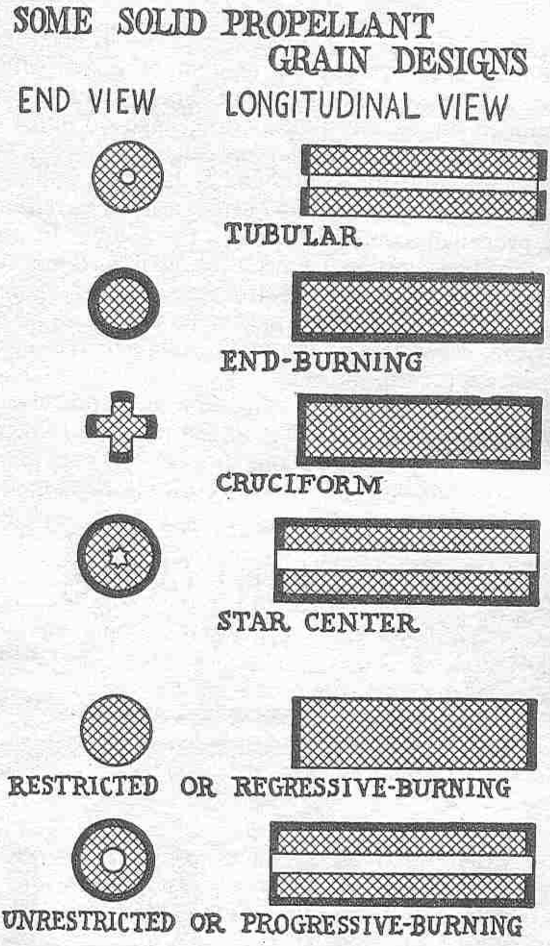
Progressive-burning charges are those in which the burning surface *increases* during the burning process, with a resultant increase in the amount of propellant burned per time period, and a constantly rising pressure.

In order to give you a better idea of what some of these grains look like, three-dimensional drawings of some popular types are shown in Illustration *7* together with a cutaway view of a concentric ring grain inserted in a rocket motor.

Restricted Burning and the Use of Inhibitors: The burning characteristics of any propellant grain are achieved through a combination of grain design and the application of *inhibitors* (noncombustible or slow-burning substances) which are applied to portions of the grain surface in order to prevent burning on that part of the surface. Grains which have been so treated are known as *restricted-burning* grains. The heavy black borders shown on various portions of the grains in Illustration *6* indicate the presence of an inhibiting material. The material used for this purpose is usually similar in nature to the propellant to which it is applied. For cordite, for instance, cellulose acetate is often used for the inhibitor coating.

In Illustration *6* you will note that the end-burning, or cigarette-burning, type of grain has a layer of inhibitor on every surface except the one end on which it is desired to have burning take place. In the case of grains which are cast into the combustion chamber so that a tight bond is formed between the grain and the chamber wall, the bond itself acts as an inhibitor, and no coating of the grain is necessary. By studying the grain designs shown in the illustration carefully you will be able to determine the type of burning that the designer is trying to achieve, i.e., the surfaces which are to be allowed to burn, and the direction in

ILLUSTRATION NO. 6

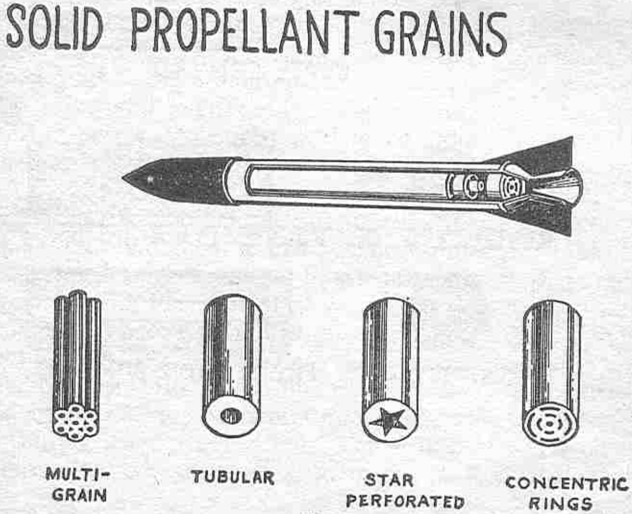


which burning is to progress. You will also note that some grains burn from the inside outward, some burn from the outer surface toward the center, and others burn in both directions simultaneously. End-burning, of course, progresses longitudinally throughout the length of the charge.

Burning Rate: The type of burning that is achieved by a particular grain design, the amount of grain surface exposed to burning, and the amount of propellant (by weight) consumed during any time period, have no effect on the *burning rate* of a particular propellant in themselves, although the differences in chamber pressure induced by a grain design may well affect burning rate. The burning rate of a propellant combination (i.e., the number of inches of it that will be consumed in each second of burning) is determined empirically by exhaustive tests, and is a figure which remains constant for that particular propellant at a given pressure, regardless of the grain design or the amount of surface exposed to burning.

Burning proceeds in a direction perpendicular to the burning surface and, as long as the pressure remains constant, it progresses at the same number of inches per second no matter how large an area of surface is burning. To illus-

ILLUSTRATION NO. 7



trate the difference between the burning rate of a propellant and the amount of propellant consumed per second, let us assume that you have a rectangular block of propellant that is one inch square and twelve inches long. The *burning rate* of the propellant is one *linear* inch per second. If you ignite just one end of the block and allow it to burn, the burning surface exposed amounts to one square inch. Since the block is twelve inches long, and the burning rate is one inch per second, it will obviously take twelve seconds for the entire block to burn. If, on the other hand, you can ignite one entire side of the block you will have twelve square inches of surface exposed to burning, and since burning proceeds in a direction perpendicular to the burning surface, and the block is only one inch wide, the entire block of propellant will be consumed in just one second. In the first instance the *amount* of propellant consumed per second was one cubic inch. In the second case the amount consumed per second was twelve cubic inches. In both cases, however, the burning rate was the same: one *linear* inch per second.

As a practical matter, however, the larger the burning surface is the faster the burning rate will be; because the increased amount of propellant consumed each second generates higher pressures in the rocket chamber; and as pressure increases, the burning rate generally increases. If the propellant being used is particularly sensitive to pressure changes and its burning rate increases rapidly with increasing pressures, then the burning may get entirely out of control and produce an explosion. For this reason it is generally desirable to have a propellant whose burning rate remains fairly constant over a wide range of pressure changes.

Another factor affecting the burning rate of a propellant is the temperature produced within the combustion chamber. Higher temperatures tend to cause faster burning rates, but propellants vary widely in their response to temperature increases. Since it is not within the scope of this book to present a thoroughgoing analysis of propellants and their behavior under varying conditions of pressure and temperature changes, it is recommended that the more advanced reader who is interested in the subject consult the many excellent reference works listed in the bibliography in the Appendix.

Burning Time: It can be seen from the foregoing that it is a very simple matter to calculate the burning time for any propellant charge once the burning *rate* is known, and the chamber pressure is known (the first being dependent on the second). The burning time for any propellant grain is equal to the *web thickness* of the grain divided by the burning rate.

$$\text{Burning time} = \frac{\text{web thickness}}{\text{burning rate}}$$

The web thickness is the linear distance measured in a perpendicular direction from the burning surface to the surface opposite. If you have an end-burning grain, then the web thickness is the length of the entire grain. If, on the other hand, you have a tubular grain which is three inches in diameter and has a one-inch diameter hole bored in the center, then the web thickness is one inch. If this grain had a burning rate of one inch per second, then the entire grain would have a burning time of one second, regardless of how long it was.

It should be noted here that this discussion of burning rates and times applies only to solid propellants which are compacted into a solid grain, whose density is known. It is impossible to predict, with any degree of accuracy, the burning rates or burning times of solid propellants in loose powder form, for several reasons. For one thing, no two compositions will ever be precisely the same. Density, crystal size and the amount of air trapped in pockets will vary with every mixture. For another thing, there is no means of controlling the area of the burning surface with inhibitors, or by bonding, with the result that the flame front tends to shoot out at random throughout the mixture and cause erratic burning. For this reason, the burning rates and times that are given for the zinc and sulfur combination discussed later are only approximate and represent average performance figures taken from a great many tests.

The burning rates shown for the solid propellants listed in the table in Illustration *8* are valid only for a chamber pressure of 1000 psi. Higher or lower pressures will vary these rates.

Solid Propellants for Amateur Use: There have been many propellant combinations used by amateur groups in the unending search for the "ideal propellant." Some have been very dangerous combinations that have caused accidents because the people using them were unfamiliar with their properties. Had they known a little more about the ingredients they were using, they probably would not have attempted the foolhardy experiments which ended in disaster. But some people learn only by trying and are never content to listen to the advice and counsel of others, nor do they bother to research available information on a subject before attempting to find out for themselves by experimentation. This type of person will find no place in the scientific community of the future because his working habits and thought processes are not consonant with sound scientific procedure; indeed, it is highly probable that he will blow himself up at an early age, long before he can cause a major disaster to others.

All accidents are regrettable and the possibility of serious injury or death is not pleasant to contemplate. But any accident, whether it injures anyone or not, causes public alarm over the hazards of amateur rocket activity, and increases the possibility of restrictive measures against further rocket experimentation. Amateur rocket societies, if they expect the public to take them seriously, must do everything they can to promote the confidence of public officials and civic organizations who are in a position to render them valuable assistance. A record of serious scientific achievement unattended by foolhardy risks is the best recommendation a group can have when it seeks the support it needs from the community.

Consequently, no amateur group should attempt to mix or use propellants which are obviously beyond its capacity to handle. This includes all of the propellants listed in the table in Illustration *8*, except the zinc-sulfur. As previously mentioned, the equipment necessary to handle and mix these materials properly costs hundreds of thousands of dollars. The best professional know-how in the country is devoted to the task, and accidents still occur. Amateurs attempting such a job are flirting with certain disaster.

There is a great deal of development work yet to be done before any amateur rocket society in the country can boast that it has exhausted the potential of the two propellants to which the rest of this chapter is devoted. This is true both in the case of rocket motor design and in the development of the propellants themselves. In the case of the zinc and sulfur combination it is safe to say that the average amateur rocket does not utilize more than ten per cent of the power this propellant can develop. Of the hundreds of amateur rockets and rocket designs the author has seen, only two could be said to make efficient use of it.

Why, then, should amateur groups be obsessed with the notion of experimenting with ever more powerful and dangerous propellants when they cannot, as yet, effectively utilize the most readily available one? The answer, of course, is that those who are constantly seeking a more powerful propellant are merely trying to achieve something the easy way. They conceive of the science of rocketry as a quest for altitude—and altitude alone. And they have very little appreciation for the design problems involved in creating an efficient propulsion system.

If there are members of your groups who are inclined to put the major emphasis on experimentation with propellants, and less on the challenge of design, let them consider this:

> The zinc and sulfur combination is capable of sending a properly designed amateur rocket to altitudes in excess of 100,000 feet.
>
> 98% of the amateur groups using this propellant have failed to get a rocket beyond 3,000 feet.

The conclusion that can be drawn from this is obvious. The average amateur group hasn't even begun to learn anything about motor design, nor bothered to develop a zinc and sulfur grain that will give optimum performance. If your own group has advanced to the point that it is capable of producing rockets which will reach 100,000 feet consistently, then perhaps it is ready to move on to development work utilizing a more powerful propellant. But not until then. And since there are very few places in the country where it is possible to launch a rocket to such heights, it would seem safe to assume that amateur rocket operations will be confined to altitudes below this figure, and that the zinc and sulfur propellant (or something similar to it) will be the standard propellant for most amateur purposes for a long time to come.

The "Caramel Candy" Propellant: Of the two most widely-used amateur propellants, the mixture of potassium nitrate (KNO_3), commonly known as saltpeter, and sugar, is probably the most readily available. Called "Caramel Candy" by many young rocketeers, it delivers a fair impulse, ignites readily, and will send a one-foot rocket to a height of about a thousand feet. However, it is somewhat messy to use and must be melted to mix properly. Any melting operation can be dangerous, and this one is no exception, even though there is a fairly wide margin between the melting point (350°F.) of the mixture and the flash temperature (600°F.).

Mixing must be done under carefully controlled conditions and should be supervised by an expert chemist. The molten mixture must be poured directly into the rocket motor chamber while at melting temperature. This means that the rocket motor and any ladles or funnels used in the pouring process must be preheated to the melting temperature (350°F.) in order to prevent premature cooling during pouring. If the pouring process is interrupted, partial cooling of the mixture will cause cracks and air bubbles to develop which will increase the burning surface of the grain. The resultant uncontrolled and erratic burning will produce pressures and temperatures beyond design maximums, and may cause an explosion, or at the least, a rupture of the motor chamber wall.

Besides the dangers of a flash explosion from overheating of the mixture and the likelihood of cracks and air bubbles developing in the grain, there are other hazards that must be carefully guarded against when preparing this mixture. For one thing, the mixture is sticky and syrupy, like molasses, and adheres to any surface it touches. Consequently, everything that has come in contact with it must be thoroughly cleansed with hot, soapy water after pouring of the grain has been completed. This includes all utensils used, and protective equipment such as asbestos gloves, aprons, face shields, etc. Particular attention must be paid to the seams of gloves and other wearing apparel, and to cracks and crevices in table tops and floors where small amounts of the propellant are apt to gather and crystallize. Secondly, extreme care must be exercised to avoid the accumulation of small particles in threaded sections of the rocket motor. If the nozzle of the rocket screws on to the rocket body, or is bolted to it, then tiny grains of propellant embedded in the threads can detonate when subjected to friction or pressure. *Never pour any propellant, molten or powdered, through a threaded section* without first covering the threads with masking tape, and then wiping them clean and inspecting them carefully after the pouring is completed. A funnel should always be used when pouring through a threaded section.

The potassium nitrate and sugar combination can be ignited with an electrical squib, Jetex fuse, or the standard black powder fuse that is used for fireworks. In all cases, of course, the fuse itself must be ignited by an electrical firing circuit similar to those described in Chapter 8. You can make a reliable electrical squib by simply dipping a piece of nichrome wire (or a piece of any heating element) into the propellant mixture several times, allowing each coating to dry partially between drippings. The squib is sometimes coated with a putty-like mixture made of black powder and a little water. Remember that black powder is only recommended for ignition charges, and only a few ounces of it should be mixed at one time.

The proportion most frequently used in mixing the "Caramel Candy" propellant is 60% potassium nitrate and 40% sugar by weight. Other proportions may give effective results, and if your group has a qualified chemist adviser it might be worth your while to undertake a development project on this particular propellant with a view to determining an optimum proportion for the mixture under varying chamber conditions. It also would be worthwhile to investigate the feasibility of cold-casting the mixture, using some type of binder or solvent, and producing prepackaged grains which do not have to be cast in the rocket motor. This work should not be attempted, however, unless you do have a competent adviser and laboratory facilities which have been approved for such a purpose by local fire and police officials. Not too much experimental work has been done with this propellant and it is not known how shock-sensitive or friction-sensitive it is under varying temperature, pressure and humidity conditions. The potassium nitrate, at normal room temperature, can be ground lightly to break up large crystals, for the ingredients must be well mixed and sifted before they are melted. It is known, however, that the mixture absorbs moisture readily from the air, and therefore grains made from it cannot be stored for any length of time.

The mixture described here has not been fired successfully as an end-burning grain. A larger burning surface is required to develop sufficient chamber pressure, and the grain is usually cast in the rocket motor with a pintle (or slender rod), approximately one third the inside diameter of the motor chamber, being used to form a hole through the center of the grain. This gives a *tubular* grain such as the one shown in Illustrations 6 and 7.

Zinc and Sulfur—or Micrograin: By far the most widely used amateur rocket propellant is the combination of zinc dust and powdered sulfur which many amateurs refer to as "micrograin." The latter term, which is not particularly descriptive and could be applied to any propellant in fine powder form, was popularized by amateur rocket societies on the West Coast who were among the first to conduct extensive experiments with the combination. Very little authentic, or well-substantiated data is available on it; and it is understandable that the average amateur rocket enthusiast is pretty well confused by the widely-varying and sometimes conflicting claims made for it. As examples: it is credited with specific impulse ratings as low as 20 seconds and as high as 150 seconds; and burning rates are given for it which range all the way from 14 inches per second to 290 inches per second. Obviously something is wrong in this situation, and obviously there is a need for definition.

The fact of the matter is that probably all of the widely disparate performance claims made for this propellant are reasonably true. That is, they are true if you adopt the same criteria and conditions as the person making the claim, *and* if you can duplicate precisely the combination he used and the motor in which he fired it. The performance of a propellant is affected by many variable factors —in the composition of the propellant itself, in the design of the propulsion system, and in the atmospheric conditions surrounding the test. To attempt to compare performance figures from any two tests when none of these variables can be controlled is sheer nonsense. No basis for comparison exists.

Let us consider the one simple factor of the proportion of the ingredients used in a propellant combination. Zinc-sulfur has been loaded into a rocket and fired successfully in the simple proportion of one part zinc to one part sulfur, by weight. It has also been fired successfully using a proportion of *eight* parts zinc to one part sulfur. It has even been fired using a proportion of one part zinc to *three* parts sulfur. In all these cases the rocket performed satisfactorily, so far as the observer was concerned. Whether the performance obtained was an *optimum* performance is another question. With this wide a variation in just the *proportion* of the ingredients used you can appreciate how futile it is to attempt to establish reliable performance parameters for the propellant. You might just as well try to estimate the weight of a bag of feathers without knowing whether the bag contained two feathers or two million, whether they were tightly packed or loose, whether they were wet or dry, and with no information as to the size and weight of one feather.

Another reason why no firm performance parameters have been established for zinc and sulfur is that it has been most frequently used in loose powder form. It has already been stated that burning rates for powdered materials cannot be established because there is no controlled burning surface. More often than not, powders tend to burn all at once rather than in an orderly progression. A fourteen-inch rocket packed with zinc and sulfur has been known to burn for seven seconds on a test stand. On the other hand, a fourteen-foot rocket with a combustion chamber measuring twelve feet by three inches, fired in California, had a total burning time of one-half second. If the density of the mixture is known, however, an approximate burning rate can be calculated.

Among the many other factors which vary greatly in powdered mixtures and make it impossible to compare performance data reported from various sources are:

The purity of the ingredients
The particle size of the ingredients
The density to which the ingredients are compacted
The conditions of humidity to which the ingredients have been exposed, both in storage and in use
The thoroughness with which the ingredients are mixed
The amount of air present in the chamber
The conductivity of the chamber walls

The efficiency of the propulsion system in which the mixture is fired

In addition to its use in loose powder form, amateur groups have fired zinc and sulfur packaged in cartridges, pressed into a solid grain under high pressure, and cold cast into a solid grain by use of a solvent such as alcohol. There is a limited amount of information available on its performance in these three forms and this will be discussed briefly at the end of the chapter.

The only reliable data on zinc and sulfur in loose powder form is that developed by the Army Artillery and Missile School at Ft. Sill, Oklahoma, as the result of extensive tests conducted there for the purpose of establishing some standards for the propellant which could be recommended to amateurs. The optimum mixture arrived at in these tests consists of 2.04 parts of zinc combined with 1 part sulfur by weight, compacted to a density of 161 pounds per cubic foot. (On the density scale this would mean a density or specific gravity of 2.58 compared with water which has a density of 62.4 pounds per cubic foot.) Based on this ratio of ingredients and this density the following performance factors were found applicable when burned in a combustion chamber at a pressure of 1,000 p.s.i.:

Burning rate—90 in/sec.
* Effective exhaust velocity—1,490 ft/sec.
Flame temperature—3,060°R. (2,600°F.)
Specific heat ratio—1.25
Molecular weight—97.45 lbs per mole
Specific Impulse—46 sec.

* (Ideal theoretical exhaust velocity actually works out to 2,980 feet per second. However, a total correction factor of 50% was applied because one of the exhaust products, zinc sulfide, has a heat of sublimation of 2,600°R. (Rankine); which means that this portion of the gas would convert to a solid at any temperature above 2,600° and would no longer expand to produce thrust. The degree to which this occurs, and whether it actually occurs, are matters of some dispute, however. Consequently the figure of 1,490 ft/sec. can be regarded as a very conservative estimate of exhaust velocity. The calculations necessary to determine effective exhaust velocity, specific heat

ratio, and specific impulse will be discussed in Chapter *4)*

The ensuing discussion of the zinc and sulfur propellant combination, and the criteria presented in Chapter 5 are based on the performance factors listed above for the 2.04 to 1 mixture.

Handling: Zinc and sulfur in combination will burn readily in open air (not a desirable characteristic for a professional propellant), and can be ignited easily with an electrical squib, a small charge of black powder, or a bare nichrome wire from a heating element. It is relatively shockproof and when solidified can be lightly machined. Its chief hazard is that of all powders and finely divided metals. It creates a suspension of dust in the air when it is being poured from one container to another, and a sufficient concentration of this dust in an unventilated area may result in an explosion. Neither zinc nor sulfur is particularly toxic, but the dust can cause irritation of the eyes and nasal passages. It is best to avoid prolonged contact with the dust and to wear a respirator and face mask when handling the propellant in powder form.

Mixing: Since zinc and sulfur will ignite easily, even from a random spark, all utensils used in mixing the ingredients should be made of nonmetallic materials. The mixing can be done either in a wooden rotating drum, a glass jar or a cloth bag. Continuous rotation and shaking of the container is normally sufficient to produce a smooth blending that is uniform in color and texture. It is not usually necessary to sift or grind the ingredients, but if small lumps appear in the sulfur they should be broken up with a wooden spoon or stick, or eliminated from the mixture prior to weighing of the ingredients. Mixing should be very thorough. Uneven mixing or lumpiness will cause erratic burning, or "chunking," in the combustion process, and is one of the many reasons why there is such a wide variation in the performance of this propellant.

Prior to the mixing, the quantities of each ingredient must be carefully weighed out on an accurate scale such as is used in a school chemical laboratory. In order to determine the amount of propellant that you need you must know the volume of the chamber you are filling and the density to which you wish to pack it; then you can calculate the weight of propellant necessary to achieve that density. But first let us consider how to determine the relative amounts of each ingredient of the mixture.

The recommended proportion of 2.04 parts zinc to 1 part sulfur is calculated on the basis of the atomic weights of the two elements.

The atomic weight of zinc (Zn) is 65.38
The atomic weight of sulfur (S) is 32.07

In the reaction which takes place in the combustion chamber one atom of zinc combines with one atom of sulfur to produce the compound zinc sulfide:

$$\mathrm{Zn} + \mathrm{S} \rightarrow \mathrm{ZnS} + \text{heat}$$

Knowing this we can determine the formula weight of a mixture which will produce a complete reaction, i.e., a reaction in which all of the fuel (Zn) consumes all of the oxidant (S). The formula weight is determined by multiplying the atomic weight of each ingredient in the formula by the number of atoms of that ingredient which are required for a complete reaction, and then adding the totals together:

$$\text{Formula weight: } \overset{\textit{Zinc}}{\overline{(1 \times 65.38)}} + \overset{\textit{Sulfur}}{\overline{(1 \times 32.07)}} = 97.45$$

To find the amount (or percentage) of each chemical, divide the atomic weight of that chemical by the total formula weight.

$$\text{Zinc} = \frac{65.38}{97.45} = 67\%$$

$$\text{Sulfur} = \frac{32.07}{97.45} = 33\%$$

In other words, to mix one pound of propellant you will need 0.67 pounds of zinc and 0.33 pounds of sulfur. To mix ten pounds of propellant you need 6.7 pounds of zinc and 3.3 pounds of sulfur. Whatever the total weight of propellant you need, multiply that weight by 0.67 to get the weight of the zinc you should use, and by 0.33 to get the weight of the sulfur.

To determine the total propellant weight needed to fill a rocket chamber you must first calculate the volume of the chamber and then multiply that volume by the density of the propellant you wish to use. Normally rocket motor chambers are cylindrical in shape and flat at both ends. The volume is calculated by the simple formula you probably have already learned in high school geometry.

$$V = AL$$

where: V = volume
A = area (of one end)
L = length of the cylinder

To find the cross-sectional area of one end of the cylinder use the formula for finding the area of a circle:

$$A = \pi_r{}^2$$

As an example, find the volume of a cylindrical rocket chamber with a diameter of 3 inches and a length of 40 inches (not necessarily desirable design dimensions):

$A = \pi_r{}^2$ (and $r = ½$ the diameter or 1½")
$A = 3.1416 \times 2.25$
$A = 7.07$ inches
$V = AL$
$V = 7.07 \times 40$
$V = 282.2$ cu. in.

If the rocket chamber is not perfectly cylindrical in shape (such as a chamber with tapered ends) you can determine its volume without any calculation by simply filling the chamber with water and then pouring it out into a graduated beaker. If the beaker is graduated in cubic centimeters you can convert the cubic centimeters to cubic inches by multiplying by the factor 0.061. (I.e., 10 cc. × .061 = .61 cu. in.)

In order to determine the propellant weight needed to fill the chamber we have now only to multiply the volume by the density of the propellant being used, being careful to use consistent units (e.g., if the volume of the chamber is expressed in cubic inches we must multiply by the density expressed in pounds per cubic inch). Using the previous example of a chamber 3 inches in diameter by 40 inches in length (282.2 cu. in.) let us calculate the total propellant weight and the weight of each ingredient necessary to fill it to the desired density of 161 pounds per cubic foot (0.0932 lbs. per cu. in.).

$W = V\ (282.2\ \text{cu. in.}) \times D\ (0.0932\ \text{lbs./cu. in.})$
$W = 282.2 \times 0.0932\ \text{lbs.}$
$W = 26.3\ \text{lbs.}$
$Zn = 26.3\ \text{lbs.} \times 0.67 = 17.62\ \text{lbs. zinc}$
$S = 26.3\ \text{lbs.} \times 0.33 = 8.68\ \text{lbs. sulfur}$

This means that in order to fill a chamber 40 inches long and 3 inches in diameter to a density of .0932 pounds per cubic inch, using a combination of 67% zinc and 33% sulfur, you need 17.62 pounds of zinc and 8.68 pounds of sulfur. When mixed together they give a total propellant weight of 26.3 pounds. Using this amount of propellant, simply continue filling the chamber, tamping as necessary, until all of the propellant has been loaded. You then have the desired propellant density.

Loading and Compaction: The loading of a rocket motor chamber with a loose powder propellant is best accomplished by simply pouring the mixture through a funnel using a ladle or cup to pour with. This must be done in the open air, or in a well-ventilated enclosure (see illustration of fueling pit in Chapter 8). Whether loading is done through the nozzle end or the front end of the chamber is immaterial, and will depend on the type of rocket you have constructed. The propellant should be poured into the chamber in small amounts, with each increment being carefully compacted as it is added. Powdered fuel may be compacted by several methods. Among these are tamping with a rod or pestle, shaking or vibrating the rocket, and applying mechanical pressure. The most effective means has been found to be vibration applied to the outside of the rocket body. This can be done by simply tapping vigorously with a wooden mallet, or by using an electric vibrator. If an electric vibrator is used (such as a small sander, or body massage vibrator) it should be covered with a plastic bag to prevent sparking. Simply hold the vibrator against the body of the rocket for brief periods of time, and add the propellant gradually. Follow the directions given in Chapter 8 in respect to positioning of the rocket, use of protective clothing and barriers, etc., for complete safety. It is imperative that the accumulation of dust in the air be avoided.

Ignition: The igniter should not be inserted in the rocket until it is placed on the launching rack. However, if your rocket is of the nose-loading type, and the diaphragm and igniter are combined into one unit, then this unit must obviously be inserted before loading commences. It is recommended that in such cases the igniter be of the plain nichrome-wire type in order to reduce the possibility of a premature ignition of the rocket. The types of igniters suitable for the zinc and sulfur combination have already been indicated and are illustrated in Chapter 5.

Other Compositions of Zinc and Sulfur: Considerable work has been done by some advanced amateur groups and individual experimenters in the direction of increasing the power yield of zinc and sulfur. Although some of this experimentation has been conducted for several years, progress has been slow because amateurs simply do not have the time, the facilities nor the funds to conduct the enormous number of tests under controlled conditions that would be necessary to establish valid comparative data on the performance of various mixtures and types of compositions. Nevertheless, enough progress has been made to indicate that there is a potential in this propellant which may be three or four times as great as its normal rating.

One method of packing zinc and sulfur developed by California groups is known as "cartridge" or "capsule" loading. The method consists of packaging the powder in small cardboard capsules with tissue paper ends. The capsules are approximately one inch deep and the same diameter as the interior of the rocket chamber. The alleged purpose of capsule loading is to establish some measure of control over burning rate and to prevent packing of the propellant in the front end of the chamber as the result of the pressure build-up during combustion. Whether it accomplishes either of these objectives is open to question. The same groups that complain of the propellant packing under pressure, also complain that it tends to fall out of the nozzle end as the result of acceleration. It can hardly do both of these things at the same time, obviously. Considering the pressures generated in even a small rocket chamber burning zinc and sulfur (300 p.s.i. to 1000 p.s.i.) it is doubtful that a flimsy material like cardboard could prevent packing very effectively.

The idea appears to have some merit, however, and apparently has worked with reasonable success. But it is a troublesome and time-consuming method of preparation, and it stands to reason that it can only act to reduce the power of the propellant if for no other reason than the fact that it uses up a lot of space in the chamber which could otherwise be filled with propellant. As an example, a three-foot rocket designed by one California group and loaded in this manner, has a design altitude between 500 and 1000 ft. claimed for it. Yet rockets of similar dimensions packed with loose powder have risen above 3500 feet. No specific performance data is available on zinc and sulfur packaged in this form, but groups using it generally credit it with a specific impulse of about 20 seconds.

Another California group has done considerable work in forming solid grains by simply pressing the dry powder mixture of zinc and sulfur in a hydraulic press, using a piston the size of the inside diameter of the rocket chamber. The group claims to have subjected the mixture to pressures as high as thirteen tons, but this has been done using professional equipment provided by an aircraft company with adequate safety measures being taken. The mixture used is 85% zinc and 15% sulfur compressed to a density of 0.141 pounds per cubic inch as compared with the 0.06 to 0.093 pounds per cubic inch achieved by hand tamping or vibration. When compressing the propellant under such high pressures the group uses a chrome-molybdenum steel casing with a .125 inch wall thickness and an inside diameter just slightly larger than the rocket chamber for which the grain is intended. The grain produced can be shaved or machined lightly, but has not been subjected to any definitive tests for shock sensitivity. It will not burn at atmospheric pressure, which is a desirable property of any solid propellant, since it not only reduces hazards but also means that the propellant cannot be made to release its energy at low chamber pressures which are insufficient to produce effective thrust. It does burn well at high pressure, according to the group that has developed it, but again, no controlled experiments have as yet been conducted to establish reliable parameters for its performance.

By far the most interesting and potentially productive work on the zinc and sulfur combination has been done by groups who have developed methods of cold-casting the mixture by using some solvent such as alcohol. A small amount of alcohol added to zinc and sulfur produces a putty-like mixture which can be stuffed into a rocket chamber or casting mold. It generally takes five or six days to cure properly, but the resultant grain is a smooth, hard metallic substance which will not burn in open air and can be sawed or machined to fit. As in the case of the pressed grain described above, however, no tests have been performed to determine whether it will detonate under extreme pressure, impact, or the heat of prolonged machining. One group has tested such a mixture for impact sensitivity by dropping a 25-pound weight on a small amount of it from a height of about 15 feet. So far, they have not been able to make it detonate.

Some grains have also been produced using acetone and similar substances as the binding agent. Some of these grains have dried within a few hours and cross-sectional cuts made in them to inspect the grain composition. They appear to have a smooth, uniform composition, and densities in the neighborhood of 0.139 pounds per cubic inch have been achieved. One group in Brooklyn, New York, has had excellent results in casting such grains, using certain other additives, which they hope to produce in quantity for commercial sale. When actual burning tests are completed and firm performance parameters are obtained, the group will apply for an Interstate Commerce Commission rating on the propellant and further information on it may then be available.

A group in Colorado has conducted experiments for several years with cast grains of zinc and sulfur, using alcohol as the solvent. The work of this group has been outstanding, and while their findings are by no means definitive, as yet, the results they have achieved have been spectacular in some instances. If nothing else, they serve to point up the fact that there is a much greater potential in zinc and sulfur than most people believe. Here are some of their findings (tentative of course):

All cast grains require more burning surface than end burning affords. Therefore the group casts most of its grains in the tubular configuration shown in Illustration 6.

Specific impulse ratings as high as 125-150 seconds have been obtained.

A tubular cast grain has sent 24-inch rockets to altitudes of 7,000-10,000 feet, compared with only 1500 feet for the same rockets loaded with loose powder.

Two-stage rockets employing these grains have attained altitudes in excess of six miles.

The group claims to have fired a three-stage rocket to an altitude of 80,000 feet; which, if true, is far above any previous amateur record, so far as the author is aware.

Exhaust velocities between 4,000 and 5,000 feet per second have been obtained.

Density of the grains has been about 0.139 pounds per cubic inch.

Rockets 24 inches in length, 1½ inches in diameter, with a nozzle throat-diameter of ½ inch have developed 500 pounds thrust with a burning time of 0.7 seconds.

Considering the progress that has been made by groups such as those cited in the foregoing examples, it would appear that there is much room for effective development work in this area, and that cast grains of zinc and sulfur may well prove to be a far more effective propellant than the loose powder has proved to be. It would also appear that cold-casting of the mixture can be accomplished with safety and with relative ease (none of these groups has ever had an accident, but that is no reason for not observing all of the precautions that are recommended here).

It is the opinion of the author that an orderly development project undertaken by any amateur group, with qualified assistance and good equipment, will eventually produce a zinc and sulfur grain which will easily satisfy the requirements of the most advanced amateurs. Do not undertake such a project, however, unless you are well equipped to pursue it, and observe the safety rules which are appended here.

II SAFETY RULES—PROPELLANT HANDLING

Following is a summary of the more important safety rules you should observe whenever members of your group handle, mix or experiment with propellant ingredients. Read the rules carefully and often. Insist on their observance by all members of your group.

A. *Handling and Storage*

Do not allow chemical substances, liquid or solid, to come in contact with your skin. If some does, wash it off immediately with soap and water, or follow the directions in the first-aid section of the appendix.

Always have a fire extinguisher on hand.

Always have a readily available source of water.

Always have the antidotes on hand that are recommended in the first-aid appendix.

Always have a first aid kit on hand.

Always have a telephone at hand.

Always have another person with you.

Always have a heavy blanket (preferably asbestos or impregnated canvas) to wrap about a person whose clothing may catch fire.

Do not use metal objects that will cause sparks when handling or mixing fuels.

Do not smoke or permit open flames in any area where chemicals are handled or stored. *Remember that water heaters, oil and gas, furnaces, ovens, space heaters, etc., have open pilot flames burning all the time—even in summer.*

Do not use electric motors or open electric coils (such as in electric heaters, toasters, etc.) in an area where chemical dust may be present. If necessary to use one—to operate a fan, for instance—cover the motor casing with a plastic bag to prevent sparking.

Do not store large amounts of propellant ingredients in one place. Break up your storage area into small "dumps," widely separated. Store ingredients separately, not together. Provide protective barricades.

Avoid storing propellant ingredients in shatterable containers which will produce fragments in the event of an explosion. Use cardboard cartons, wooden boxes, plastic or cloth bags as much as possible.

Follow the Quantity—Distance Table and Thickness of Protective Barriers Table (Chapter 8) for safe storage of propellants.

Do not use match heads for any purpose.

Do not use chlorates, picrates, iodates or fulminates for any purpose. Beware of the dangerous properties of the following substances and avoid their use:

Potassium Chlorate Sodium Chlorate	Explode readily when rubbed, ground or mixed. Not even used professionally.
Powdered Metals:	Small-grained powders of pure iron, magnesium, lithium, beryllium, zirconium, and aluminum will ignite spontaneously when dispersed in the air. All of these are extremely shock-sensitive when mixed with an oxidizer.
Metallic Sodium:	Can ignite spontaneously in the air if moisture is present.
Metallic Potassium:	Ignites spontaneously in the air.
Yellow Phosphorus:	Ignites spontaneously in the air.
Fluorine:	Extremely toxic. Will react violently with anything containing carbon; such as human flesh, wood, paper, etc. Its fumes are toxic and can form a deadly gas.
Hydrazine:	Will spontaneously ignite in combination with many substances. Fumes are toxic.
Nitrocellulose (Gun cotton) and Nitroglycerin:	Both extremely shock sensitive as well as toxic.
Potassium Ferrocyanide Potassium Ferricyanide	React violently with oxidizers and explode when mixed with chlorates.

Do not attempt to transport propellants, or explosive propellant ingredients, in a vehicle or on a public highway without getting a permit from your State Police and the Interstate Commerce Commission. *You must abide by the conditions they impose.*

B. *Mixing and Loading*

Do not mix chemical substances whose properties and behavior you are not familiar with.

Do not attempt to melt, or heat, chemicals unless:

a. you are positive of the melting temperature and the flash temperature (point at which a substance will flash and burn) of each element;

b. there is a sufficient safety margin between the two temperatures;

c. you have an adult supervising the operation;

d. you have a police or fire dept. permit to conduct such an operation.

When mixing chemicals you must wear:

a heavy rubber apron
asbestos gloves
a face shield
protective glasses
respirator or gas mask

Always have a heavy safety shield between you and your work—as large as is practical.

Do all mixing and all laboratory work in the open air, as far as possible. If this is not practical, use a *well-*ventilated room.

Don't allow dust or vapors from chemicals to accumulate in your work area. If they do, *stop* the operation.

Do not remain in an area where dust or vapors have accumulated.

Do not breathe in dust or vapors from chemicals, and do not let them get in your eyes.

Do not rub your eyes, scratch your skin, or lick your fingers or lips when handling chemicals.

Clean your fingernails thoroughly, wash your hair, ears and exposed skin, and blow your nose well after handling chemicals.

When you have finished, wash all tools, utensils, protective equipment, wearing apparel, floors and table tops that have been exposed to chemicals.

Be particularly careful about the seams of gloves, hinges of eyeglasses and face shields, cracks in protective equipment, etc., when cleaning up. Residue in such places can cause trouble.

Mix only *small* amounts of any propellant combination being tested. The power of an explosive increases as the *cube* of the weight. Two ounces of an explosive is *8* times as powerful as one ounce. Three ounces is *27* times as powerful. Five ounces is *125* times as powerful.

Do not mix more propellant than is necessary to load one rocket at a time.

Do not keep excess amounts of propellant in the fueling pit, or any other place where a rocket is being loaded, or where mixing is in progress.

Do not pour powdered or molten propellant through a threaded section: Use a funnel. Wipe all threads clean and inspect carefully.

Do not *rub* or *grind* chemical ingredients unless you are *positive* they are nonfriction-sensitive.

Do not use a nail or screw driver to probe into a propellant mixture. Be particularly careful in this respect of chemicals composed of large crystals.

Do not attempt to use any solid propellant grain which shows *cracks* or *air bubbles* in its composition. Dispose of it by getting your Fire Department, Police, or an Army Ordnance Explosive Disposal team to detonate it in a safe place.

SOLID AND LIQUID PROPELLANTS

Combinations and Characteristics

In the table following, some possible solid and liquid propellant combinations are listed together with their product specific heat ratios, gas constants, combustion temperatures, and specific impulse values for the oxidizer-fuel ratios shown.

The oxidizer-fuel ratio is measured in pounds of oxidizer per pound of fuel and is listed as O/F ratio.

The combustion temperature, T_c is given in degrees Fahrenheit (°F.) and should be converted to degrees Rankine (°R.). The gas constant, R. is in foot-pounds per pound-degrees Rankine $\left(\frac{\text{ft.lb.}}{\text{lb.°R.}}\right)$, as is the specific heat ratio, k. The specific impulse, I_{sp}, is in pound-seconds per pound or seconds.

ILLUSTRATION NO. 8

POSSIBLE PROPELLANT COMBINATIONS (LIQUIDS)

OXIDIZER	FUEL	O/F Ratio	T_c (°F.)	R.	I_{sp}	k
Chlorine Trifluoride:	Ammonia*	3.93	4980	70.2	240	1.30
	Hydrazine*	0.677	5840		251	
	Methyl Alc.*	2.88	5150		218	
Fluorine:	Ammonia*	2.90	7512		295.5	
	Hydrazine*	1.98	7692	85.9	300	1.33
	Hydrogen*	9.42	8072		371	
		3.77	4469		356	
	Lithium	2.19	7000		335.5	
	Methyl Alc.	2.37	7472		298	
Hydrogen Peroxide:	Aluminum Borohydride*	3.0	5772		200	
	Hydrazine*	1.69	4200	86.0	240	1.25
	Methyl Alc., Hydrazine & Water (57-32-11)	2.54	3934		224	1.23
	Nitromethane	0.42	4719		232	
	n-Octane	5.10	4095		230	
Oxygen:	Acetylene	1.23	6012		266	
	Aluminum Borohydride	1.32	6000		276	
	Ammonia	1.25	4834	81.3	250	1.23
	Ethane	2.30	5308		254	
	Ethyl Alc.	1.50	5297	67.4	242	1.22
	75% Ethyl Alc.	1.31	4887	70.3	234	1.22
	Ethyl-Methyl Alc. (95-5)	0.84			240	
	Ethylene	1.86	5538		264	
	Gasoline	2.26	5660	68.1	252	1.22
	Hydrazine	0.83	5382	97.1	263	1.23
	Hydrogen	2.89	3886		345	
	Isopropyl Alc.	1.85	5553		241.1	
	Kerosene	2.28	5702	71.5	249	1.24
	Lithium*	1.15	13000		318	
	Lithium Borohydride*	1.47	8300		306	

	Lithium Hydride*	1.34	6400		268	
	Methane	2.33	4874		263	
	Methyl Alcohol	1.15	5076	67.8	237	1.20
	80% Methyl Alc.	1.50	4881		228	
	Nitromethane	0.076	4703	73.6	226	1.23
	n-Octane	2.20	5498		248	
Ozone:	Ammonia	1.13	5175		267	
	Hydrazine	0.63	5418		277	
	Hydrogen	2.65	4280		373	
Red Fuming Nitric Acid ($6.5\%\ NO_2$):	Aniline-Furfuryl Alc. (80-20)*	3.35			228	
	Aniline-Furfuryl Alc. (65-35)	2.70			226	
	Hydrazine*	1.00	4437		240.6	
	68% Hydrazine*	0.494	3519		211	
	Isopropyl Alc.	3.33	4797		218.1	
	n-Octane	4.56	5005		222	
RFNA ($16\%\ NO_2$):	Aniline*	3.00	5067	61.8	221	1.22
	Ethyl Alc.	2.50	4555	65.2	219	1.21
	Hydrazine*	1.16	4728		242	
WFNA:	Aniline*	3.00	4942		222	
	Furfuryl Alc.	2.65	4885		210	1.2
	Gasoline	4.60	4941		223	
	Hydrazine*	1.22	4681		246	
	Hydrogen	12.6	5360		298	
	JP-4	4.7	5000		229	
	Methyl Alc.	2.36	4480		219	
	Octane	4.00	4744		229	

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* Indicates that propellant combination is hypergolic, i.e., mixture results in spontaneous combustion.

PROPELLANT COMBINATIONS (SOLID)

OXIDIZER/FUEL (weight %)	T_c (°F.)	R.	k	I_{sp}
Pot. Perchlorate $KClO_4$ (50-80)				

Ethylene Oxide C_2H_4O (50-20)	2800-5000	44.1-61.8	1.24-1.27	165-210
Ammonium Perchlor. NH_4ClO_4 (50-80) Ethylene Oxide C_2H_4O (50-20)	2800-4500	61.8-70.2	1.22-1.26	175-240
Ammonium Nitrate NH_4NO_3 (80) Ethylene Oxide C_2H_4O (18) Catalyst (2)	2700	70.2	1.26	195
Ammonium Picrate (70-40) Potassium Nitrate KNO_3 (20-50) Ethylene Oxide C_2H_4O (10-10)	3200	51.5	1.25	160-200
Asphalt (22-30) Potassium perchlor. $KClO_4$ (78-70)	3800-5300	51.5	1.25	180-195
Zinc (Powdered) Zn (50-80) Sulfur S (50-20)	2600	20.4	1.25	approx. 20-50

Chapter 4

ROCKET MOTOR SYSTEMS

I PRINCIPLES OF PROPULSION

The small rockets discussed in Chapter 2 are the product of very simplified design based on "rule of thumb" calculations. They are, consequently, not expected to be very efficient or particularly reliable. There are a great many factors which have a bearing on the ability of a rocket motor to make effective use of the energy released by a propellant. A rather small change in any one of these factors can conceivably affect the performance of the rocket as much as two or three thousand per cent.

As explained in Chapter 2, the propulsive force of a rocket is obtained from the rapid expansion of the gases which are produced when the propellant burns. These gases do not *push* against anything (such as the ground, or air particles)in order to move the rocket forward. In fact, if there *is* anything for them to push against, this resistance tends to slow the rocket down rather than speed it up. That is why a rocket motor works more efficiently in space where there is no air, or atmospheric pressure, to push against. If this seems difficult to understand, it should become clear to you in a moment.

Using the familiar analogy of a man seated in a swing, let us assume that he kicks his feet violently out in front of him, thus imparting a backward motion to the swing. The swing begins to oscillate like a pendulum, and each time that he kicks his feet out he imparts a little more motion and a little more velocity to it until he has it swinging to the top of its arc. Theoretically, if he were physically able to kick his feet out rapidly enough, and often enough, and if the swing were not held to a bar by ropes, he could actually make it fly; because there would be no downswing if he could kick fast enough to counteract the reverse pull of gravity.

Now let us assume that on the first kick the man can send the swing backwards a distance of one foot. If someone steps in front of him, however, and stops his feet in midair, the swing will move backward only a few inches. This is because the person stepping in front of him stops the "impulse" of his kick. The same thing happens in a rocket motor. If the movement of gases to the rear is stopped, or slowed down, by any obstruction, a back pressure results which slows down the expansion of the gases in the combustion chamber. Since "for every action there is an equal and opposite reaction," it follows that if you slow down the *action* (or movement) of the combustion gases toward the rear, you also slow down the reaction, or the movement of the rocket forward.

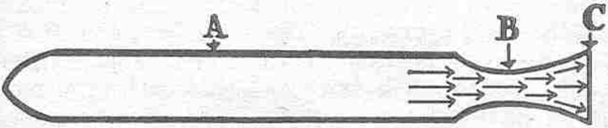
The pressure of the atmosphere at sea level is approximately 14.7 pounds per square inch. This means that the gases escaping from the nozzle of a rocket must push against 14.7 pounds of air in every square inch of nozzle exit area. This "back pressure" slows the gases down, consequently destroying some of the impulse they impart to the rocket. But as the rocket rises the atmospheric pressure decreases rapidly, enabling the gases to escape with greater velocity and gradually increasing the efficiency of the motor. Above 60,000 feet the pressure is less than 1 lb./sq. in. and it rapidly decreases to a value approaching zero. When zero atmospheric pressure is reached, the rocket engine can be said to be operating at full efficiency, assuming nothing has gone wrong with it.

The pressure at any given altitude, or under any given set of conditions, is referred to as the *ambient* pressure, which simply means the pressure of the atmosphere surrounding the nozzle, wherever it is.

With this in mind we can then define the objectives of good rocket motor design as:

1. To enable a propellant substance to burn in such a manner as to produce the maximum amount of gases at the highest possible pressure; and
2. To enable those gases to escape in a direction opposite to that which we wish the rocket to take, at the greatest possible velocity and with the least obstruction.

ILLUSTRATION NO. 9



Let us take a look at a simple rocket motor that is designed to do both of these things (*see* Illustration 9).

The sketch shows a solid propellant rocket motor consisting of a combustion chamber (A) and a nozzle. The throat of the nozzle is indicated by the letter "B." The letter "C" indicates the exit area, or port, of the nozzle. This is the simplest type of rocket motor, but virtually all motors are based on this design. A complete rocket motor, then, consists of nothing more than a combustion chamber to burn the propellant, and a nozzle to direct the combustion products to the rear and accelerate them to the highest possible velocity. For it is the velocity achieved by the exhaust gases that produces the thrust which moves the rocket forward. And the rapidity with which a high velocity is reached is the most important factor.

Refinements of this basic motor design, or variations of it, together with the various mechanisms designed to feed fuel to the chamber (in the case of liquids) or control the flow of the gas products, are referred to as *motor systems.*

You will note in the sketch above that the nozzle of the rocket motor has a curved inner surface which narrows at the throat (B) and then widens again to the approximate diameter of the rocket chamber at the exit point (C). Other types of nozzles are used, but variations of this design have proved most efficient and are most widely used. This particular shape is known as the De Laval nozzle, and is the invention of a French engineer. De Laval reasoned that in order to accelerate the exhaust gases as they departed the combustion chamber he could take advantage of a basic physical law affecting both liquids and gases. This law holds that as the diameter of a tube decreases, the speed of a liquid or gas flowing through it *increases* in direct proportion. Thus, by decreasing the diameter of the nozzle for a portion of its length, added velocity of the exhaust gases can be obtained above what would be obtained from a straight exhaust tube. This narrowed or "pinched" portion of the nozzle is called the nozzle throat. Its function, or purpose, is to accelerate the flow of the gases until they reach sonic velocity.

You have seen this same principle in operation if you have watched your local fire department handle its hose. When a fireman opens the valve on a fireplug, the water gushes out under high pressure; but because the diameter of the outlet is large (4 to 6 inches), the water shoots through the air only fifteen or twenty feet before it hits the ground. If a hose is attached to the plug outlet, however, and the water is forced through a long nozzle with an opening of approximately one inch, its velocity becomes so great that it shoots several stories into the air. The pressure behind the water is the same in both cases. All that has been done to increase the velocity and the distance is to force the stream of water through a smaller aperture.

You will notice, also, if you watch a hose company at work, that it sometimes requires four or five men to wrestle a hose into submission and direct the stream of water at the fire. This is because the velocity of the water is so great that it tends to kick the nozzle back toward the fire plug. When a hose gets loose it thrashes about in all directions until the water pressure is shut off. This is one of the best examples in everyday life of the propulsion principle at work. (This example may suggest to you the possibility that a boat could be propelled by pumping water in through its front end and ejecting it under pressure through a jet nozzle in the rear. It could be; but whether such a system could be as cheap and effective as the ordinary propeller is another question.)

The second important feature of the De Laval nozzle is the design of the section to the rear of the throat, which flares outward sharply. The purpose of this configuration is to allow the exhaust gases to expand rapidly and reach atmospheric pressure as soon as possible, so that no back-pressure will be created. During this expansion process the gases gain additional velocity (supersonic), and in a correctly-designed nozzle they will reach their greatest velocity and also achieve atmospheric pressure when they reach the exit point (C). The speed with which exhaust gases reach atmospheric pressure is important in order to prevent a "balling up" of gases, or a pressure block, which would inhibit the escape of the remainder of the gases. Ideally, they should be reduced to atmospheric pressure at the exit. The length of the nozzle section from throat to exit is therefore a critical factor in nozzle design, as are the diameter of the throat, and the angles of convergence *to* the throat and divergence *from* it. Because of its general conformation this type of nozzle is frequently called a *con-*

verging-diverging type or a *convergent-divergent* nozzle.

To summarize what we have learned thus far about rocket motors and nozzle design, we can say that the ideal rocket motor has to:

1. be built of material which will permit the propellant to be burnt at a high enough temperature and pressure to produce a maximum flow of gas particles;
2. be designed so as to direct the random motion of these particles in *one direction,* so that the maximum kinetic energy can be realized from the heat energy being released;
3. have an exhaust system (nozzle) which will permit maximum utilization of that kinetic energy by allowing the exhaust gases to accelerate to the greatest possible velocity (thus producing maximum thrust); and
4. allow the exhaust products to reach atmospheric pressure immediately after ejection from the nozzle exit to prevent back-pressure buildup.

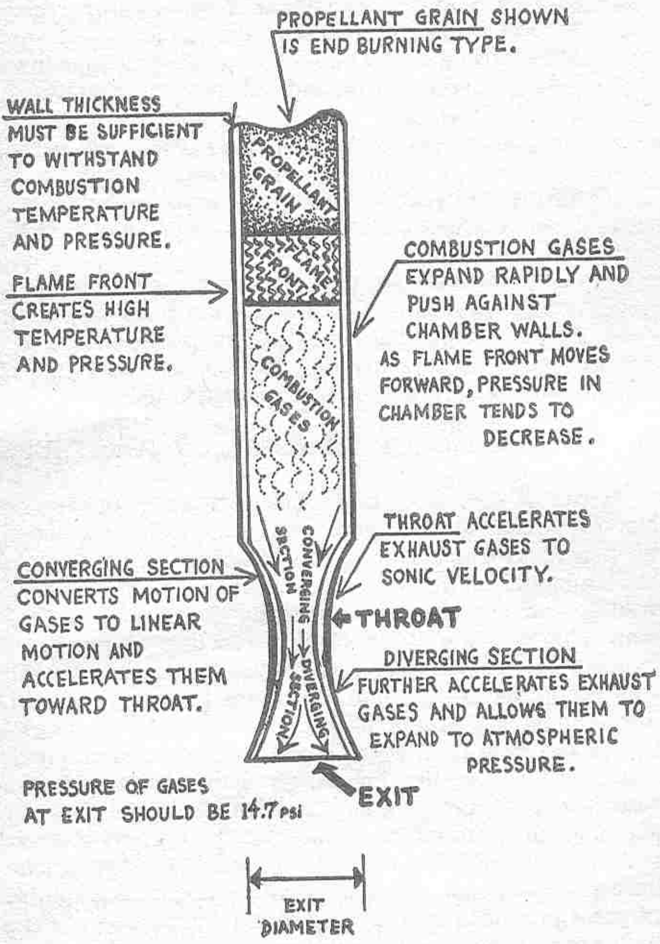
Let us look again at a diagram of a simple rocket motor with these desirable design characteristics indicated.

II ROCKET MOTOR DESIGN: FOR AMATEURS

As can be seen from the drawing shown in Illustration No. *10,* the problem of accelerating the exhaust gases to the proper velocity is largely a matter of achieving a proper conformation of the nozzle in relation to the chamber volume and the pressure created by the burning propellant. This pressure is, in turn, a function of the flame temperature and burning rate of the propellant and will vary according to the amount of burning surface exposed. The amount of burning surface is determined by the design of the grain (i.e., whether end burning, tubular, cruciform, etc.) and by the dimensions of the chamber. In the case of an end burning grain, the diameter of the chamber automatically determines the area of the burning surface, and consequently the amount (or weight) of propellant burned per second. In order to accommodate the volume of gases produced in a given period of time, and convert the heat and pressure to useful kinetic energy, the nozzle must obviously be of a particular shape. Certain dimensions of the nozzle are critical and must be calculated by

Illustration No. 10

FUNCTIONS of a ROCKET MOTOR



PROPELLANT GRAIN SHOWN IS END BURNING TYPE.

WALL THICKNESS MUST BE SUFFICIENT TO WITHSTAND COMBUSTION TEMPERATURE AND PRESSURE.

FLAME FRONT CREATES HIGH TEMPERATURE AND PRESSURE.

COMBUSTION GASES EXPAND RAPIDLY AND PUSH AGAINST CHAMBER WALLS. AS FLAME FRONT MOVES FORWARD, PRESSURE IN CHAMBER TENDS TO DECREASE.

THROAT ACCELERATES EXHAUST GASES TO SONIC VELOCITY.

CONVERGING SECTION CONVERTS MOTION OF GASES TO LINEAR MOTION AND ACCELERATES THEM TOWARD THROAT.

DIVERGING SECTION FURTHER ACCELERATES EXHAUST GASES AND ALLOWS THEM TO EXPAND TO ATMOSPHERIC PRESSURE.

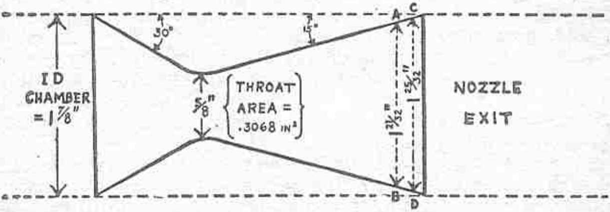
PRESSURE OF GASES AT EXIT SHOULD BE 14.7 psi the designer based upon his knowledge of the burning characteristics of the propellant and the size of the chamber in which it is to be burnt.

Simplified Nozzle Calculations: For end burning grains with properties similar to the zinc and sulfur combination discussed in Chapter 3 (i.e., flame temperature of approximately 2600° F. and a burning rate of 90 in./sec.) certain "rule-of-thumb" nozzle dimensions have been established by experimenters and are widely used by amateur rocket builders. These rule-of-thumb measurements, or proportions, have been independently arrived at by experimentation or simplified calculation, and have been found to work reasonably well. If you adopt them, however, you should not assume that they are *safe,* or that they are guaranteed to give optimum performance. That they have been found to be workable is about all that can be said for them. Neither can any one of the proportions necessarily be reconciled to another. In other words, taken together they do not represent a total design concept. But they may be applied individually. They are:

a. The diameter of the nozzle throat should be approximately one third the inside diameter of the combustion chamber.

b. The angle of the converging section of the nozzle should be approximately 30 degrees, and the angle of the diverging section should be approximately 15 degrees. Thus:

ILLUSTRATION NO. 11



c. The cross-sectional area of the nozzle exit should be 7 to 8 times the cross-sectional area of the throat. ($A_e = 7A_t$ or $A_e = 8A_t$.) Or, stated another way, the area ratio of exit to throat should be in the neighborhood of 7 or 8 to 1. Thus, to determine the nozzle exit area needed for the nozzle in the above diagram simply multiply .3068 sq. in. by 7 (or 8). This gives you the area in square inches of the nozzle exit. Then use the formula for the area of a circle *($A = \pi r^2$ or $A = \frac{\pi d^2}{4}$), solving for *d*, to determine the diameter of the nozzle exit. In the diagram above the nozzle exit *area* would be 2.1476 in.^2 if you use the 7 to 1 ratio, and the *diameter* of the nozzle exit works out to $1\frac{21}{32}$ inches. This would be slightly smaller than the inside diameter of the combustion chamber; and the position of the nozzle exit relative to the throat, in this case, is indicated by the dotted line AB. The position of the nozzle exit if an area ratio of 8 to 1 is used, is shown by the dotted line CD.

d. If a tubular grain is used (or any other type with a hollow core), then the cross-sectional *area* of the hollow core at the end of the grain nearest the nozzle should be at least three times the *area* of the nozzle throat.

If the proportions, or ratios, outlined above are used, then it is obviously unnecessary to calculate the length of any section of the nozzle; since the ratio of diameters and the angles of convergence and divergence automatically establish the overall length of any section of it. (In other words, with a given angle of divergence of two lines, you

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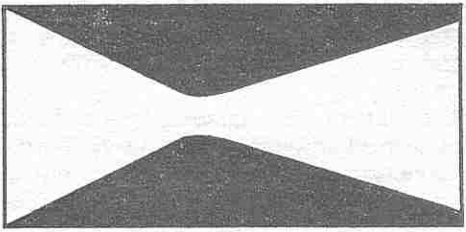
* You can determine the diameter of any cross-sectional area (or the cross-sectional area for any given diameter) by consulting the table of functions of numbers included in the appendix. For diameters which are not shown in the table, you can calculate the area of any circle by a quicker method than the standard formula. Simply square the diameter and multiply by the factor 0.7854 ($A = d^2 \times 0.7854$). This is the same computation as $A = \pi d^2 \div 4$ except that the value of *4* has been factored out of the equation (i.e. $\pi = 3.1416 \div 4 = 0.7854$). For construction purposes, however, all that you are really interested in is the *diameter* of the nozzle exit, since this is the dimension by which rough bar stock is sold, and the dimension to which it is machined.

In the case of the nozzle throat-to-exit ratio, the diameter of the exit area can be calculated directly without bothering to compute the area of either section. If you want the area ratio to be 7 to 1; simply square the diameter of the throat, multiply by 7, and extract the square root of the result. This gives you the diameter of an exit area which will be 7 times the area of the throat. If you can't do square roots you can multiply the diameter of the throat by 2.64 to get the diameter of the exit for a 7 to 1 area ratio, or by 2.81 to get the diameter of the exit for an 8 to 1 area ratio. However, you shouldn't be designing rockets if you can't do square roots yet.

have simply to extend those lines until they are the desired distance apart—a distance equal to the diameter you want.) This makes for simplified nozzle design; but not professional design. Professional engineers work the other way around. The lengths of the converging and diverging sections are very critical dimensions in professional rocket engines. They can be, and are, calculated for a particular propellant and a particular chamber size. Once they have been calculated, then the angles of convergence and divergence are automatically established, rather than vice versa. Because the calculation of nozzle lengths is a complicated and laborious process, amateurs generally are better off to use arbitrarily established angles which have been determined to be effective, and let the lengths determine themselves. Angles slightly smaller than 30° (converging) and 15° (diverging) can be used, but it is not recommended that *larger* angles be used. Remember that the smaller these angles are, the longer the nozzle will be (and the greater the weight).

If you design your nozzle according to the ratios given in a, b, and c above, the nozzle exit will always be slightly smaller than the diameter of the combustion chamber. If it is machined out of bar stock (which it should be), it will look something like this in cross section:

ILLUSTRATION NO. 12



Note that the throat has been purposely rounded off to reduce friction and allow a smoother flow of the gas particles. For other nozzle-exit-to-throat ratios based on varying chamber pressures and varying specific heat ratios *see* Table I on page 119.

Such design is perhaps adequate for a fairly wide variety of amateur rockets where optimum performance is not the objective of the designer. For beginning groups of amateurs with average ability and average facilities, these proportions will prove satisfactory, providing no more powerful propellant is used, and providing other design criteria pertaining to wall thickness, diaphragm construction and types of material are carefully followed (*see* Chapter 5).

For more advanced groups, and for students who are equipped to handle the mathematics involved, the following presentation of basic nozzle and thrust chamber design calculations is provided. Even this is simplified to a certain degree, but for the great majority of amateur design configurations the calculations presented will prove adequate.

MORE ADVANCED ROCKET THRUST CHAMBER CALCULATIONS

1. *Combustion Temperature:* The design of the thrust chamber and nozzle of the rocket motor is, in general, dependent on the nature of the propellant used. The latter, in turn, determines the combustion temperature, whether the propellant is liquid or solid.

The determination of this temperature provides, in addition to the temperature itself, a value, k, called the ratio of specific heats, and a value, R, called the gas constant. Both figures represent values for the *products* produced by the chemical reaction of either the solid or liquid propellant, and do not represent properties of the propellant *before* reaction.

The calculation of these values is long and difficult, even with an extensive knowledge of chemistry. For this reason, a list of combustion temperatures for various propellants has been provided at the end of Chapter 3. These values may be used in the calculations which follow.

2. *Nozzle Calculations:* When the combination of propellants, either solid or liquid, has been selected, and a thrust level and a chamber pressure have been chosen, the nozzle dimensions can be calculated.

Basically, the nozzle, is so designed that it will convert the slow-moving (subsonic), high pressure combustion gases to a stream of gases moving at a higher velocity (supersonic) and a lower pressure. In fact, if the nozzle is designed correctly, then the gases will pass through the throat at a Mach number, $M = 1$ (the gas velocity is equal to the velocity of sound in the gas) and will accelerate (increase in velocity) to a Mach number greater than one (supersonic) in the expanding (diverging) part of the nozzle.

We may refer to the diagram of a typical rocket chamber shown in Illustration *13* to recognize the symbols we will use. Section *i* for liquid propellant chambers represents the injector, and for solid propellants, the so-called "end of burning" or burnout section. Section *c* is the end of the straight cylindrical section and beginning of the nozzle, and section *t* is the minimum nozzle section or throat. The last section, *e* is the exit or exhaust end of the nozzle.

The pressure at this last section is to be fixed in such a way that it will be equal to the pressure of the atmosphere at whatever altitude the rocket chamber is to be used for either the greatest length of time or for greatest efficiency.

The calculations which we will go through here apply equally well to both liquid and solid propellant rocket chambers, and will be dependent only on the following values:

a. combustion temperature of the propellants, T_c
b. specific heat ratio of the combustion products, k
c. gas constant for the combustion products, R
d. desired thrust, F
e. chamber pressure, P_c
f. specific impulse of the propellant combination, I_{sp}
g. atmospheric pressure, P_a at selected altitude where $P_a = 14.7$ psi at sea level.

Mathematical aids and units for the various values will be reviewed at the end of this outline.

For a given or assumed chamber pressure, P_c, and thrust, F, the required throat area to produce sonic velocity can be calculated. It is necessary first, however, to determine the effective thrust coefficient, C_f which is an approximate measure of the nozzle's efficiency. The equation used for this is,

$$C_F = \sqrt{\frac{2k^2}{k-1}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}\left[1-\left(\frac{P_e}{P_c}\right)^{\frac{k-1}{k}}\right]+\frac{P_e-P_a}{P_c}\left(\frac{A_e}{A_t}\right)}$$

where $P_a = 14.7$ psi. For the purpose of this calculation, we shall let the last term be zero, since it adds but little to the overall value of the thrust coefficient.

ILLUSTRATION No. 13

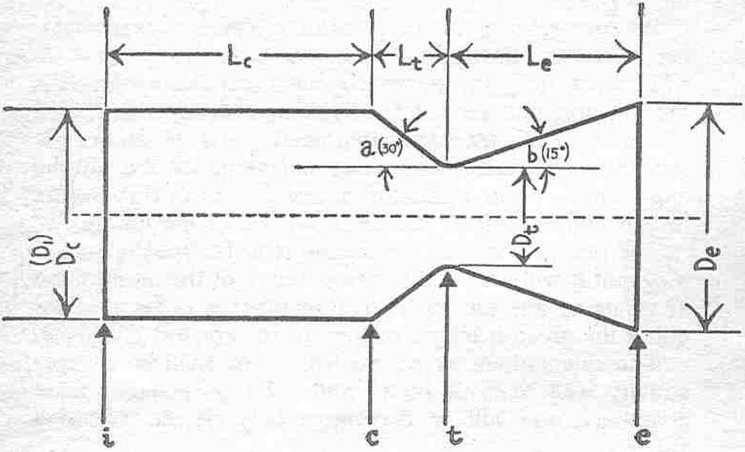


DIAGRAM for ROCKET THRUST CHAMBER CALCULATIONS

In some cases, a thrust correction factor is also used which has values between 0.92 and 1.00 depending on the percentage of unburned propellant in the exhaust gases.

Since the value of the correction factor is in all cases very close to one, we shall assume that no unburned propellant reaches the nozzle, and therefore, the value which we will use will be equal to one.

The throat area is then,

$$A_t = \frac{F}{C_f \, P_c}$$

and the throat diameter is,

$$D_t = \sqrt{\frac{4A_t}{\pi}}$$

The combustion chamber cross-sectional area is calculated using the equation,

$$\frac{A_c}{A_t} = \frac{M_t}{M_c}\left[\frac{1+\frac{k-1}{2}M_c^2}{1+\frac{k-1}{2}M_t^2}\right]^{\frac{k+1}{2(k-1)}}$$

where M_t is the Mach number of the gases in the throat, and M_c is the Mach number of the gases at the end of the cylindrical section (c).

The value of M_t as has already been stated, is equal to one. The value of M_c for any chamber is dependent upon the amount of energy which has been released in the rest of the chamber. The exact determination of this value requires a long and difficult analysis as well as proof through experiment. For most chambers, this value is approximately, $M_c = 0.25$ or $M_c = 0.30$.

Using the value, $M_c = 0.30$, $M_t = 1.0$, the equation becomes

$$A_c = \frac{A_t}{0.3}\left[\frac{1+\frac{k-1}{2}(.09)}{1+\frac{k-1}{2}}\right]^{\frac{k+1}{2(k-1)}}$$

Supplying the correct value of k and the value for A_t (calculated above) the chamber cross-sectional area, A_c, can then be calculated.

Then the chamber diameter is:

$$D_c = \sqrt{\frac{4A_c}{\pi}}$$

The velocity of the gases at the exit is found using the equation,

$$v_e = \sqrt{\frac{2gk}{k-1}RT_c\left[1-\left(\frac{P_e}{P_c}\right)^{\frac{k-1}{k}}\right]}$$

where *R* is the gas constant for the combustion gases in foot-pounds per pound — °R (degrees Rankine), T_e is the combustion gas temperature in °R, g is the gravitational constant = 32.2 feet per second, P_e is the exit pressure in pounds per square inch, absolute, and P_c is the chamber pressure, also in pounds per square inch, absolute (psia).

The velocity of sound in the combustion gases is calculated by

$$a = \sqrt{kgRT_e}$$

where a is the sonic velocity in feet per second, (ft./sec.).

Therefore, since the Mach number is the ratio of the gas velocity to the speed of sound in the gas,

$$M = \frac{v}{a}$$

the Mach number at section e is

$$M_e = \frac{v_e}{a} = \sqrt{\frac{2}{k-1}\left[1 - \left(\frac{P_e}{P_c}\right)^{\frac{k-1}{k}}\right]}$$

The value of P_e used in this equation is set equal to the pressure of the atmosphere at the altitude for which the rocket is intended to function most efficiently or for the greatest time. This governs the degree to which the nozzle expands the combustion gases. A difference in this value either way will give either an overexpanding or underexpanding nozzle.

With this value of M_e, the value $M_t = 1.0$, the specific heat ratio, and the throat area, A_t, the area ratio equation may again be applied to find the exit area, A_e. Then,

$$\frac{A_e}{A_t} = \frac{M_t}{M_e}\left[\frac{1+\frac{k-1}{2}M_e^2}{1+\frac{k-1}{2}M_t^2}\right]^{\frac{k+1}{2(k-1)}}$$

or, to simplify the equation, if $M_t = 1.0$ then:

$$A_e = \frac{A_t}{M_e}\left[\frac{1+\frac{k-1}{2}M_e^2}{1+\frac{k-1}{2}}\right]^{\frac{k+1}{2(k-1)}}$$

The lengths of the converging and diverging portions of the nozzle, l_t and l_e, are fixed by the area values and the permissible convergence angle *a*, and divergence angle *b*. These angles differ, in general, for various gases.

Usually however, the convergence angle is limited to 30° and the divergence angle limited to 15°, as shown in the sketch. Any values less than these may be used, although the smaller the angle, the longer will be the nozzle.

These angles, together with the combustion chamber, throat, and exit diameters will satisfy the nozzle design.

3. *Combustion Chamber:* The length of the combustion chamber, 1_c, is dependent on the propellants used and whether or not complete combustion of the propellants is desired. (In solids and liquids both, very often the mixture ratio is fixed to be fuel rich; that is, more fuel is supplied than will burn). It is for this reason that a characteristic chamber length (L*) has been adopted. Characteristic length is simply an index that is established for each type of propellant to indicate how long a chamber should be, or what the ratio of length to diameter should be for a particular chamber volume and throat area. (In other words, it gives some idea as to whether the chamber should be 20 inches wide and only 2 inches long, or 20 inches long and 2 inches wide.) A search in the literature on rockets will show that L* varies for different propellants and chamber pressures. This is because, in simple terms, no single chamber length will be good enough to provide the most efficient burning for all propellants.

Since the chamber cross section has already been calculated, the combustion chamber volume is, in cubic inches,

$$V_c = \frac{\pi D_c^2 l_c}{4}$$

where D_c is the chamber diameter in inches, l_c is the chamber length in inches.

The basic equation involving L* for the chamber volume is

$$V_c = L^*A_t$$

where L* is in inches, A_t is the throat area in square inches.

Equating these two relationships gives

$$\frac{\pi D_c^2 l_c}{4} = L^*A_t \text{ or } l_c = \frac{4L^*A_t}{\pi D_c^2}$$

This equation will give us the length of the combustion chamber if you have the values of L* for the particular propellant you are using. Values for the characteristic chamber length (L*) for various propellant combinations are not as yet easily obtained. Some values are listed below, but for those not listed, it is suggested that a value of approximately 36 to 40 inches will satisfy quite well.

	*L**
RFNA-Aniline	45-78
Oxygen-Alcohol	36-120
Nitromethane	192 and above

For the solid propellant, the chamber length is found using the equation, $l_c = \frac{M}{\rho A_c}$ where l_c is the chamber length in inches, M is the weight of the grain in pounds, ρ is the density of the propellant in pounds per cubic inch, and A_c is the combustion chamber area in square inches.

Mathematical Aids: No doubt, some of the foregoing mathematical relationships will cause trouble for some students. To help overcome this, some of these will be discussed here.

1. For the formula for area ratios

$$\frac{A_e}{A_t} = \frac{M_t}{M_e}\left[\frac{1+\frac{k-1}{2}M_e^2}{1+\frac{k-1}{2}M_t^2}\right]^{\frac{k+1}{2(k-1)}}$$

the value of the right side of the equation is most easily found using logarithms (ℓn is the symbol for logarithm).

Suppose that

$$x = \left[\frac{1+\frac{k-1}{2}M_e^2}{1+\frac{k-1}{2}M_t^2}\right]^{\frac{k+1}{2(k-1)}}$$

Then, the natural logarithm is

$$\ln x = \frac{k+1}{2(k-1)} \ln \left[\frac{1+\frac{k-1}{2}M_e^2}{1+\frac{k-1}{2}M_t^2}\right]$$

and

$$x = \text{anti}\ln \left\{\frac{k+1}{2(k-1)} \ln \left[\frac{1+\frac{k-1}{2}M_e^2}{1+\frac{k-1}{2}M_t^2}\right]\right\}$$

That is, find the logarithm of the quantity

$$\left[\frac{1+\frac{k-1}{2}M_e^2}{1+\frac{k-1}{2}M_t^2}\right]$$

Multiply this by $\frac{k+1}{2(k-1)}$ and then find the number, *x*, for which this product is the logarithm.

The term in the equation for V_e and C_f, that is $\left(\frac{P_e}{P_c}\right)^{\frac{k-1}{k}}$, is calculated in the same way.

The remainder of the calculations should give little trouble, but in the event that they do, ask your own school mathematics teacher for assistance.

For all values of pressure and temperature, the so-called absolute scale is used. That is, these quantities are to be called correctly, absolute temperature and absolute pressure.

Absolute pressure is in *psia,* or pounds per square inch, absolute. When a pressure is given in gauge pressure (*psig*) adding 14.7 psi (atmospheric pressure) to it will give the pressure in *psia.*

Absolute temperature is measured in degrees Rankine (°R). In order to convert degrees Fahrenheit to degrees Rankine, add 460 degrees to the Fahrenheit temperature.

As a further aid to the mathematical calculations necessary in designing your rocket motor, the tables which follow may be helpful. They show the values for the nozzle exit to throat *area* ratio $\left(\frac{A_e}{A_t}\right)$, Table I; the coefficient of thrust (C_f), Table II; and the expansion ratio (value of the term $\left[1-\left(\frac{P_e}{P_c}\right)^{\frac{k-1}{k}}\right]$) Table III; for various chamber pressures and values of the ratio of specific heats (k). The range of chamber pressures shown in the tables is sufficient to cover the great majority of amateur rockets. The tables were prepared by the U. S. Army Artillery and Missile School at Fort Sill, Oklahoma, and appear in a booklet published by the school entitled "A Guide to Amateur Rocketry."

Illustration No. 14

TABLE I

Nozzle Exit-to-Throat-Area Ratio

$$\text{Area Ratio} = \frac{A_e}{A_t}$$

Ratios Shown in Table Are Those Required to Achieve an Exit Pressure (P_e) Equal to Atmospheric Pressure (14.7 psia)

Values of k

		k = 1.15	k = 1.2	k = 1.25	k = 1.3	k = 1.4
CHAMBER PRESSURE	600 psia	6.8 to 1	6.0 to 1	5.6 to 1	5.2 to 1	4.5 to 1
	700 psia	7.6 to 1	6.8 to 1	6.3 to 1	5.8 to 1	5.0 to 1
	800 psia	8.4 to 1	7.6 to 1	6.8 to 1	6.4 to 1	5.4 to 1
	900 psia	9.2 to 1	8.2 to 1	7.4 to 1	6.8 to 1	5.8 to 1
	1000 psia	10.0 to 1	8.8 to 1	8.2 to 1	7.4 to 1	6.2 to 1
	1100 psia	10.9 to 1	9.5 to 1	8.7 to 1	7.9 to 1	6.7 to 1
	1200 psia	11.6 to 1	10.2 to 1	9.3 to 1	8.4 to 1	7.0 to 1
	1300 psia	12.4 to 1	10.8 to 1	9.8 to 1	8.9 to 1	7.4 to 1
	1400 psia	13.0 to 1	11.5 to 1	10.4 to 1	9.4 to 1	7.7 to 1

TABLE II

Coefficient of Thrust
C_F where $P_e = P_{atmos} = 14.7$ psia

Values of k

CHAMBER PRESSURE	k = 1.15	k = 1.2	k = 1.25	k = 1.3	k = 1.4
600 psia	1.55	1.52	1.50	1.48	1.46
700 psia	1.58	1.54	1.52	1.50	1.48
800 psia	1.60	1.56	1.54	1.52	1.50
900 psia	1.62	1.58	1.56	1.54	1.51
1000 psia	1.63	1.59	1.57	1.55	1.52
1100 psia	1.64	1.60	1.58	1.56	1.53
1200 psia	1.66	1.62	1.59	1.56	1.54
1300 psia	1.67	1.63	1.60	1.57	1.54
1400 psia	1.68	1.64	1.61	1.58	1.55

TABLE III

Expansion Ratio Efficiency Factors

Values of $\left[1-\left(\frac{P_e}{P_c}\right)^{\frac{k-1}{k}}\right]$ Where $P_e = P_{atmos} = 14.7$ psia

Values of k

CHAMBER PRESSURE

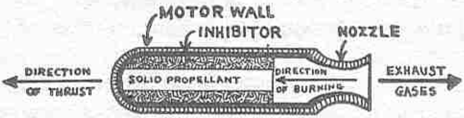
	k = 1.15	k = 1.2	k = 1.25	k = 1.3	k = 1.4
600 psia	0.384	0.460	0.523	0.574	0.655
700 psia	0.396	0.474	0.539	0.590	0.671
800 psia	0.407	0.486	0.551	0.602	0.683
900 psia	0.416	0.495	0.561	0.612	0.693
1000 psia	0.424	0.504	0.570	0.622	0.703
1100 psia	0.431	0.511	0.578	0.630	0.711
1200 psia	0.437	0.518	0.585	0.636	0.718
1300 psia	0.442	0.526	0.591	0.643	0.724
1400 psia	0.448	0.531	0.597	0.650	0.730

Features of Liquid Motor Systems: The examples of rocket motors presented thus far in the illustrations have been of the solid propellant type. This is because we have been discussing principles of motor design, and the motor, per se, consists only of a combustion chamber in which the propellant burns, and a nozzle which exhausts the gas products. In the case of the solid propellants these two elements comprise the entire *motor system.* The principles discussed apply equally well to liquid motors, however, and the chamber and nozzle configurations are much the same for both types of propellants. But because liquid propellants are not initially stored in the combustion chamber (as in the case of the solids), the complete *motor system* for liquid engines contains other elements, primarily tanks, fuel feed lines, valves and pumps. The drawings in Illustration 15 provide a comparison between a simple solid propellant motor and three types of liquid systems.

The diagrams of the liquid systems are, of course, extremely simplified. Do not get the idea that it is a simple matter to build a liquid propellant motor system just because the drawings you see in books and magazines do not look complicated. Most of the drawings you see have been intentionally simplified by the artist in order to illustrate certain features to the reader. They do not contain sufficient information for construction purposes; nor do they include even a suggestion of the multitude of valves, gauges and electronic controls that are needed, or show any of the intricacy of the injection and ignition systems that are required in liquid motors. No amateur group should even attempt the construction of a liquid propellant motor unless it is prepared to invest several hundred dollars in *one* rocket, and unless it has the advice and assistance of a hydraulic engineer and an electronics engineer who have considerable experience in the design and operation of fluid flow control devices and remote control devices. It is one thing to throw together an assemblage of tanks, fuel lines and a combustion chamber, and quite another thing to determine how you are going to start the flow of fuel and oxidizer into the chamber from a distance of 150 feet or more (you can't stand beside the rocket turning valve handles while it blasts off, you know)—or insure the proper mixtures of fuel and oxidizer, or com-

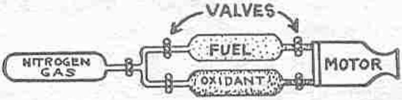
ILLUSTRATION No. 15

A



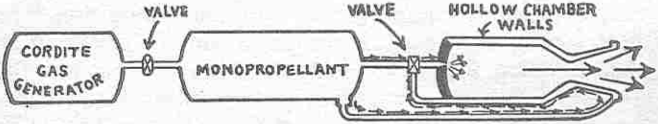
TYPICAL SOLID PROPELLANT MOTOR SYSTEM

B



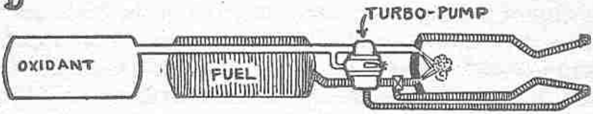
SIMPLIFIED BI-PROPELLANT LIQUID SYSTEM
WITH NITROGEN PROVIDING THE FEED PRESSURE

C



MONOPROPELLANT SYSTEM EMPLOYING
REGENERATIVE COOLING THROUGH CHAMBER WALLS

D



S
SIMPLIFIED BI-PROPELLANT SYSTEM EMPLOYING
TURBO-PUMP FEED AND REGENERATIVE COOLING

pensate for the effect of acceleration on fluid flow, or prevent an accumulation of raw propellant in the chamber, etc., etc. It was pointed out in Chapter 3 that if alcohol and liquid oxygen are allowed to come into contact at room temperature they will form gelatinous globules that have 100 times the explosive power of TNT. This means that if just one pound of this mixture got into the combustion chamber of your rocket before ignition took place, you would have an explosion equivalent to that of a 100-pound aerial bomb.

Referring to the diagrams in Illustration 15, Figure *A* shows a typical solid propellant motor with a tubular-type grain designed to burn from the center outward. The solid black area immediately surrounding the grain is an inhibitor which prevents burning on the outer grain surface. This is a complete solid propellant system, except for the igniter which is not shown.

Figure *B* shows a liquid bipropellant system which uses a tank of some inert gas, such as nitrogen, to provide the pressure necessary to force the fuel and the oxidizer into the combustion chamber where they are mixed in a fine spray and ignited. The injector is not shown, but it must be so designed as to provide a fine spray of fuel and oxidizer in proper proportions for optimum combustion. The most widely used injector design creates a helical spray pattern which throws the propellant mixture against the chamber walls with a spiraling motion. This type of injection accomplishes several purposes, one of which is to partially cool the chamber walls. If you are interested in liquid systems you will have to do a great deal of studying on injector designs. You can find good presentations of the subject among the references listed in the bibliography.

Figure *C* shows a typical layout of a *monopropellant* liquid system. A monopropellant, such as nitromethane, is a substance which contains its own oxidant and consequently will burn by itself. The system shown here uses cordite, burned in a chamber of its own, to produce a gas which provides the pressure for forcing the propellant into the combustion chamber. Hydrogen peroxide, which produces gas readily, is also used in pressure systems similar to this. Another feature of liquid systems illustrated here is the principle of regenerative cooling, whereby the propellant is circulated through the hollow walls of the combustion chamber before it reaches the injector. This constant flow of liquid around the chamber walls has a considerable cooling effect, permitting the use of lighter, less heat-resistant walls, or higher combustion temperatures within the chamber, whichever is desired. The propellant itself, of course, captures a certain amount of heat from the walls, thus raising its own temperature, and this in turn promotes better vaporization and more responsive combustion of the propellant when it reaches the chamber.

Figure *D* shows a bipropellant system in which the feed pressure is provided by a turbo-pump located just forward of the motor. The sizes of feed lines and valves determine the proportions of fuel and oxidant to be fed into the chamber, and the capacity of the pump determines the rate of flow (pounds per second) of the propellant. The pump may be operated by a small electric motor operating on batteries, or by liberating hydrogen peroxide which forms a gas to drive the turbines. The system shown here employs the principle of regenerative cooling, also, circulating the fuel through chamber walls. Virtually all liquid motors designed today make use of this method of cooling the chamber.

Some Advantages of Liquid Systems: Liquid motor systems possess certain advantages, most of which were discussed in the chapter on propellants. Aside from the higher thrust, greater availability and lower per-pound cost of liquids, there is one very attractive feature of liquid motors which will probably ensure their use for a long time to come. The thrust of a liquid rocket motor can be controlled from the ground (or programed), so that it may be varied during flight to meet changing flight conditions. If desired, the motor can be shut off completely and reignited at any time. The latter is a particularly important feature in the case of satellite launchings, where the velocity of the vehicle through different segments of the flight path must be closely controlled, and *cutoff* must be precisely timed. With the liquid motor these things can be accomplished by simply varying the propellant flow rate (by adjusting valves or pump pressures) or by shutting off the flow of propellant altogether. This one important feature gives the liquid motor a versatility which the solid motor does not possess. For once a solid propellant grain is ignited it continues to burn until it is entirely consumed.

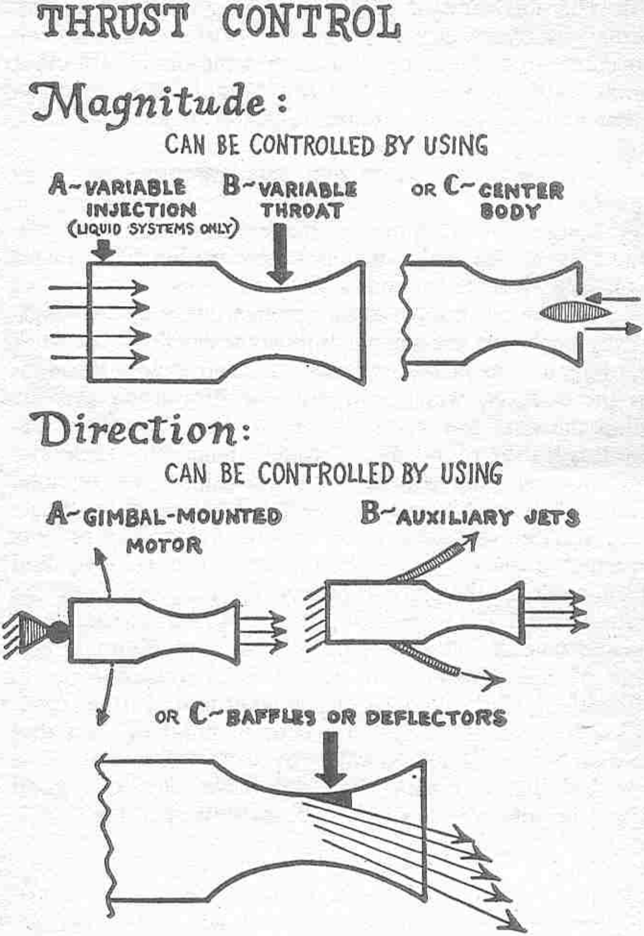
At present, there is no practical means of varying the performance of a solid propellant motor in flight, nor of stopping its burning and reigniting it. Many development projects are presently under way seeking a solution to the problem of thrust control in solid propellant motors and you can find discussions of them in some of the reference works listed in the bibliography. Among the methods being investigated are nozzle designs with a variable throat aperture, and the use of a movable *center body* at the nozzle exit which will produce a choking effect on the exhaust jet as it is moved forward toward the throat. Some of the methods under study for controlling both the *magnitude* of thrust and the *direction* of thrust are shown in Illustration 16.

Most of the methods shown apply equally well to liquid or solid motors. The most promising method for controlling the burning rate of a solid propellant, however, is a system for bombarding the grain with high-frequency, ultra sonic sound waves. The sound waves stimulate or depress the burning according to their intensity, and a major breakthrough in the application of this technique was recently announced by Princeton University and the Acousticon Corporation.

Disadvantages of Liquid Systems: The disadvantages of liquid systems were also discussed in the chapter on propellants; but to summarize them briefly here, it may be said that:

a. Although the motor itself may be smaller and lighter than a solid propellant motor of equivalent thrust, this advantage is more than offset by the added weight of tanks, valves, pumps, gauges, tubing, etc., required for a complete *motor system*; and the added weight and size of the additional supporting structure necessary to house all this apparatus further reduces the thrust-to-weight ratio to the point that it is no longer competitive with solid systems. (There are only two reasons why liquid systems are still used for the larger satellite-launching missiles and ICBM's: one is the factor of close control of thrust and cutoff, and the other is that solid charges cannot yet be manufactured in the sizes needed.)

Illustration No. 16



b. Propellant handling hazards are a source of added expense and annoyance.

c. Propellant loading is complicated, slow and costly (an important factor for military missiles).

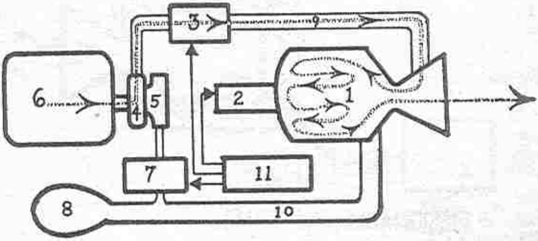
d. The intricacy of liquid systems presents two important disadvantages: (1) long and elaborate countdown procedure, and (2) a high degree of *unreliability* (in other words, liquid systems are full of "bugs" which cause unanticipated delays and failures in performance.)

SOME SYSTEMS FOR THE FUTURE

Although the chemically powered rocket will undoubtedly be the major means of propulsion for missiles and space vehicles for many years to come, other means of propulsion are known to be practical, once certain engineering problems are solved. Important development work is now going on in laboratories and test centers throughout the country, which will produce propulsion systems within the next few years that make use of some of the newer methods of releasing energy. Generally speaking, these new systems will be more efficient, more reliable, cheaper than existing systems, and will deliver much greater thrust. Among these systems are the *nuclear-heat* process (in which a reactor is used simply to heat a working fluid which produces the exhaust gases), the *fusion* process, the *fission* process, the *electric arc heater,* the *particle accelerator,* and several methods of using solar heat. You will find some of these systems illustrated in simplified form in Illustrations 17 through 20. If you want to do further reading on some of these systems, bear in mind the fact that different writers refer to them by different names. You may find this confusing until you have formed a good picture in your mind of how each system operates.

Illustration No. 17

NUCLEAR ROCKET SYSTEM



1—REACTOR—HEAT EXCHANGER
2—CONTROL ROD
3—CONTROL VALVE
4—PUMP
5—TURBINE
6—PROPELLANT TANK
7—CONTROL VALVE
8—STARTING GAS SOURCE
9—PROPELLANT LINE
10—TURBINE GAS LINE
11—PROGRAMMER & CONTROLLERS

Illustration No. 18

GASEOUS FISSION REACTOR

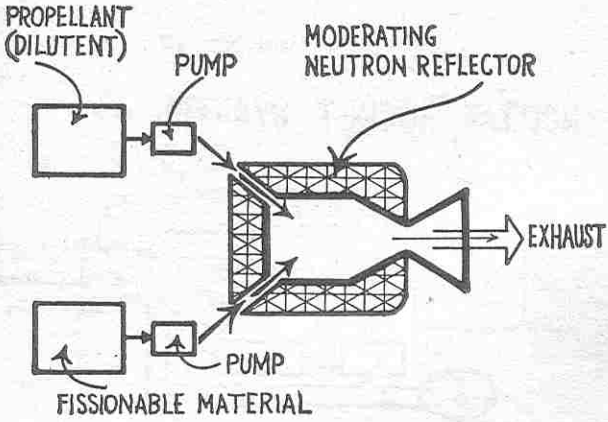
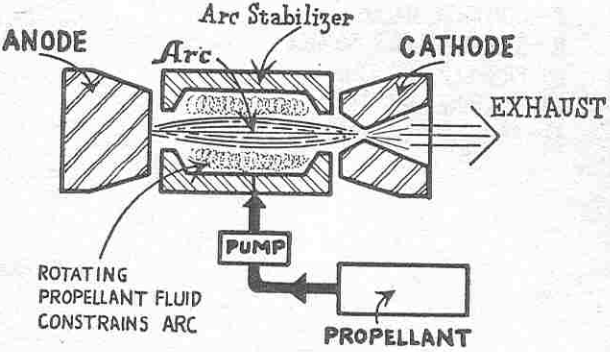


Illustration No. 19

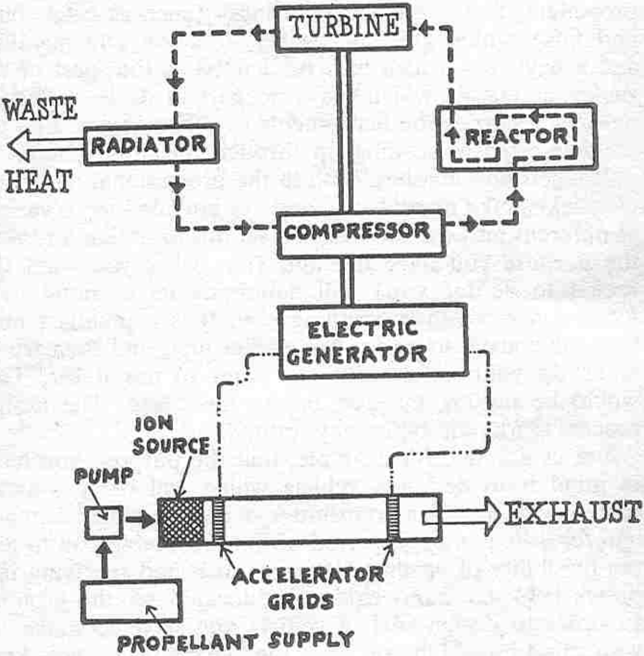
ELECTRIC POWER FROM NUCLEAR REACTOR VIA TURBO-GENERATOR



Direct Electric Arc Heater

ILLUSTRATION No. 20

Direct Particle Accelerator



Chapter 5

MORE ADVANCED ROCKET DESIGN

Now that you have learned something of rocket propellants, the combustion process and the design of rocket motors it is time to consider the over-all design of complete rocket systems. By a complete rocket system we mean the rocket itself (combustion chamber and motor), the propellant, the aerodynamic surfaces (such as nose cones and fins) which give the rocket direction and stability, and a payload—which may be defined as that part of the rocket or missile which plays no part in its performance but which carries the instruments or other objects that we are interested in sending up through the atmosphere.

Rockets and missiles, both in the professional and amateur fields, take many forms and are intended for a variety of different purposes. When you set out to design a rocket, the *purpose* you have in mind (i.e., what you want the rocket to do for you) will determine its eventual conformation more than anything else. It is a pointless mistake, obviously, to design the rocket first, and then try to make up your mind what you want to use it for. This would be putting the cart before the horse. The design process works the other way around.

Let us assume, for example, that the purpose you have in mind is to design a vehicle which will carry a small radio receiver and a transmitter a great enough distance and for a long enough period of time to enable you to test the feasibility of sending messages to it and receiving impulses back on radio equipment located on the ground. In order to design such a vehicle you have to make up your mind how high you want the vehicle to go, how long you want it to stay up, and what weight you want it to be able to carry. These are your *design requirements*. Once these have been established you can set about determining the size and power of the vehicle necessary to meet these requirements. When you have determined these factors you have the *design specifications* for a rocket system. The steps in the process are really rather simple, but you must follow them systematically if your design process is to make any sense.

First of all, the height to which the vehicle goes and the length of time it stays aloft are interdependent factors determined by natural physical laws—assuming the rocket is to be a free-flight vehicle. In other words, no matter what the weight of the rocket and payload, the height to which it will rise is determined by its initial velocity; and the length of time that is required for it to attain maximum altitude is determined solely by the time required for the force, or attraction, of gravity to overcome its initial velocity. On the downward flight, the vehicle will consume a roughly equal period of time in reaching the ground, unless it is slowed by a parachute or some other means of aerodynamic "braking." Therefore, for all practical purposes—and always in the case of rockets with a short burning time and a strong initial thrust—the time of flight is predetermined by the altitude to which the vehicle goes. Let us assume that you wish the rocket to carry its payload to an altitude of 10,000 feet. Assuming the rocket derives all of its motive power from a strong initial thrust, which is the case with virtually all amateur rockets, it will require 25 seconds to reach a height of 10,000 feet and will also require 25 seconds for the return trip to earth, giving a total flight time of 50 seconds. In order to reach such a height, the rocket must have an initial, or *takeoff*, velocity of 800 feet-per-second (545 mph) regardless of its size and weight—discounting aerodynamic drag.

Given the desired altitude and the initial velocity required to reach it, the next step is to determine the amount of power (or thrust) necessary to impart that velocity to a given vehicle. To start with, we must know the weight of the payload (the section carrying the radio receiver and transmitter) and to it must be added the weight of the propulsion system (or rocket). The weight of the former can be determined once the package and its housing have been designed. Naturally, it is to the advantage of the researcher to design this package so that it is as small and as light as possible. The weight of the rocket itself can only be determined after a propellant has been selected, and the amount of it necessary to give the desired thrust has been computed. Since we don't know how much thrust we will need until we know the total weight of the entire rocket system, we are faced with the age-old problem of "which comes first—the chicken or the egg?". The problem is further complicated by the fact that the weight of the propellant itself must be added to the total load to be lifted, and this weight is substantially more than the total rocket and payload weight combined, in the average system. Where do we go from here?

Rocket engineers generally solve this problem by considering a variety of combinations of possible propellant and thrust chamber designs, until they hit upon one which seems to offer the greatest amount of thrust for the amount of weight involved. There is no pat mathematical formula which will give the optimum selection. But a very valuable guide which can be used in determining the eventual size and weight of the rocket system needed to put your payload where you want it is the *mass ratio* formula. *Mass ratio* is defined as the initial mass (or weight) of the rocket fully loaded, divided by the weight of the rocket after all the fuel has been exhausted (weight at burnout). This relationship is expressed in the formula:

$$\text{mass ratio} = \frac{\text{weight of vehicle loaded}}{\text{weight of vehicle empty}}$$

or

$$\text{mass ratio} = \frac{\text{initial weight}}{\text{cutoff weight (or burnout wt.)}}$$

or

$$n = \frac{W_i}{W_b}$$

As in the case of most other formulas used by rocket engineers you will find a variety of symbols used for the terms which appear in this simple formula. You may find it written $m_r = \frac{m_o}{m_c}$, (original mass/mass at cutoff) or a dozen other ways. But don't let them confuse you, as they all mean the same thing. It is simply a way of expressing the relationship between the empty weight of the rocket and its loaded weight.

The significance of this ratio is directly related to the matter of velocity. And it is a particular velocity of the vehicle that we are trying to achieve in order to propel it to the altitude we desire. (In this case a velocity of 800 feet-per-second in order to achieve an altitude of 10,000 feet.) In Chapter 4 we learned how to calculate the exhaust velocity produced by a particular propellant in a particular chamber design. This exhaust velocity (the speed of the exhaust gases as they leave the nozzle exit) is directly translated into velocity on the part of the vehicle. And the amount of velocity imparted to the rocket is dependent upon the mass ratio. Theoretically, if we wish to accelerate the rocket to a velocity *equal to* the exhaust velocity of the gas products, our rocket system must have a mass ratio of at least 2.7183 to 1. In other words, the weight of the rocket fully loaded must be 2.7183 times the weight of the empty rocket shell after all the propellant has been exhausted. This means that 63.2 per cent of the total initial weight of the rocket must consist of propellant, and only 36.8 per cent can be devoted to the propulsion system, control surfaces and payload. If we wish to achieve a velocity at burnout which is *twice* the exhaust velocity the mass ratio must be a little better than 7 to 1. In this instance 86 per cent of the initial weight of the rocket will be propellant.

Let us assume, then, for the sake of simplicity, that we can design a payload with a miniaturized radio receiver and transmitter in it that weighs only one pound. Its weight, together with the weight of the propulsion system, cannot equal more than 36.8 per cent of the total, *if* we want to accelerate it to a velocity equal to the exhaust velocity. We can do this, and reach an altitude of 10,000 feet, if we can design a propulsion system which has an exhaust velocity of 800 feet-per-second, weighs no more than 2.68 pounds (exclusive of payload), and will carry 6.32 pounds of propellant. This would make a total initial weight of 10 pounds, of which 63.2 per cent is propellant. This is a large order, and I doubt that it could be done using the materials with which amateurs must work. But it might be done by virtually doubling the size of the rocket, so that we have a 1 pound payload, a 6.36 pound propulsion system, and a 12.64 pound propellant charge, for a total initial weight of 20 pounds. It might also be done by using a better propellant or more efficient rocket motor, so that the exhaust velocity could be increased (say to 1200 or 1400 feet-per-second), thus enabling us to use a lesser weight of propellant and a less restrictive mass ratio.

These are but two of the alternatives open to the rocket engineer in deciding how to combine the various design elements which determine the performance of a particular rocket configuration. Generally speaking, increased propellant performance means increased strength (and consequently greater weight) in the propulsion system, and vice versa; so that the design process becomes a process of *selecting* an optimum combination from a great many alternatives. This may be done theoretically, by calculating the thrust and the weight of several alternative combinations of propellant and chamber design; or it may be done empirically by conducting static tests of several propellants in different types of combustion chambers. Usually a combination of these two approaches is used; and in any case the rocket engineer does not decide upon the final design, nor build a full-scale working system until he has proved that the design will work efficiently by testing a great number of small-scale models.

The most important thing to remember about design, however, is the fact that it has to be directed toward a specific objective. No design can exist until it has first been decided what the proposed vehicle is intended to do. The mission to be accomplished is the starting point of all design. Without a clear idea of what your end objective is you cannot design anything—except by accident.

In the case of amateur rocket experimentation there are a great many objectives to be served. You may want to put a rocket into the air or static test one for any one of the following reasons, for example:

To achieve a specific altitude.
  (Remember that this is a question of mass ratio and not just a matter of size. A five-inch rocket with a high mass ratio will go higher than a five-foot rocket with a low mass ratio—assuming the exhaust velocity is the same in both cases.)
To test a propellant.
To test a particular fin design or an aerodynamic configuration.
To test instruments.
To test the effects of altitude, acceleration, atmospheric pressure or temperature changes on biological matter or mechanical components.

To test the reliability of mechanical parts, such as parachute release mechanisms, gravity switches, etc.
To test telemetering devices.
To record temperatures, air pressure changes, rate of rotation of the rocket, etc.
To take photographs.

This list could be extended almost indefinitely. But whatever the purpose you wish your rocket to serve, it must be specifically designed to achieve that purpose. Just building a rocket for no reason other than that you *want* to build one is rather pointless. The challenge and the educational value come in designing the rocket to do a specific thing, and in achieving this objective with the greatest economy of materials and the greatest ingenuity.

In this chapter we will consider some of the methods of design and fabrication employed by amateur groups throughout the country, both for component parts of the rocket (i.e., fins, nose cones, nozzles, igniters, etc.) and for entire rocket systems. With the exception of the two rockets shown in Illustrations *31* and *32*, none of them are *professional* designs, in the sense that they were designed by professional people. Most of them are amateur work—but work that is of high caliber, generally, and that has stood the test of many firings.

Neither can any of these rockets be considered *safe*. There is no such thing as a *safe rocket*, commercial advertising claims notwithstanding. *All* rockets are dangerous. The ones described in this chapter may be less likely to explode on the launching rack than the average amateur product, but *all rockets can explode*, under certain conditions, no matter how well designed they are. For proof of this you need look no further than the front page of your daily newspaper where you have seen innumerable pictures of the best-designed missiles modern engineering has produced going up in clouds of smoke.

The key to safety in amateur rocketry does not lie in design nor in strength of construction. It lies in the observance of the time-proven precautions and protective techniques established over a period of hundreds of years by military ordnance and the munitions and explosives industries. A well-designed rocket can make just as big a hole in your head when it explodes as a poorly-designed one. The only way to prevent injury-producing accidents is to make certain you are not around when an explosion occurs. Above all, don't be misled by the hue and cry raised by professional do-gooders who criticize amateurs for the crudeness of their designs, and thereby imply that good design would reduce the hazard of amateur rocketry. It is simply not true. Good design might reduce the likelihood of a particular rocket exploding, but it does not make the rocket any safer. In Chapters 8 and 9 of this book you will find illustrations and explanations of a great many of the protective devices and precautionary measures that can be employed to make amateur rocket experimentation relatively safe. If you faithfully observe these precautions it is very unlikely that your group will ever have an accident, regardless of how good or bad the design of your rocket is.

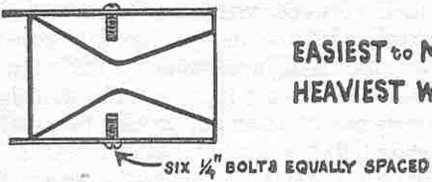
Nozzles: In the preceding chapter we have already discussed nozzle design in some detail and reviewed the step-by-step calculations necessary to compute the dimensions for converging-diverging nozzles designed to give optimum results for particular propellant and chamber design combinations. Three methods of machining nozzles of this type are shown in Illustration 21. If your group is advanced enough to be able to do the design work, and if you have the money and facilities to accomplish the machining required, this type of nozzle is certainly the best. If not, there are several alternative types of nozzles widely used by amateur groups, many of which have given excellent results and proved to be reliable in static and flight tests.

Two such "substitute" nozzles are shown in the design for a basic rocket in Chapter 2. We might call these the *straight throat* and *counter-sunk* types. In addition to these, amateur groups use a variety of other types of nozzles in an effort to get around the problems of intricate machining and high cost. For small rockets, the CO_2 cartridge used to charge carbonated beverages is widely employed. The cartridge is modified in several ways, but most frequently it is used as is, with the nozzle aperture simply reamed out to a diameter of approximately ¼ of an inch, if a propellant such as the zinc and sulfur com-

ILLUSTRATION No. 21

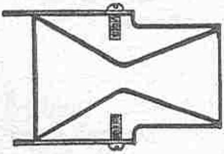
Some Suggested Nozzle Conformations

1.



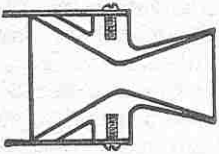
EASIEST to MACHINE
HEAVIEST WEIGHT

2.



MEDIUM MACHINING
MEDIUM WEIGHT

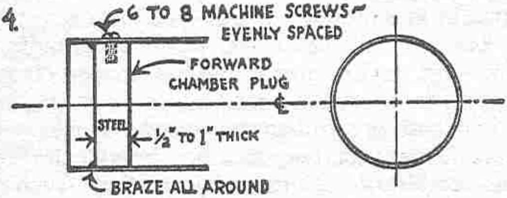
3.



DIFFICULT to MACHINE
LIGHTEST WEIGHT

Suggested Forward Bulkhead Construction

4.



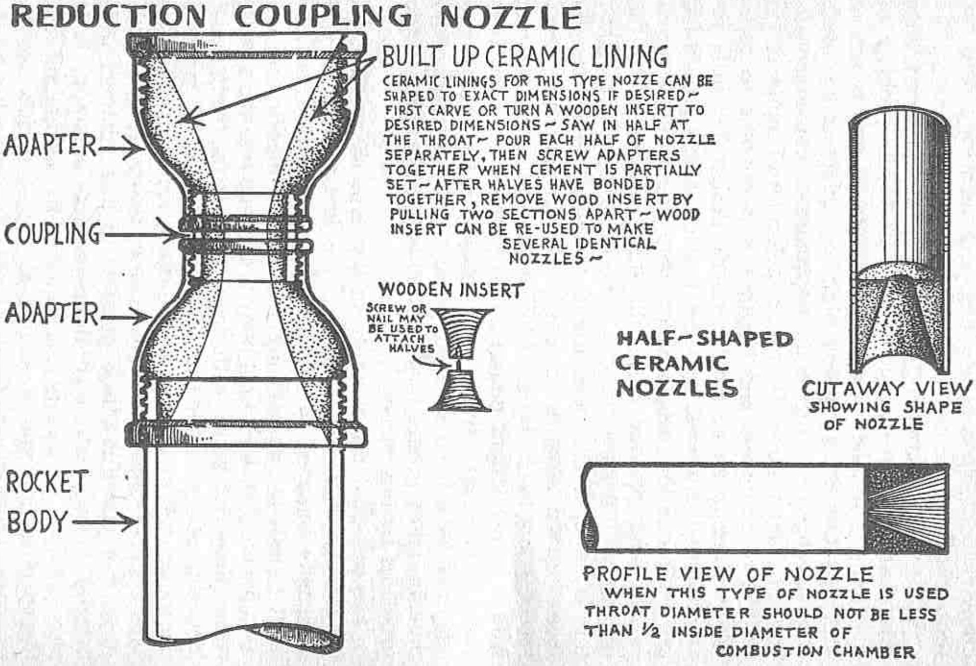
bination is to be used. (In Illustration 30 you will find an example of the use of this type of cartridge to power a small and simple test rocket.)

The other types of substitute nozzles used by amateurs we might classify under three general headings: full-shaped ceramic nozzles, half-shaped ceramic nozzles, and reduction-coupling nozzles. There are other types used, but these are the three most popular.

The full-shaped ceramic nozzle is a convergent- divergent-type nozzle with the design configuration of the De Laval nozzles discussed in Chapter 4. The only difference is that the nozzle is cast in a ceramic mold instead of being machined out of steel bar stock. The process is simpler and cheaper if you are intending to make a considerable number of nozzles of the same design dimensions. If you have access to a craft shop or a ceramic pottery works, you can probably learn to make this type of nozzle very quickly, once you have established the configuration needed and constructed the basic mold. A wide variety of hard, heat-resistant ceramic materials is used with considerable success by amateur groups throughout the country, and it is usually not too difficult to find someone with a knowledge of ceramics who can give you advice on this. One type of material used for this purpose is known as Durham's rock hard water putty. Ceramic nozzles have the advantage of being light and cheap to make, but they are practical only if you are going to make a considerable number of them, because of the work involved in designing and fabricating the original mold.

The half-shaped ceramic nozzle is a rather extreme compromise, but it apparently gives good results when used for small diameter rockets with relatively low chamber pressures. In fact, nozzles of this type have sent small rockets of one-inch diameter, or less, to altitudes in excess of one mile. An example of the half-shaped ceramic nozzle is shown in Illustration 22. As you can see, it is simply the rear half of a full-shaped nozzle. It allows the exhaust gases to expand, but does not provide for contraction and acceleration of them before they reach the throat. This type of nozzle is extremely easy to make, and many groups simply pour the ceramic material into the end of the rocket and shape the divergent aperture with a shaping tool as the material hardens. It is also very

ILLUSTRATION No. 22



CERAMIC LININGS FOR THIS TYPE NOZZE CAN BE SHAPED TO EXACT DIMENSIONS IF DESIRED ~ FIRST CARVE OR TURN A WOODEN INSERT TO DESIRED DIMENSIONS ~ SAW IN HALF AT THE THROAT ~ POUR EACH HALF OF NOZZLE SEPARATELY, THEN SCREW ADAPTERS TOGETHER WHEN CEMENT IS PARTIALLY SET ~ AFTER HALVES HAVE BONDED TOGETHER, REMOVE WOOD INSERT BY PULLING TWO SECTIONS APART ~ WOOD INSERT CAN BE RE-USED TO MAKE SEVERAL IDENTICAL NOZZLES ~

WHEN THIS TYPE OF NOZZLE IS USED THROAT DIAMETER SHOULD NOT BE LESS THAN ½ INSIDE DIAMETER OF COMBUSTION CHAMBER simple to make a mold from a sawed-off section of the tubing you use for the rocket chamber and insert an inverted metal or wood cone into it which corresponds to the divergent shape you want. Ceramic nozzles are generally held in place by welding a retainer ring onto the rocket body at the exit end.

The reduction coupling nozzles used by amateur groups represent another attempt to get around the problem of machining and high cost. An example of one is shown in Illustration 22. Common plumbing adapters are used, coupled together to give an approximate convergent-divergent configuration. By proper selection of adapters (in respect to diameters and lengths) it is possible to come pretty close to an acceptable nozzle design if a little reworking of the interior surfaces is done. Many groups file down the interior surfaces in order to round off the throat section and provide a smooth finish. Others coat the interior with a hard ceramic material, or graphite. When this is done, it has been found that the nozzles can be reconditioned after firing, easily and inexpensively, and reused many times. By a combination of filing and coating with a heat-resistant material it is possible to come very close to an ideal interior conformation if the proper size adapters have been selected. With a little ingenuity and thought, many groups have been able to solve their nozzle problems by this means.

The principal disadvantage of this type of nozzle is its weight. Another disadvantage is the fact that the nozzle is usually attached to the rocket body by threads, and most plumbing adapters are made with interior threads. This means that the rocket body is screwed *into* the nozzle, rather than vice versa, with the result that the overlapping front end of the nozzle extends outward from the sides of the rocket and creates some additional aerodynamic drag. This disadvantage can be overcome, however, in several ways. For one thing, it is possible to find adapters with exterior threads, although these are less common. It is also possible to modify the adapter by sawing off the threaded section and threading the outer surface; or to use some other means of attachment to the rocket body, such as attachment by machine screws or a retaining ring. In any event, reduction couplings represent one very satisfactory means of working out the nozzle problem. It is important, however, to do a little research into the composition and bursting strength of the adapters you select. This information should be available from the manufacturer if you cannot get it from any other source.

Fin Design: One of the most frequent questions asked by amateur rocket designers is, "What size fins should I use?" The only answer that can be given to this question, even by a professional rocket engineer, is that you should use the size that is *proper* for your particular rocket. As to the number of fins you should use, the answer is the same—a *proper* number will do.

The point is that there is no answer to this question. The size of fins, their shape, the number to use and their placement on the rocket are all questions that can be answered only by experimentation. Even in the professional field, the character of the aerodynamic surfaces is determined only by extensive tests in wind tunnels and later flight tests of the missile itself. There is no quick and easy mathematical formula anyone can give you to guide you in the selection of fin designs. While it is possible to compute mathematically certain design characteristics of aerodynamic surfaces, the calculations involved are so extensive that they can only be accomplished by machine computers.

Generally, amateurs are prone to equip their rockets with fins much larger than are necessary. The only reason for fins on the average amateur rocket is to give the rocket stability in flight. They serve no other purpose. The feathers on an arrow serve the same purpose. If you will take a good look at a well-balanced arrow that behaves well in flight, you will get a good idea of the number of fins and the amount of fin surface you need on your rocket. (It is very little, indeed, isn't it?) You will also notice that the larger ballistic missiles have very small fin areas, and in some cases none at all. This is because they are designed to operate at very high altitudes where fin surfaces would be of no use anyway, and the initial stability of the missile is provided by good balance and auxiliary venturi which can be used, if necessary, to correct a deviation from flight path. Another good example, perhaps more directly analogous to the amateur rocket, is a large artillery projectile. The artillery projectile has no fins at all. It relies for stability on its great speed, its balance, and the spin imparted to it by the barrel of the rifle. The amateur rocket also has great speed, and it is a mistake to encumber it with large fin surfaces such as are needed for airplanes or the slower moving air-breathing missiles.

One amateur rocket society which has operated for many years on the Pacific Coast has worked out a formula for determining the fin area required for the average amateur rocket which it claims it has used with good success in building most of its rockets. This formula gives the area in square inches of one side of one fin, regardless of the shape of the fin, and applies only to a three-fin arrangement. For a rocket having four fins, the area would have to be reduced proportionately. Here is the formula:

$$\text{Area of one fin} = \frac{(d + 0.5) \times L}{6}$$

where: d = outside diameter of the rocket tube
L = length of the rocket, without nose cone

The value of 0.5 is a constant which is always added to the diameter of the rocket. The design formula further provides that the width of each fin should be at least 1¼ times the diameter of the rocket body. This minimum could also be reduced proportionately if a four-fin rather than a three-fin arangement is used.

Applying this formula to a small rocket that is one inch in diameter and twenty inches long, we find that we should have three fins which are 1¼ inches wide and long enough to give a surface area of 5 square inches on each fin regardless of its shape. This, as you can readily see, does not mean a very large fin.

There is one other rule-of-thumb applying to fin design worked out by the Army Artillery and Missile School at Fort Sill, Oklahoma, and recommended in the booklet it publishes. This rule states that the distance from tip to tip of two fins mounted on opposite sides of the rocket body should not be more than 200 times the *thickness* of the fins. Applying this rule to our small 20 inch by 1 inch rocket with fins which are 1¼ inches wide, we find that the fins should be made of a material which is at least

.0175 inches thick (meaning aluminum or steel, of course, as most other materials do not have sufficient strength or rigidity).

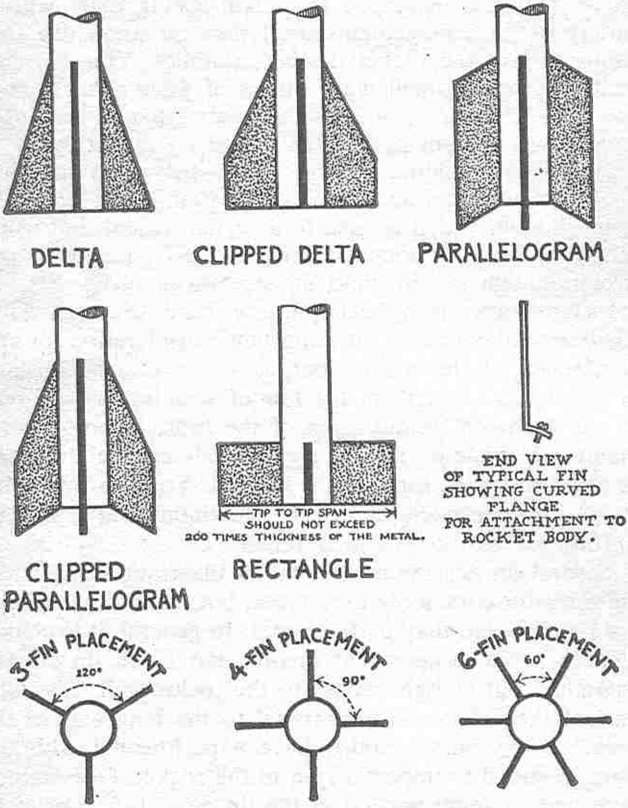
When all is said and done, however, the *cut-and-try* method of fin design is probably the most widely used and the most successful. Even if you hit upon some formula for fin design you would still have to test the result. Most groups do this by building small-scale models of the rocket they are designing and flight-testing them with a variety of fin arrangements until they hit upon one that seems to give the rocket the best stability. You can also build yourself a small wind tunnel of your own, as suggested in Chapter 7, and conduct aerodynamic tests of a scale model of your rocket before you try to test fly it.

Steel and aluminum are the most widely used materials for fin construction because they are both strong and easy to work with. Wood is used to a certain extent, but wood cannot be bent without breaking and it frequently is not strong enough to withstand the stresses involved. Plastics are sometimes strong enough, but hard to work with. Lightness, of course, is an important consideration for any component of the rocket, but do not make the mistake of sacrificing strength in the fins of your rocket in order to cut down on weight. One of the most common complaints of amateurs is that the fins fall off their rockets, or are bent by the force of the blastoff. You can avoid this if your fins are made of steel or aluminum that is at least 1/16th or ⅛th of an inch thick.

Several fin designs are shown in Illustration *23*. These are the most commonly used types, but many other shapes are possible and may perform well. In general, it is a good idea to avoid designs that involve too much fin surface extending out at right angles to the rocket hull. The long axis of the fin should be parallel to the long axis of the rocket body. Some groups have experimented with designs intended to impart a spin to the rocket. One method is to bend a small portion of the tip of each fin out of its natural alignment. Another method is to alter the alignment of the entire fin so that it is a few degrees out of parallel with the longitudinal axis of the rocket. But it is doubtful that either of these methods has met with any great success. For greatest stability in flight it is important

ILLUSTRATION NO. 23

FIN DESIGNS



that the fins be in exact longitudinal alignment with the rocket body and that the interval between fins be held to very close tolerances. Just two degrees difference in the relative positions of fins can cause the rocket to deviate violently from its intended flight path.

Illustrations *24* and *25* show you several methods of attaching the fins to the body of the rocket. The illustrations point out most of the critical details that you must be careful to observe in fabricating and assembling your fin components. The most important thing to remember is that your work must be exact, carefully done, and the finished product strong and rugged. If you end up with a rocket that is so delicate you have to handle it carefully in order to avoid knocking off a fin or bending one, then you had better do the job over again from the beginning. Your fins will never stand the stress of takeoff if they can't stand being dropped on the floor a few times.

Whatever method of attachment you use, be sure that it is strong and secure. There should be no wobble or flutter of the fins, either at the point of attachment or at the tips. Do not try to drill holes into your rocket combustion chamber in order to bolt a fin flange, or anything else to it. The only places that bolts or machine screws may be used on the rocket body are the points where the nozzle and forward bulkhead are attached and in the area forward of the front bulkhead. Any drilling into the combustion chamber wall will naturally weaken it and provide a place for the interior gas pressure to cause a blowout.

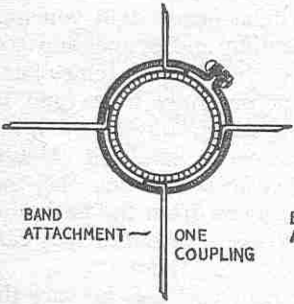
If you like to experiment you might try drilling small holes in the fins at various angles to try and create a high-pitched whistling sound. Some groups have tried this and found it a convenient aid to tracking the flight of the rocket.

Nose Cones: Illustration *26* shows some basic types of nose cones and Illustration *27* shows several methods of attaching them to the rocket body. These are not the only types, nor the only methods of attachment, naturally. In many cases it is not necessary to actually *attach* the nose cone to the rocket at all. As long as the nose cone does not form the upper end of the combustion chamber, or perform some other function, a light press fit is all that is necessary to hold it in place. Gravity and atmospheric

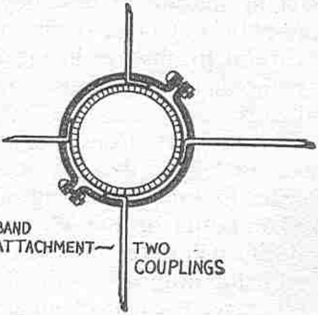
ILLUSTRATION No. 24

METHODS of ATTACHING FINS

1. BAND ATTACHMENT

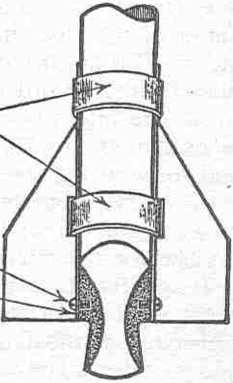


BAND ATTACHMENT— ONE COUPLING



BAND ATTACHMENT— TWO COUPLINGS

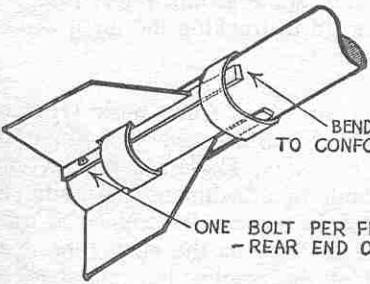
ONE METHOD OF BAND OR STRAP ATTACHMENT OF FINS



STRAPS CUT FROM SECTION OF TUBING SLIGHTLY LARGER THAN ROCKET HULL DIAMETER. BRAZE TO HULL & FIN FLANGES.

BOLTS IN HULL WHICH HOLD NOZZLE IN PLACE ALSO HOLD TAIL ENDS OF FINS.

TAP THREADED HOLES IN NOZZLE OR NOZZLE EXTENSION. —NOT IN COMBUSTION CHAMBER.



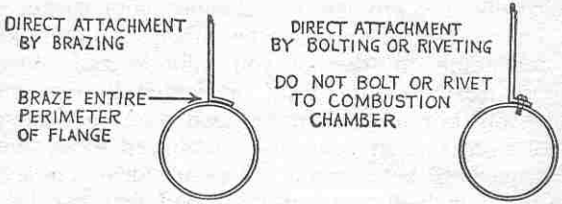
BEND FLANGES SLIGHTLY TO CONFORM TO CURVATURE OF ROCKET HULL.

ONE BOLT PER FLANGE IS SUFFICIENT. —REAR END ONLY.

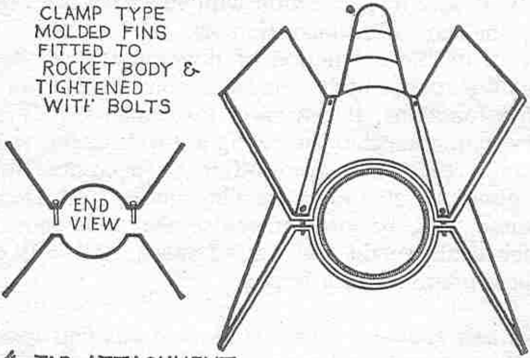
ILLUSTRATION No. 25

METHODS of ATTACHING FINS

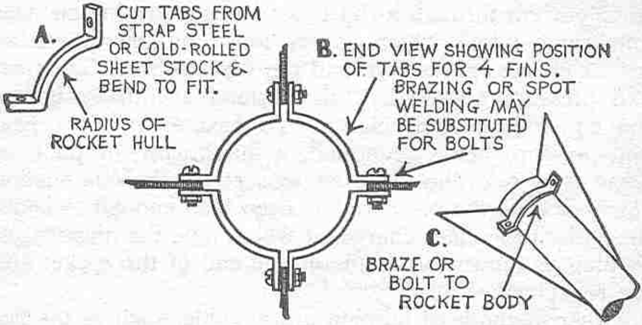
2. DIRECT ATTACHMENT



3. CLAMP ATTACHMENT



4. TAB ATTACHMENT



pressure, increased by the acceleration of the rocket, merely force it more securely in position.

Nose cones may be made from a variety of materials since they are not subjected to any particular stresses. Steel, aluminum, other metals, wood and plastics are most commonly used. As pointed out in Chapter 2, the selection of material for a nose cone gives you an opportunity to help solve the problem of balancing your rocket properly. The nose cone may also be either solid or hollowed out, depending on whether you want to add weight to the nose end of your rocket or lighten it. For smaller rockets, old broomsticks make good nose cone material; and for even smaller ones, the aluminized tubes that are used to package better grade cigars are ideal. These tubes come in ¾-inch diameter usually, and they can be used for a variety of uses in connection with small test rockets, such as the one shown in Illustration *30*.

Aside from its basic function of dividing the air flow evenly over the rocket body, the nose cone can perform several other functions. It can carry instruments, a parachute and ejection mechanism, a light for tracking purposes, a radio receiver or transmitter, or a combustible powder or liquid for creating a tracking smoke trail. Don't overlook these uses, because otherwise the nose cone is just so much dead weight and wasted space, and both of these are at a premium in a rocket.

Diaphragms and Igniters: The ignition of amateur rockets is usually accomplished by means of passing an electrical current through a short section of a heating element (nichrome wire) which causes loose propellant, or an igniter charge, packed around the wire to burn. The heat and pressure caused by this burning eventually ignites the entire propellant charge. To ensure sufficient heat and pressure being generated, a diaphragm, or plug, of some type is ordinarily used to seal off the combustion chamber until the pressure has risen high enough to ignite the entire propellant charge, at which time the diaphragm, or plug, is blown out of the nozzle end of the rocket and the rocket takes off.

Other methods of ignition are possible, such as the use of fuses or ignition by radio impulse, but they are foolhardy in the extreme and constitute the greatest single

ILLUSTRATION No. 26

NOSE CONE DESIGNS

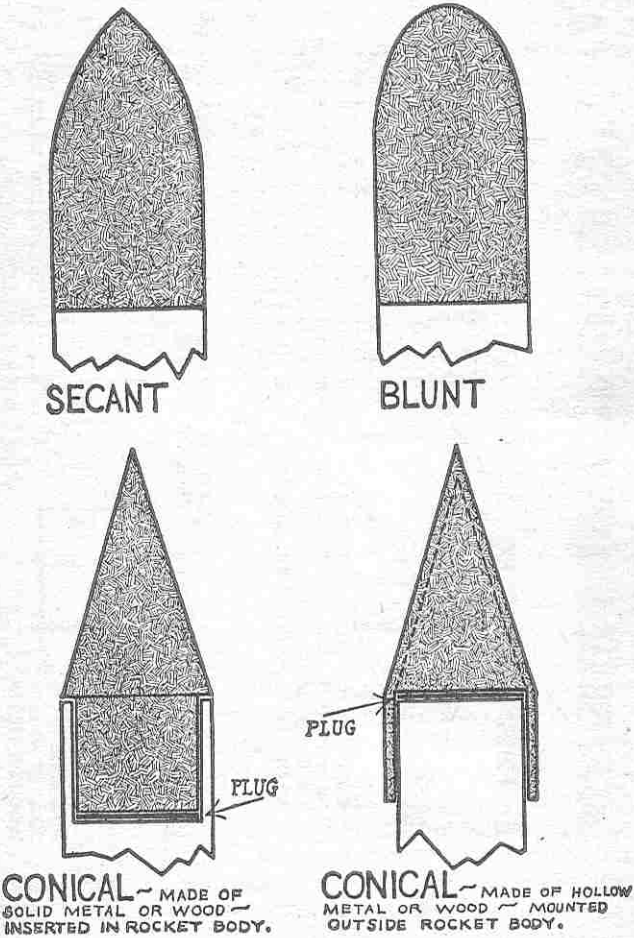
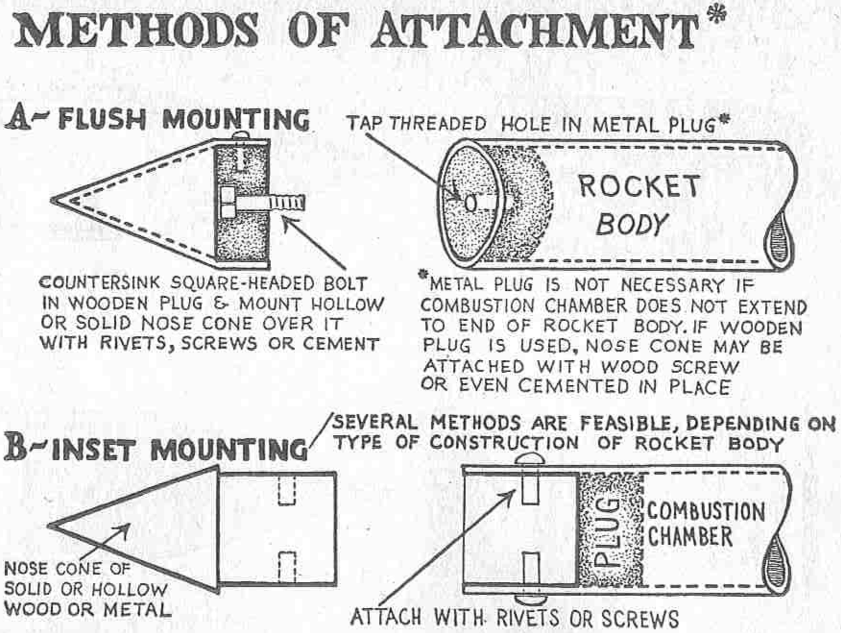


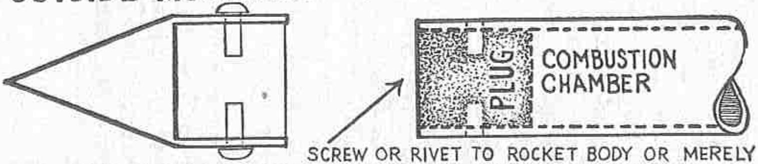
ILLUSTRATION NO. 27



THREADED SECTIONS

*NOTE: FOR ROCKETS WHICH DO NOT DEVELOP HIGH CHAMBER PRESSURES, THREADED NOSE CONES ARE STRONG ENOUGH TO ACT AS A PLUG
BRAZING IS ADVISABLE TO ADD STRENGTH.
STATIC TESTS WILL PROVE WHETHER IT WILL HOLD

C-OUTSIDE MOUNTING



SCREW OR RIVET TO ROCKET BODY OR MERELY SLIP ON. DO NOT SCREW OR RIVET TO COMBUSTION CHAMBER

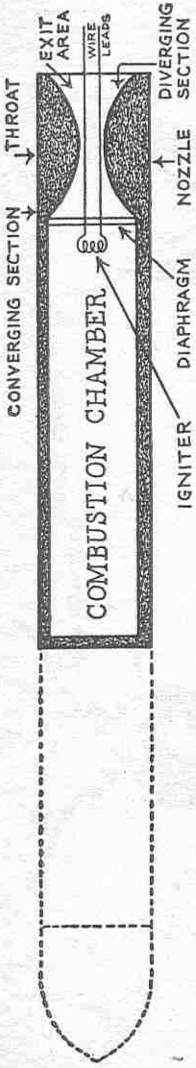
*NOTE: NOSE CONES DO NOT HAVE TO BE ATTACHED TO THE ROCKET BODY UNLESS THE NOSE CONE ALSO FUNCTIONS AS A PLUG TO SEAL THE UPPER END OF THE COMBUSTION CHAMBER. IF THIS IS NOT THE CASE, THE NOSE CONE WILL STAY IN PLACE IF IT IS MERELY INSERTED IN THE ROCKET BODY OR FITTED OVER THE BODY SHELL AS SHOWN IN **B.** AND **C.** ABOVE.

cause of accidents and injuries in amateur rocketry. An electrical circuit makes possible ignition by remote control from a safe distance (preferaby 150 feet), and this is the one most important safety precaution that *must* be observed in amateur rocket experimentation. You will learn more about the use of remote control firing systems in Chapters 8 and 9.

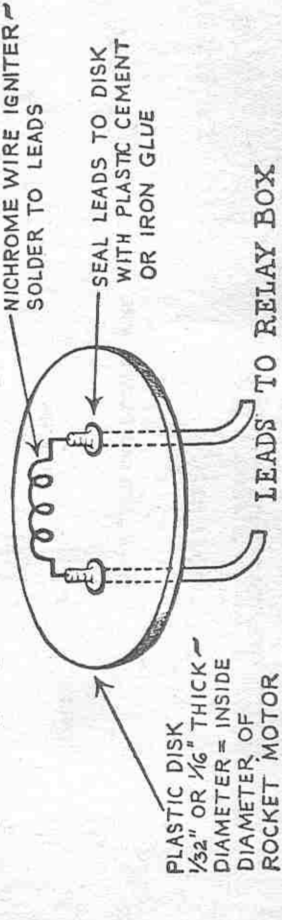
The igniter usually consists of a small piece of nichrome wire (from any heating element), or any other high-resistance conductor which will produce heat. It is inserted into the nozzle end of the rocket and embedded in loose propellant or a small charge of black powder. The latter is used if the propellant is a solid grain. It is also possible to insert the igniter in the forward end of the combustion chamber. While this requires a little more complicated arrangement, it frequently results in better and more rapid burning of the propellant, since the hot gases produced by the original ignition must pass through the hollow core and around the outer surfaces of the propellant charge on their way to the nozzle. This tends to raise the temperature of the rest of the charge, promoting more rapid burning and more complete consumption of the propellant. Here we will deal only with nozzle-end ignition, however.

The igniter is most frequently combined with the diaphragm into one assembly called the *igniter assembly*. Diaphragms, or seals, are of two general types: the *burst diaphragm,* which is a thin metal or plastic disc placed *forward* of the nozzle in the combustion chamber; and the *cork* or *plug* type, which is shaped to fit the diverging contour of the nozzle exit and is inserted into the exit end of the nozzle. Both types serve the same purpose: namely, to seal off the combustion chamber until sufficient heat and pressure have built up to give the rocket real thrust. Without some such seal, the propellant charge will frequently smolder slowly until it has been completely consumed without having ever burned rapidly enough to develop the gas pressure necessary for lift-off.

An example of the burst diaphragm igniter assembly is shown in Illustration *28,* together with a diagram of a complete rocket motor with the diaphragm in place. An example of the plug type seal is shown in Illustration *29* with another type of igniter. Burst type diaphragms should be made of some brittle material, such as plastic or brass,



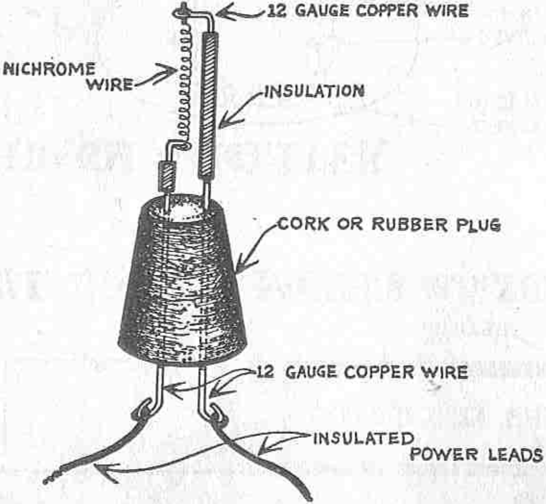
TYPICAL ROCKET MOTOR FOR A SOLID PROPELLANT



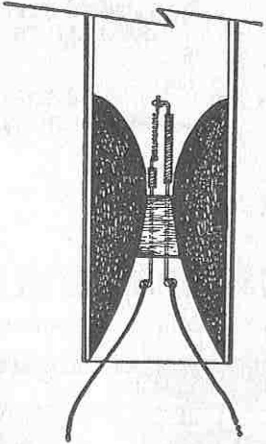
DIAPHRAGM AND IGNITER

ILLUSTRATION NO. 29

PLUG TYPE IGNITER
Assembly



Installation of
PLUG TYPE IGNITER



which will shatter into small pieces capable of being ejected through the nozzle. Thin sheets of copper are not suitable for this purpose, as they tend to melt and form into a hard ball which blocks the nozzle aperture. The plug type may be made of cork, rubber or balsa wood. In the case of both types, the igniter leads passing through them should be tightly sealed to prevent the premature escape of combustion gases. The igniter leads protruding from the nozzle exit are connected to wires leading to the power source, which can be either a generator or a 12-volt battery. A 6-volt battery will not usually provide sufficient current to give reliable ignition.

The Combustion Chamber: Combustion chambers (actually the rocket body in most instances) are made from a wide variety of materials, including even the cardboard tubes used in Fourth-of-July-rockets. The latter, of course, is not a suitable material for any sort of serious amateur work and obviously would not withstand the burning of anything but the lightest of weak powder charges. A great many cardboard rockets are flown to heights of a few hundred feet; but they can scarcely be considered anything but toys—except for their use as signal flares in the military and by ships at sea. The cardboard rocket does have one advantage. When it explodes there is no shrapnel flying through the air to injure anyone. Aside from this, however, they have nothing to recommend them.

Of all the materials used by amateurs for the construction of rocket chambers, only two can be said to have any real utility. These are steel tubing and aluminum tubing. Both should be of the seamless variety. Plastics may soon be developed which may be strong enough to stand the heat and pressures of propellant combustion, but they are not available now. The use of any materials other than steel and aluminum is foolhardy, and aluminum should be used only for very small rockets with relatively weak propellant charges and short burning times. In most compositions aluminum has too low a melting point and not enough tensile strength to be usable.

Certain members of your group should be assigned to research in metallurgy, for there is a great deal that you should learn about the strength of materials, their physical properties, and the alloys of metals if you are going to design and build workable rocket systems. You should never undertake to test-fire a rocket engine without knowing the composition of the material you are using and its melting point and tensile strength. Don't just pick up a piece of stray steel tubing from a junk yard and assume that it has the properties you need. Buy your materials direct from the manufacturer or from a reliable dealer who knows what he is selling you.

The following table will give you some appreciation of the relative strengths of a few types of aluminum and steel. This table is intended only as a preliminary guide. You will have to do much more research in the subject in order to know what you are doing. The tensile strength shown is not the bursting strength of tubes. Bursting strength will vary for each type of tubing according to the wall thickness and outside diameter of the tube.

PHYSICAL PROPERTIES OF METALS

Material	Density lbs/cu. in.	Melting Pt. F.°	Ultimate Tensile Strength (psi)
Aluminum:			
EC-0	.098	1195-1215	12,000
Wrought Alloys—			
1100-O	.098	1190-1215	13,000
2014-T6	.101	950-1180	70,000
2024-T4	.100	935-1180	68,000
6061-T6	.098	1080-1200	45,000
Steel:			
SAE 1020	.284	2760	69,000
Stainless (annealed)			
Type 304	.29	2550-2650	85,000
316	.29	2500-2550	90,000
321 & 347	.286	2550-2600	85,000
410	.28	2700-2790	75,000
Alloys (annealed)			
4130 (chrome-moly)	.283	2500-2600	80,000
4140 (chrome-moly)	.283	2500-2600	95,000
8630 (nickel-chrome-moly)	.283	2500-2600	80,000

The composition of metals used commercially is indicated by a code. In the case of steels, the code is a four-digit number established by the American Iron and Steel Institute (AISI) and adopted also by the Society of Auto-motive Engineers (SAE). The first two digits indicate the type of alloy: *10* indicates basic open hearth steel; *13* indicates the steel is alloyed with manganese; *40* indicates it is alloyed with molybdenum, etc. The second two digits indicate the carbon content of the steel: ..30 indicates the steel has 0.30 per cent carbon in it; ..40 indicates the steel has about 0.40 per cent carbon. Thus you know that SAE 1020 designates a basic steel with 0.20 per cent carbon. Any steel with less than 0.20 per cent carbon is considered a low carbon steel.

Any of the low carbon steels are good for combustion chamber construction, as are the chrome-molybdenum and nickel-chrome-molybdenum alloys. But make certain that you know what you are working with and have done some research into the physical properties of the alloy you select, so that you will know how the material is expected to react to temperature, pressure, corrosive materials, etc.

In Chapter 4 you have already learned the basic elements of combustion chamber design and how to compute the dimensions of a chamber in order to get the maximum thrust from a given propellant combination. Knowing the combustion chamber pressure to which you have keyed your design, you can easily determine the type and wall-thickness of the steel or aluminum you should use by consulting a table similar to the one shown above in a good book on metallurgy or an SAE handbook. In selecting your wall-thickness use a safety factor of *4*. That is, the material you use should be *four times* as strong as necessary. If a piece of low carbon steel tubing has a burst rating of 60,000 pounds-per-square-inch, you can consider it safe to subject it to a pressure of 15,000 psi, but no more.

The one remaining structural component of the rocket we have not as yet considered is the forward bulkhead, or plug, which constitutes the front wall of the combustion chamber. This may be the very front end of the piece of tubing you are using as a rocket body, or it may be short of that point if you are using part of the tubing as a payload section. Wherever it is located, it obviously must be just as strong as every other part of the combustion chamber. Blown-off nose cones, or front plugs, are a frequent feature of amateur rocket failures, because so many young designers fail to realize that Boyle's Law is just as applicable inside their rocket as it is inside their physics book at school. The pressure on the forward bulkhead is exactly the same as it is on every other section of the chamber walls. Consequently, your bulkhead must be good and strong and firmly held in place. The best type of bulkhead is a ½- to 1-inch section of solid steel bar. It should be threaded into the rocket body or attached by sturdy machine screws (six ¼-inch screws are recommended for the average amateur job), and then the front wall of the bulkhead should be brazed around its entire perimeter to prevent the escape of gas. Threaded or not, plugs of this type are never a tight enough fit to prevent gas leakage. An example of forward bulkhead construction is shown in Illustration *21*.

Now that we have considered each of the major components of the amateur rocket in brief detail, let us take a look at some proven designs which have already been built and flown by amateurs.

SOME AMATEUR ROCKETS YOU CAN BUILD

1. A Small Test Rocket: A very ingenious and inexpensive little rocket that you can build very quickly and in quantity from readily available components is shown in Illustration *30*. This small rocket can be extremely useful in development programs which your group may undertake, as well as in training new members of your group. It is about as safe as a rocket can be; and it has a further virtue in that it is so small and light that it is hard to conceive of it damaging anything it might hit on its downward flight, and it does not reach a very great altitude. For these reasons it is entirely possible that a great many groups could be successful in obtaining permission from local authorities to test fire this type of rocket in almost any relatively open area.

Here are some of the things this rocket can do for you, and some of the ways in which it can be useful:

To test small quantities of new propellants.

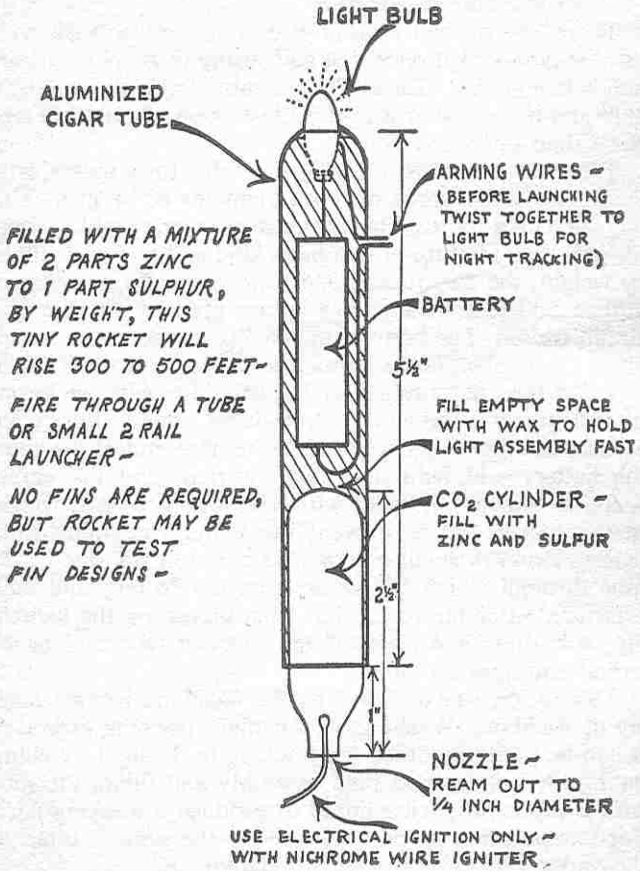
To test fin assemblies.

To test a firing circuit, and rehearse count-down procedure.

To test new igniters.

ILLUSTRATION No. 30

A SMALL TEST ROCKET



FILLED WITH A MIXTURE OF 2 PARTS ZINC TO 1 PART SULPHUR, BY WEIGHT, THIS TINY ROCKET WILL RISE 300 TO 500 FEET–

FIRE THROUGH A TUBE OR SMALL 2 RAIL LAUNCHER–

NO FINS ARE REQUIRED, BUT ROCKET MAY BE USED TO TEST FIN DESIGNS–

ARMING WIRES– (BEFORE LAUNCHING TWIST TOGETHER TO LIGHT BULB FOR NIGHT TRACKING)

FILL EMPTY SPACE WITH WAX TO HOLD LIGHT ASSEMBLY FAST

CO_2 CYLINDER– FILL WITH ZINC AND SULFUR

NOZZLE– REAM OUT TO ¼ INCH DIAMETER

USE ELECTRICAL IGNITION ONLY– WITH NICHROME WIRE IGNITER.

To train your observers in tracking.
To train photographers in getting good take-off pictures.
To test night-firing procedures and train in night tracking.
To flight test miniaturized instruments.
To sound for wind velocity and direction before firing larger rockets.
To send up colored smoke signals for communications purposes on the range.

There are probably other uses that you will discover for this type rocket once you start using it. Its chief attraction is its low cost. The entire assembly, including the light bulb and battery shown in the Illustration, should not cost more than thirty-five cents.

The rocket consists of a CO_2 cartridge for a motor, with the nozzle end reamed out to a diameter of ¼ inch. This type of cartridge can be purchased at any hobby shop. Filled with a mixture of two parts zinc and one part sulfur, by weight, the cartridge propels the rocket to altitudes of 300 to 500 feet. A standard igniter fired by an electrical circuit is used. The body of the rocket is a common aluminized cigar tube. These happen to come in ¾-inch diameter and they fit snugly over the cartridge with no means of attachment necessary. A hole large enough to accommodate the light bulb is bored in the nose end of the tube, the battery and light assembly inserted, and the empty space in the tube is filled with wax—both to add weight to the rocket and to prevent the battery assembly from tearing loose. A small hole is also bored in the side of the tube through which the wires from the battery and bulb protrude. After the rocket has been placed on the launching rack, these wires are twisted together to complete the circuit and light the bulb.

This rocket was designed by the Richland Rocket Society of Richland, Washington, for night tracking exercises. It can be easily modified for tracking in daylight by eliminating the battery and bulb assembly and filling the tube with a vapor producing liquid to produce a tracking flare. For this purpose, prepare the tube in the same manner as the vapor generator shown in Chapter 10.

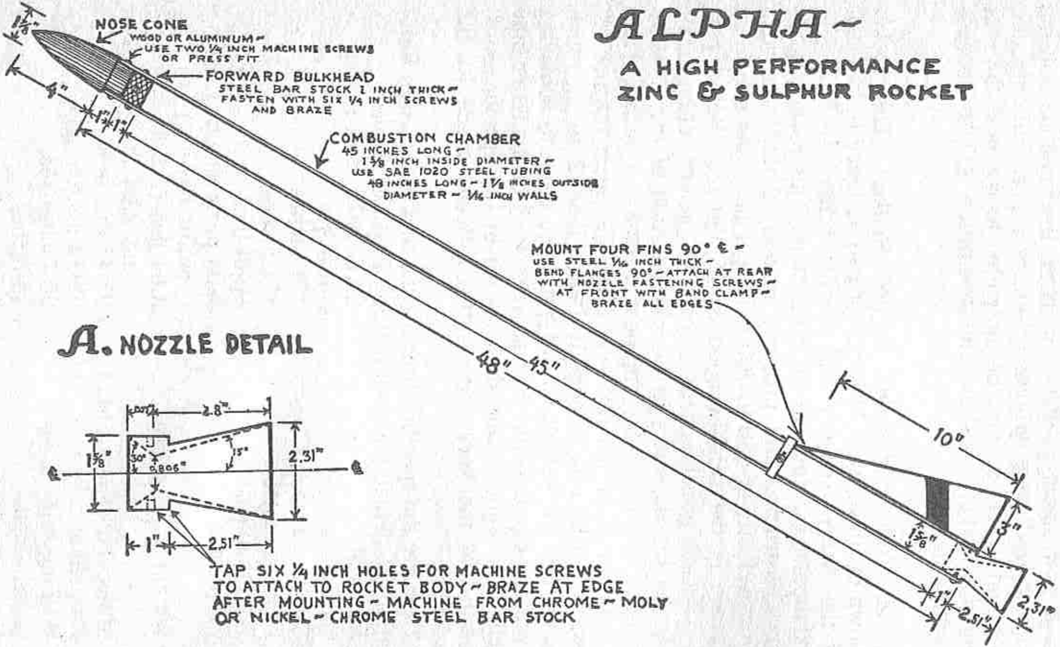
This rocket can also be used as the second stage of a larger rocket, if desired, and in this case it is fired by means of the mercury switch shown in Illustration *33*, Chapter 6. The cigar tube itself has a variety of uses in connection with larger rockets of ¾-inch diameter. It can be used as a nose cone housing a light assembly, or as an instrument package, or as an intermediate housing for a second stage ignition system or a parachute ejection mechanism. It can also be appended to the nose cone of any size rocket (as shown in Illustration *32*) to house a tracking light.

2. *A High Performing 4-Foot Rocket:* The rocket shown in Illustration *31* is one of two designed by the staff of the Army Artillery and Missile School at Fort Sill, Oklahoma, for amateur experimenters. This rocket, properly constructed and properly loaded, should achieve a cutoff velocity of 650 to 700 miles per hour and rise to an altitude in the neighborhood of 15,000 feet. Better performance is possible, because of the large correction factor used by the designers in the computation of the effective exhaust velocity of the combustion gases. A total correction factor of 50 per cent was used. The mass ratio of the system works out to slightly better than 2 to 1, which means that the vehicle would not come close to achieving a velocity equal to the exhaust velocity. But the latter may well be a higher value than shown in the specifications, because of the very conservative estimate made by the designers.

Here are the specifications for the rocket shown in Illustration *31*, which we shall call the Fort Sill Alpha:

Material	SAE 1020 steel tubing
Over-all length	54 inches
Outside diameter	1¾ inches
Inside diameter	1⅝ inches
Wall thickness	$^1/_{16}$th inch
Propellant	2.04 parts zinc to 1 part sulfur (by wt.)
Weight of propellant	8.64 lbs. (5.8 lbs. zinc and 2.84 lbs. sulfur)
Molecular weight (M_w)	97.45 lbs./mol.
Propellant density	.0932 lbs./cu. in.
Burning rate	90 inches/sec.
Grain length	45 inches
Grain diameter	1.625 inches
Burning surface	2.06 sq. in.

ILLUSTRATION No. 31



ALPHA~
A HIGH PERFORMANCE
ZINC & SULPHUR ROCKET

NOSE CONE
WOOD OR ALUMINUM~
USE TWO ¼ INCH MACHINE SCREWS
OR PRESS FIT

FORWARD BULKHEAD
STEEL BAR STOCK 1 INCH THICK~
FASTEN WITH SIX ¼ INCH SCREWS
AND BRAZE

COMBUSTION CHAMBER
45 INCHES LONG~
1⅜ INCH INSIDE DIAMETER~
USE SAE 1020 STEEL TUBING
48 INCHES LONG~1⅞ INCHES OUTSIDE
DIAMETER~1/16 INCH WALLS

MOUNT FOUR FINS 90° ℄~
USE STEEL 1/16 INCH THICK~
BEND FLANGES 90°~ATTACH AT REAR
WITH NOZZLE FASTENING SCREWS~
AT FRONT WITH BAND CLAMP~
BRAZE ALL EDGES

A. NOZZLE DETAIL

TAP SIX ¼ INCH HOLES FOR MACHINE SCREWS
TO ATTACH TO ROCKET BODY~BRAZE AT EDGE
AFTER MOUNTING~MACHINE FROM CHROME~MOLY
OR NICKEL~CHROME STEEL BAR STOCK

Burning time	0.5 sec.
Chamber pressure	1000 psia
Combustion temperature	3060° Rankine
Ratio of specific heats	1.25
Wt. of propellant burned per second	17.28 lbs./sec.
Thrust	800 lbs.
Effective exhaust velocity	1490 ft./sec.
Nozzle dimensions:	
Throat diameter	.806 inches
Throat area	.51 sq. in.
Exit diameter	2.31 inches
Exit area	4.18 sq. in.
Converging angle	30 degrees
Diverging angle	15 degrees
Length-conv. sect.	0.71 inches
Length-div. sect.	2.80 inches

To construct this rocket, start with a piece of tubing which is 48 inches long. This will allow a 45-inch chamber length with three inches left over for mounting the nozzle, the forward plug and the nose cone. The tubing must be of the seamless variety. The nozzle is machined out of steel bar stock, preferably a chrome-molybdenum or nickel-chromium alloy. The nozzle and forward plug can be attached either by threading or with machine screws as shown in the drawing. Use a diaphragm and igniter of the type shown in Illustration *28*. It is advisable to braze around the entire perimeter of both the nozzle and the forward plug at the point of attachment to the body.

The nose cone can be made of wood, turned down on a wood-working lathe. Before deciding on the material for the nose cone, however, weigh your rocket and determine the point of balance. This should be forward of the fin surfaces, but not forward of the midpoint of the rocket. When you have done this you will be able to determine the type of material and the desired weight for the nose cone. The entire rocket, when completed, should weigh in the neighborhood of eight pounds, empty.

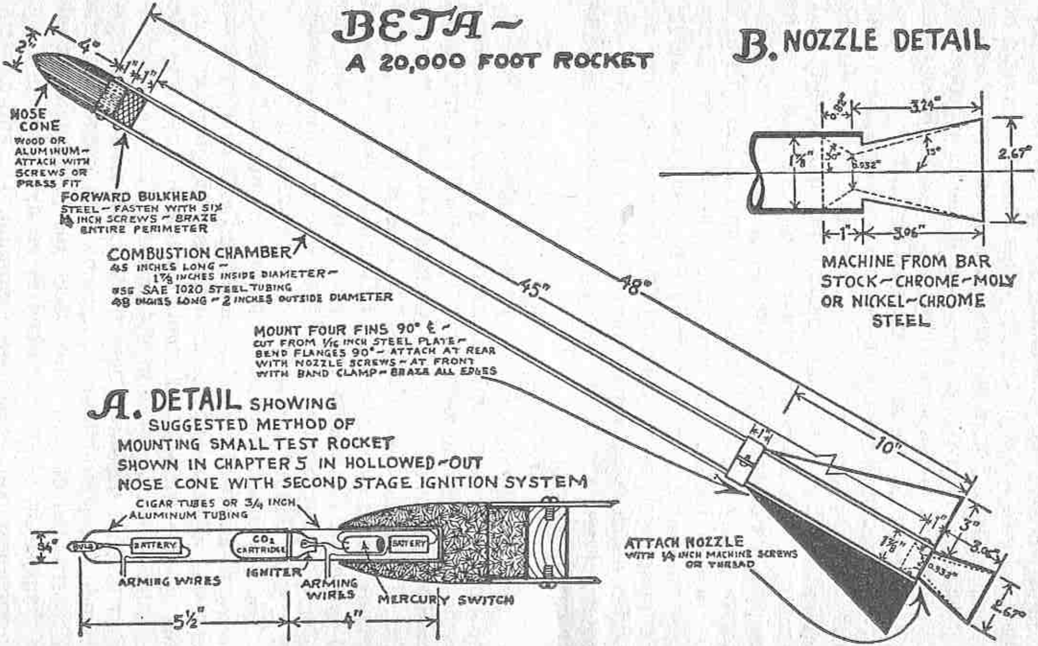
Brazing should also be done around the edges of the fin flanges and the band holding them in place. This considerably reduces the possibility of the fins tearing loose at the time of take-off. The fin flanges should be bent slightly to conform to the curvature of the rocket body.

3. *The Fort Sill—Beta:* The rocket shown in Illustration *32* is the second of the two rockets designed by the staff of the Artillery and Missile School at Fort Sill. It is very similar in most respects to the Alpha rocket, but is of slightly larger diameter, allowing about one-third more propellant to be carried with a consequently greater thrust. This rocket, on the basis of a conservative estimate, should reach a velocity of about 800 miles per hour and rise to about 20,000 feet.

Here are the specifications for the Fort Sill Beta:

Material	SAE 1020 steel tubing
Over-all length	55 inches
Outside diameter	2 inches
Inside diameter	1⅞ inches
Wall thickness	$\frac{1}{16}$th inch
Propellant	2.04 parts zinc to 1 part sulfur (by wt.)
Weight of propellant	11.58 lbs. (7.7 lbs. zinc and 3.81 lbs. sulfur)
Molecular weight	97.45 lbs./mol.
Propellant density	.0932 lbs./cu. in.
Burning rate	90 inches/sec.
Grain length	45 inches
Grain diameter	1.875 inches
Burning surface	2.76 sq. in.
Burning time	0.5 seconds
Chamber pressure	1000 psia
Combustion temperature	3060° Rankine
Ratio of specific heats	1.25
Wt. of propellant burned per second	23.15 lbs./sec.
Thrust	1070 lbs.
Effective exhaust velocity	1490 ft./sec.
Nozzle dimensions:	
Throat diameter	.932 inches
Throat area	.682 sq. in.
Exit diameter	2.67 inches
Exit area	5.59 sq. in.
Converging angle	30 degrees
Diverging angle	15 degrees
Length-conv. sect.	.82 inches
Length-div. sect.	3.24 inches

ILLUSTRATION No. 32



BETA ~
A 20,000 FOOT ROCKET

NOSE CONE
WOOD OR ALUMINUM ~ ATTACH WITH SCREWS OR PRESS FIT

FORWARD BULKHEAD
STEEL ~ FASTEN WITH SIX ¼ INCH SCREWS ~ BRAZE ENTIRE PERIMETER

COMBUSTION CHAMBER
45 INCHES LONG ~ 1⅞ INCHES INSIDE DIAMETER ~
USE SAE 1020 STEEL TUBING
48 INCHES LONG ~ 2 INCHES OUTSIDE DIAMETER

MOUNT FOUR FINS 90° ∉ ~
CUT FROM 1/16 INCH STEEL PLATE ~
BEND FLANGES 90° ~ ATTACH AT REAR
WITH NOZZLE SCREWS ~ AT FRONT
WITH BAND CLAMP ~ BRAZE ALL EDGES

ATTACH NOZZLE
WITH ¼ INCH MACHINE SCREWS OR THREAD

B. NOZZLE DETAIL

MACHINE FROM BAR
STOCK ~ CHROME ~ MOLY
OR NICKEL ~ CHROME
STEEL

A. DETAIL SHOWING
SUGGESTED METHOD OF
MOUNTING SMALL TEST ROCKET
SHOWN IN CHAPTER 5 IN HOLLOWED ~ OUT
NOSE CONE WITH SECOND STAGE IGNITION SYSTEM

CIGAR TUBES OR ¾ INCH ALUMINUM TUBING

In compacting the propellant in the combustion chamber, both in this rocket and in the Alpha, follow the directions given in Chapter 3. The performance parameters listed above have been calculated on the basis of a propellant density of .0932 lb./cu. in. When the entire weight of propellant listed above has been packed into the chamber this density will have been achieved. If you have propellant left over, you have not packed tightly enough. Remember that vigorous tapping settles the powder best.

An interesting experiment you can try with either of the Fort Sill rockets is to bore a ¾-inch diameter hole straight through the nose cone and insert a penlight battery and mercury switch assembly similar to the one illustrated in Chapter 6. You can then mount one of the small test rockets previously described in the nose end of the hole as a second stage rocket. This combination has been fired many times and found to work reliably. The small rocket should fire immediately after burnout of the main stage, when the sudden deceleration forces the mercury to the top of the switch, closing the circuit and passing a current through the small igniter.

4. An Outstanding Amateur Research Rocket: Perhaps the most outstanding amateur rocket yet built in this country is a twelve-and-a-half-foot, beautifully instrumented missile built by 15-year-old Michael Tate of New York City. This rocket was designed to burn a solid grain propellant similar in composition to Galcit-58, and is expected to reach an altitude of over twenty miles. The designer faces the same problem as the man who built the schooner in Arizona. He hasn't found a place to launch it, yet.

The instrument package contains a 35mm.-still camera, an 8mm.-movie camera, telemetering radio equipment for reporting altitude, and the temperature and chamber pressure in two pressurized compartments for carrying live hamsters, a rocket ejection and parachute recovery mechanism to float the instrument package to earth, and high-altitude radio modulator equipment. The propulsion unit is constructed of cold rolled steel, the instrument section of transparent plastic sheathed in an aluminum housing, and the nose cone is of spun aluminum. The entire assembly weighs approximately fifty-five pounds empty, and will carry one hundred pounds of propellant. The propulsion unit delivers a relatively low thrust, but has a long burning time of 5.5 seconds. This rocket required 750 hours to construct and about $600 has been invested in it.

For anyone who wants to try to duplicate it, here are the basic specifications:

Material:	
Propulsion unit	cold rolled steel
Instrument section	aluminum
Nose cone	aluminum-cadmium
Over-all length	12.5 feet
Combustion chamber	5 ft.-7 in.
Instrument section	5 ft.-7 in.
Nose cone	10.5 inches
Nozzle	6 inches
Outside diameter	4 inches
Inside diameter	3.75 inches
Wall thickness	.125 inch
Propellant	Galcit 58
Grain length	5 ft.-4 in.
Propellant density	33 gms./cu. in.
Forward bulkhead	cold rolled steel 3 inches thick
Nozzle dimensions:	
Throat diameter	1.875 inches
Exit diameter	3.75 inches
Convergent angle	30 degrees
Divergent angle	60 degrees
Length	6 inches

This, of course, is not an average or *typical* amateur rocket—it is an unusual one. But it might be considered representative of the type of work that *can* be done by serious-minded amateurs, given the opportunity to learn. The young man who built this rocket has launched hundreds of smaller prototypes and tracked them by telemetering, using a standard Hallicrafter S38-E receiver. He has built another rocket similar to the one detailed above, nine-and-a-half feet in length with slightly less sophisticated instrumentation. He is not an amateur rocketeer, by strict definition. He is studying to be a doctor, and he anticipates that space medicine will be the most rewarding and demanding field in which he can work. For this reason, most of the rockets he has launched have contained some type of live organism, the tissues of which he examines immediately after recovery to observe the effects of the exposure to acceleration, altitude and rapid temperature changes. His work is an excellent example of the intent of advanced amateurs to make rocketry serve a further scientific purpose.

You and the members of your group should have the same seriousness of purpose if you hope to attract support and interest from individuals and organizations who are in a position to help you. Whether you are building twelve-inch rockets or twelve-foot rockets is immaterial. What is important is whether they are designed to serve a scientific purpose, and whether you have incorporated in them the best design information available to you. Some suggestions were made in Chapter 1 as to possible sources for technical help. You can also get valuable information and an unending supply of new design ideas from corresponding with other amateur groups, from books in your library, professional journals and many periodicals. An increasing number of monthly magazines in the mechanical and model fields are beginning to include material written for and about amateur rocket experimenters. Two that now include amateur rocketry material as a regular monthly feature are *Speed Age*, published by Great American Publications, and *The American Modeler*, published by Street & Smith. Others that include articles from time to time are *Scholastic Magazine, Science World, Scientific American* and most of the popular newsstand magazines devoted to electronics, mechanics and science. From these periodicals you can obtain many stimulating ideas, but a word of caution is necessary. It is a good idea to get an opinion from a thoroughly qualified engineer or chemist on any project you expect to undertake that has been suggested to you by a magazine article. Editors frequently lack the space to include all of the information relative to the hazardous aspects of an experiment, or the author himself may be unaware that all of his readers do not have the requisite background to be able to recognize them. Particularly is this true of the professional journals, where the author thinks he is writing for a professional audience and does not realize that young amateur scientists are reading his work.

Chapter 6

ROCKET INSTRUMENTATION

The field of rocket instrumentation is so broad and complex that it would require an entire book to treat the subject adequately. It is not intended to do more in the present volume than discuss the methods and purposes of instrumentation for rockets and the types of instruments that can be used, and then present a few examples of simple instruments that you can put into your rocket for experimental or practical purposes.

Instrumentation generally includes everything that is not a part of the rocket structure, the rocket motor system —or the payload in cases where the payload is a warhead, a passenger, satellite, mail, freight or something else that is being delivered to a destination or target area. In some cases, instruments themselves may constitute the payload of the rocket; and this is the case with virtually all of the research rockets now being launched in such great numbers for the purpose of exploring the threshold of space or solving certain technical problems in connection with ballistic trajectories or space flight. In other cases the term may include a great many of the mechanisms or devices used to control the functioning of the motor system or to control the flight of the missile. But the primary purpose of instrumentation, usually, is to measure and record (or transmit back to earth) certain information relating to the flight behavior of the missile or the conditions it encounters during its flight.

There are a great many types of instruments used in rockets and missiles, and a great many uses to which they are put. Functionally they can be divided into three major categories, which together comprise most of the instruments commonly used. (There may be a few instruments, or a few uses to which instruments are put, that would not conveniently fall into any one of these three classifications, but they are fairly comprehensive.)

Instruments are used:

To control the flight of a missile or to control the functioning of certain mechanisms within it.

To measure or monitor the performance of the missile, its flight behavior, or the performance of certain mechanisms it contains, and to record this information *or* report it back to earth.

To measure and record, *or* transmit back to earth, information on environmental conditions the missile may encounter in its flight (e.g., temperature changes, cosmic ray bombardment, gravitational attraction, meteorite bombardment, wind and weather conditions, etc.).

For the amateur, of course, the number of instruments he can use, and the uses to which he can put them, are comparatively limited. Nevertheless, there is a considerable variety of them. The following examples may serve to illustrate the fairly broad range of instruments and instrument employments available to the amateur, most of which are already familiar to amateur rocket experimenters. (These are flight instruments, of course, not static test instruments.)

TYPES AND USES OF INSTRUMENTS IN THE AMATEUR FIELD

Altimeters for measuring altitude.

Accelerometers, both for measuring peak acceleration and changes in acceleration at different points in the trajectory.

Parachute ejection mechanisms.

Second stage ignition systems.

Igniter systems for tracking flares.

Tracking light assemblies.

Roll indicators.

Temperature measuring devices.

Air pressure measuring devices.

Cameras.

Gyro mechanisms.

Gravity and Inertia switches.

Telemetering systems (used for actuating many of the above devices, or for transmitting to earth the information they measure).

Telemetering and Doppler radar systems (used for tracking a missile or measuring its velocity).

In the case of the instruments included in this list which are intended to measure, or monitor, some atmospheric condition or performance factor, there must also be a means of *recording* the data measured, *or* a means of transmitting the data back to earth during flight. If a recording device of some type is used, then there must be some means of recovering the device after flight (if not the entire instrument package), and there must also be some means of protecting the recording instrument from damage due either to acceleration or impact on the ground. If neither a recoverable recording device, nor a telemetering system is provided, the measuring instrument itself is obviously useless, since you would never know what information it obtained.

Telemetering Systems and Safety: The use of radio transmitters and receivers for telemetering purposes in connection with amateur rockets is, of course, quite widespread. It is, also, an intensely interesting and challenging activity and the number of useful purposes it can serve is considerable. So far, amateur groups have barely scratched the surface of telemetering potential in a practical sense; but they are generally aware of the enormous variety of things that can be done by telemetering, and once given sufficient equipment and training in the basic principles of electronic transmission they display a great deal of ingenuity and inventiveness in the art. There is one use to which radio transmission can be put which is extremely dangerous, however, and which should never be attempted. That is the use of a radio signal to trigger an ignition system for any sort of explosive charge, whether it be ignition of the rocket propellant itself, ignition of the second or third stage of a multi-stage missile, or even the ignition of a separation or ejection charge, or a tracking flare.

The reason for this is rather simple, but it seems not to have occurred to many amateurs, with the result that some disastrous accidents have happened. While you can be reasonably sure that you have exclusive control of an electrical circuit, or other means of ignition, *you do not have control of the air waves.* Neither do you own them. Nor does any other person. The frequency that you must use for any civilian purpose is also available to millions of other persons for hundreds of uses; and any one of thousands of them may decide to use it at the same time that you want to, and in the same area. If you are using radio to ignite the propellant in any part of your rocket, some person miles away can inadvertently set it off while you are standing beside it. This has happened. In one case it sent four people to the hospital very badly injured. The four were clustered around a rocket already placed on the launcher while one of them connected the wires from a tiny radio receiver to the igniter for the second stage of the rocket. The instant the wires were connected the second stage ignited and the heat of the burning caused the entire rocket to explode. Somebody (nobody knows who, or how far away) was transmitting on the frequency for which the receiver was set. It received an impulse the moment it was turned on.

Instances of odd and unaccountable radio interference are so commonplace that they no longer cause much comment. Tiny five-watt transmitters will carry fantastic distances at times, for reasons that no one completely understands, as yet. In England, two years ago, a model airplane contest was held up for two hours while a ham radio operator in Des Moines, Iowa, chatted about nothing on the frequency used for remote control of the planes. A host of atmospheric, spatial and solar phenomena affect radio transmission in ways that scientists can only guess at, at present. Blasting operations are constantly threatened by radio interference. Radar sightings of "flying saucers" are believed, in some instances, to have been caused by strange airwave phenomena. The Civil Aeronautics Administration is seriously investigating the possibility that certain mysterious and unexplainable air crashes involving engine ignition failure were actually caused by errant transmissions from an unknown source, or some odd behavior of radio signals.

The Federal Communications Commission, in this country, is responsible for establishing regulations for control of radio transmissions and use of the air waves. But it can only establish regulations. It cannot actively control radio transmissions, and it certainly has no control over natural phenomena. It can enforce its regulations and take punitive action *after* a misuse of the air waves has occurred and been discovered. But it cannot prevent it from occurring. Moreover, it has established a citizens service band for the use of anyone who has the money to buy the equipment. No license is required, and no control of transmissions is exercised. With the introduction of this band the use of two-way radio equipment has mushroomed all over the country. Commercial and industrial concerns of all types use it. Boat owners, fleet owners, home owners and farmers use it. In addition the use of two-way radio transmission by municipal and state agencies increases yearly. State police organizations now use radio to control traffic lights over miles and miles of superhighways in order to save the cost of laying cable.

All of this increased activity on the air waves increases the likelihood that your radio signals will be interfered with. The amateur experimenter who wants to use radio must understand this and guard against it. And the best way to guard against a disaster is not to use radio at all for any purpose connected with propellants or explosives.

Protection of Instruments: Instruments, as a general rule, are delicate mechanisms sensitive to shock and easily damaged. If you wish to recover them from a spent rocket and preserve the information they have registered, you must take measures to protect them. They may be damaged either by the shock of sudden acceleration at blast off, or by the shock of impact with the ground. Very delicate ones may even be damaged by the relatively light impact of a landing by parachute.

Most anyone with a bit of imagination can conceive of methods of furnishing shock protection for delicate cargo, and with a little thought you can probably devise a system for ensuring the safe recovery of your instruments that will best suit your particular rocket and your particular instruments. As a guide to stimulate your imagination we will consider very briefly some of the methods and materials that are used by amateurs, or could be used by them. Bear in mind that none of these methods is necessarily suitable for all types of instruments. The nature of the mechanism itself, and the manner in which it has to function, will in large measure determine the type of protection that is best suited to it.

To begin with it is generally desirable to have instruments securely fastened to whatever housing they are contained in. This must be done with materials that are strong enough and of large enough gauge to withstand the extreme forces of acceleration and impact to which the rocket will be subjected. Don't underestimate these forces.

They can be one hundred times as powerful as the force which throws you to the floor when a train stops suddenly. A very fast race car may accelerate from 0 to 100 miles-per-hour in about eight seconds. This is an acceleration of a little more than half a *g*. A fair-to-middling amateur rocket may accelerate from 0 to 500-miles-per-hour in *one* second—forty times as fast and with a force of about 23 *g*'s.

This force can tear fastenings loose and shear bolts off. You must protect your instruments from this possibility. Packing your instrument chamber with cotton, sawdust, shredded paper or some similar material, may help to cushion the impact in the event the instruments do tear loose from their fastenings—providing such packing does not interfere with the normal functioning of the instruments. In other cases, filling the instrument section with wax, heavy grease, or even oil, may serve the purpose if the instruments are of the type that could operate in such a medium. Springs and miniaturized shock absorbers, elastic cables and other suspension devices are another possibility, but they may require a great deal of painstaking work.

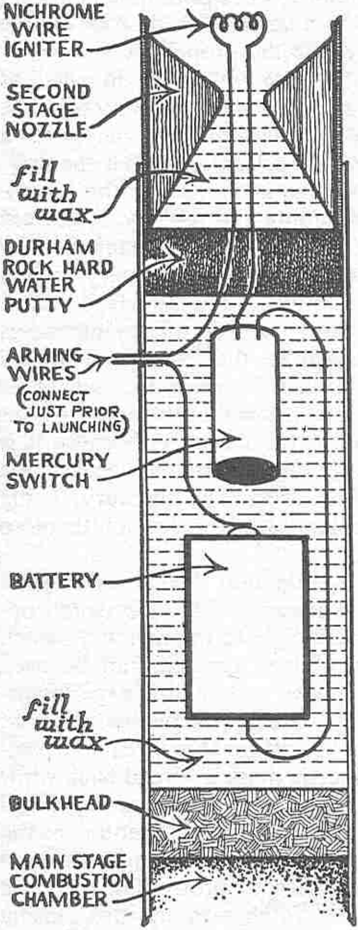
One of the best methods of ensuring the protection of instruments, if it can be done without interfering with their function, is to house them in a cylinder or package which is entirely independent of and separate from the structure of the rocket body. This instrument package can then be shock-protected in a variety of ways: by suspending it on springs or cables, fitting it with shock absorbers of the airplane-type, packing cotton or wool waste above and below it, or immersing the entire package in oil, grease or wax. If it is necessary for electrical wires to connect any instrument to another part of the rocket, this can be done providing the medium in which the package is immersed is not a conductor, or if the wires are well-insulated. An accelerometer housed in such a package would not give a true reading, of course, if there were any movement of the package in relation to the rocket body.

SOME SIMPLE INSTRUMENTS YOU CAN CONSTRUCT

Second-Stage Ignition Devices: A device for igniting the propellant in the second stage of a two-stage rocket is

ILLUSTRATION No. 33

A MERCURY SWITCH ASSEMBLY FOR SECOND STAGE IGNITION



THIS SECOND STAGE IGNITION SYSTEM IS SIMPLE AND RELIABLE— IT CAN BE CONSTRUCTED IN ANY SIZE DESIRED USING THE SAME BASIC DESIGN— ENTIRE SYSTEM CAN BE HOUSED IN 3/4 INCH DIAMETER CIGAR TUBE FOR SMALLER ROCKETS IF PENCIL-SIZED BATTERY IS USED— FOR LARGER ROCKETS USE FAST PRIMER CHARGE SUCH AS BLACK POWDER IN SECOND STAGE DUE TO SMALL CURRENT SUPPLY AND SHORT TIME OF CONTACT— IGNITION OCCURS IMMEDIATELY AFTER BURNOUT OF FIRST STAGE AS SUDDEN DECELERATION OF ROCKET ALLOWS MOMENTUM OF HEAVY MERCURY TO CARRY IT FORWARD TO CONTACT WIRES—

shown in Illustration *33*. The most important element in it is an ordinary mercury switch which you can easily make yourself if you cannot buy one. A small medicine vial, a cork and a few ounces of mercury is all that you need. For small rockets a penlight battery will do for the power source. The igniter itself should be the filament from a high-speed flashbulb, which does not require much current, and it should be imbedded in a small flash powder charge to insure sufficient heat to ignite the propellant.

The entire assembly should be imbedded in wax, as shown, to prevent breaking of the wires at blast off. The arming wires must not be connected until the rocket is on the launcher, and *in the upright position,* so that the mercury is not touching the contacts at the top of the switch.

The system operates very simply and reliably. Hundreds of two-stage rockets have been successfully launched by amateur groups using this device. The mercury switch actuates immediately after burnout of the first stage motor. The rapid deceleration of the rocket at this point causes the mercury to move forward in the switch (relatively speaking), and provide a contact between the two wires at the top. (Actually, what happens is that the entire rocket moves *backward* in relation to the mercury, because it is less dense and is more rapidly affected by the deceleration forces—both gravity and air drag. The mercury, being heavy, builds up greater momentum and reacts a little more slowly to the deceleration.)

A second type of two-stage ignition device utilizing an inertia switch is shown in Illustration *34*. This switch operates on a roughly similar principle to the mercury switch device. A cylindrical piece of lead or steel can be used for the inertia mass. You will have to do a little experimenting to determine just the proper weight for the inertia mass, and the proper strength for the spring. It is possible to calculate both, however. The inertia mass is forced backwards by the acceleration at take off depressing the spring to full compression. After burnout of the first stage motor, as the *g* forces decrease, the spring forces the inertia mass forward again. On its upward travel the cam protruding from the side of the mass pushes the switch arm upward closing the circuit.

Recording Accelerometers: Illustration *35* shows a simple

ILLUSTRATION No. 34

AN INERTIA SWITCH ASSEMBLY
FOR SECOND STAGE IGNITION

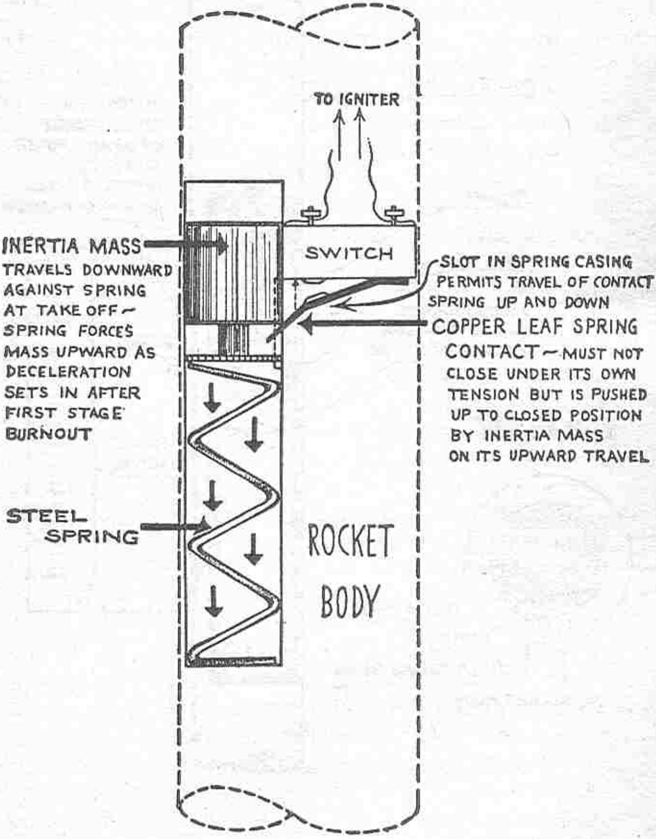
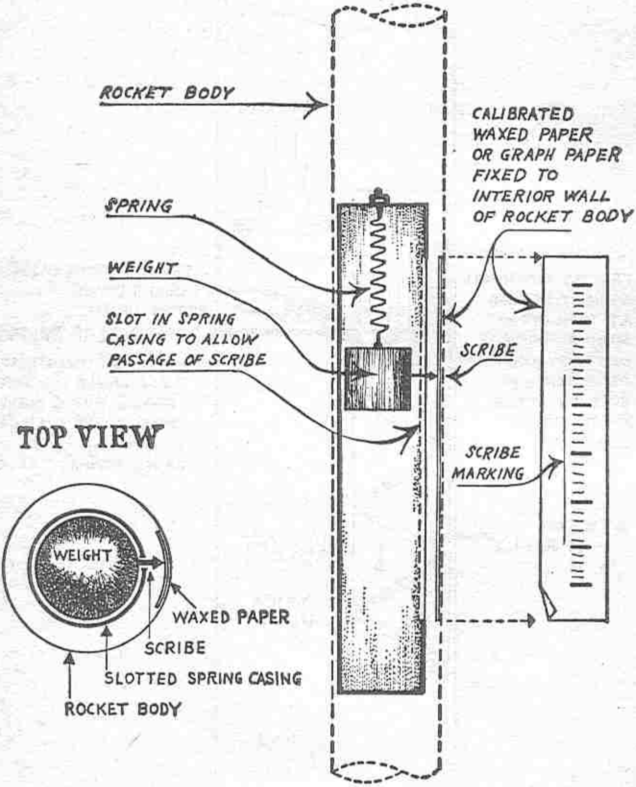


ILLUSTRATION NO. 35

SPRING SCALE ACCELEROMETER
WITH
RECORDING DEVICE



TOP VIEW

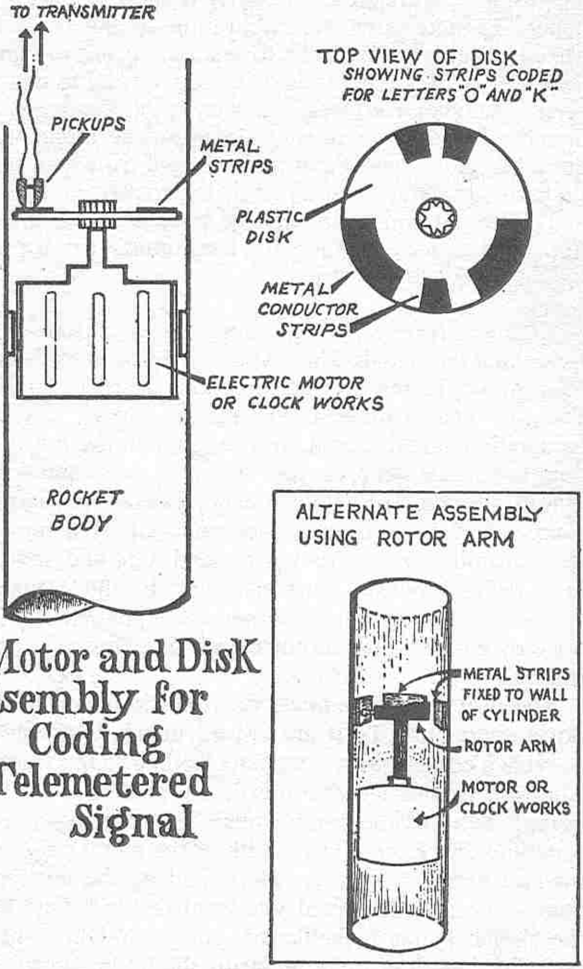
accelerometer which can be mounted in small rockets. The weight, or inertia mass, suspended from the spring moves downward under acceleration and the attached scribe (which can be a simple piece of wire bent to shape) records the distance traveled by the weight on a piece of waxed paper. To determine the calibration of the scale on the waxed paper you will have to test the spring to determine the number of foot-pounds of force required to extend it a given distance. Knowing the weight of the inertia mass attached to it, you can then compute the momentum required to move the weight that far, and from this calculate the peak acceleration attained by the rocket.

The weight and spring can be housed in a channel section, or in a piece of tubing if a longitudinal slot is provided for the scribe to travel in.

A Coding Disc for Telemetering: A simple arrangement for coding the signals which you may want to transmit from your rocket to the ground via radio is shown in Illustration *36*. The purpose of coding, of course, is to ensure recognition of the signal. If you get nothing but a steady hum or regular beep on your receiver, you cannot be sure that it is coming from your rocket and not from some other source. Coding is usually accomplished by arranging for the transmitter in the rocket to send long and short beeps in a definite pattern corresponding to the Morse Code symbol for one or more letters of the alphabet. This can be done by means of the motor-driven disc shown in the illustration.

The disc should be made of a plastic material which is not a conductor. To it are affixed metal strips which will provide a contact with the points leading to the transmitter. The disc rotates slowly, alternately making and breaking contact between the points, much as a rotor does in an automobile distributor. The length of the metal strips and the interval between them is determined by the dot and dash composition of the signal you want to send. One letter of the alphabet may be sufficient, but you might want to use two. The length of the *dash* strips should be approximately three times the length of those representing *dots,* in order to be able to distinguish clearly between them. If you use more than one letter, the interval between the two should

ILLUSTRATION NO. 36



A Motor and DisK Assembly for Coding a Telemetered Signal be about four times as long as the interval between symbols of a letter.

The motor unit used to drive the disc can be a small electric motor such as are available in hobby shops for model boats and planes, or it can be a small clock mechanism—either electrical or spring-driven. The latter is perhaps preferable because it is already equipped with a system of reduction gears which will move the disc slowly.

The same type of device can be constructed utilizing a hollow cylinder, instead of a disc, with the metal strips affixed to the interior surface in a ring. In this case the cylinder can remain stationary and a small rotor arm from a distributor can be attached to the drive shaft of the motor to revolve inside the cylinder. The motor, of course, is driven by batteries.

Miniaturized radio transmitters of the type used in model planes and boats are available in hobby shops.

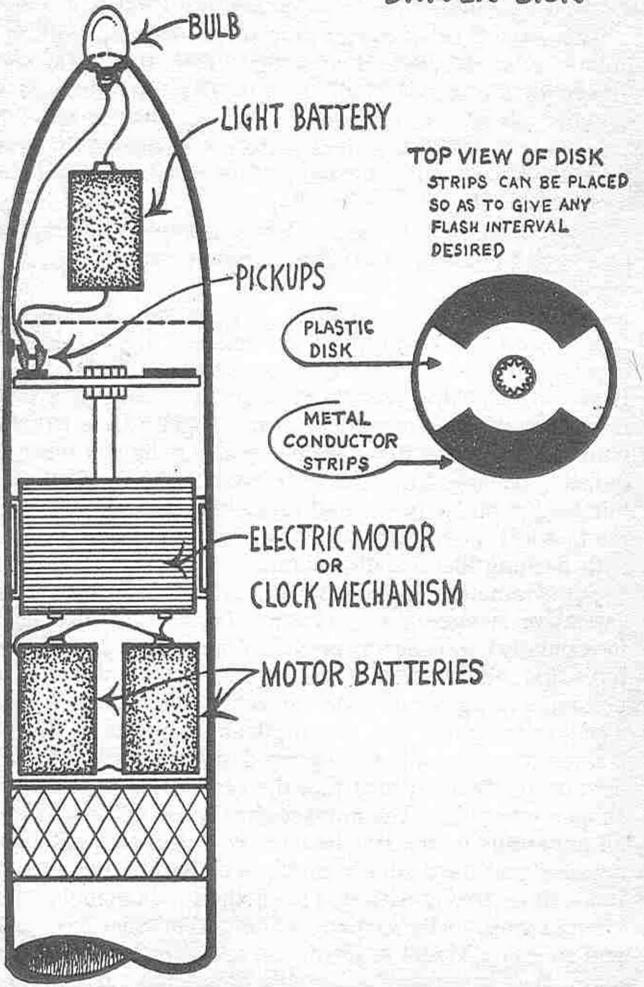
A Flashing Light Assembly: Illustration *37* shows the same type of revolving disc device used to provide intermittent current to a light bulb to achieve a flashing effect. If you are tracking rockets at night (as many groups do) it is more effective to have a flashing light source to follow with the eye than a steady beam. A steady light will become indistinguishable from the stars after it has reached a certain height, and may become very difficult to follow, despite the fact it is moving. This is why aircraft are now equipped with flashing identification lights.

Some amateur groups have devised complicated and expensive strobe-light assemblies (which are also heavy, incidentally) in order to provide a flashing light for tracking. This would seem to be an extravagant waste of expensive equipment in order to achieve so simple a result. The strobe-light is also a complicated apparatus, and it is a cardinal rule of all engineering design (particularly in the field of instrumentation) that the end product should be as simple as possible. The more sophisticated and complicated an apparatus is, the less likely it is to function effectively, because you have simply multiplied the number of things that can go wrong with it. This is the fundamental and significant reason why so many Vanguard missiles have failed, and so many Model A Fords are still running on the highways. It is also one reason why American car buyers are

ILLUSTRATION No. 37

A FLASHING LIGHT ASSEMBLY

UTILIZING MOTOR-DRIVEN DISK



turning in increasing numbers to cars of European manufacture which have fewer gadgets and fewer things to repair. Whatever else you do, try to keep your designs as simple as possible for every component of your rocket.

Speaking of simplicity, the light flasher described here is probably more complicated than necessary. Has it occurred to you that you probably buy a self-contained light flasher in the 5-and-10 cent store every year at Christmas time which will do the same thing? It costs a few pennies, is reliable, and operates on the simple principle of a circuit-breaking filament which is extremely sensitive to temperature changes and expands and contracts rapidly as the current pulses through it. Most of them are designed for 110 volt current, but they can be reworked, and they are also available in lower voltage ratings for use with electric trains. Try one in your rocket sometime.

Chapter 7

PREFLIGHT TESTING

Virtually any product of modern technology, or any commercial product of common use, is subjected to a rigorous series of tests before it is offered to the public for sale or put to its intended use. Testing programs are an important feature of any industrial effort and are the heart and soul of development work. Man has learned through bitter experience that it is virtually imperative to discover flaws and correct deficiencies in any new device *before* time, money and perhaps human lives are risked in putting it to practical use. Amateur rocketry, far from being an exception to this rule, is probably more affected by it than most fields of human endeavor.

If your rocket group hopes to be successful in its projects it must have a well-thought-out and objective testing program as a major activity. And any serious, scientifically-motivated group will soon find that more of its time and effort is expended in its testing program than in any other phase of its activities. In this chapter we will consider some of the purposes and methods of testing, and discuss a few of the simpler devices recommended for use in testing various components of amateur rocket systems. Many of these devices are already widely used by amateurs, and some of them were developed by amateurs.

WHY TEST?

Why should you test the various components of your rocket before launching it? There are many reasons, but one very obvious one is the simple fact that it is very foolish and shortsighted to make elaborate preparations for a launching only to see a very fine rocket assembly go up in smoke because just one part of it failed to function properly. This is a disheartening experience, particularly if the malfunction was due to some very minor defect which could have been corrected quickly and simply, if it had been known to exist. Such a fate befell a rather well-organized amateur rocket society in the Southwest a few years ago. Their experience, while seemingly inexcusable, is typical of the tendency of amateurs to concentrate on the big things and let the details take care of themselves. More than three months of work and an investment of fifty dollars had been put into a fine rocket, the sole purpose of which was to make it possible to track the rocket's trajectory at night by following a tiny light encased in the transparent nose cone. The rocket fired beautifully, but no one had any idea how high it went, or where it went (although it was recovered later)—simply because the bulb in the nose cone failed to light. Subsequent investigation revealed that the batteries provided for the light assembly had been put into the instrument section three months earlier, when work had first started on the rocket. Nobody had replaced them, *nor bothered to test them,* prior to the launching. They simply had no more life. However a good time was had by all, on the fifty-mile trip into the desert.

Among the specific reasons you should have a thorough and systematic testing program are the following:

To prove, or improve, design.
To establish material specifications.
To ensure proper performance of mechanical devices.
To determine performance characteristics of propellants and motor designs.
To avoid costly mistakes or disasters.

WHAT CAN YOU TEST?

Virtually every component of the rocket, and much of the auxiliary hardware and ground equipment can, and should, be subjected to some testing process to determine whether it can reasonably be expected to perform adequately and reliably the function for which it was designed. A great many testing procedures will require no special equipment and no special techniques on your part. Others will. For example, it is a very simple matter to pick up one of your field telephones, if you have them, and make sure that you can communicate with someone on the other end of the line. It is also relatively simple to determine whether your firing circuit is delivering sufficient current to ignite the propellant. These tests, or checks, simple as they are, should become a matter of routine with you, even though you may not consider them very important. Other tests, such as the measuring of thrust and burning time, may require fairly elaborate equipment and a considerable amount of ingenuity and inventiveness on the part of the members of your group.

The more important items that should be tested before a rocket system is fired in earnest, are the following:

Rocket Motor. The rocket motor should be tested to determine the thrust it develops, its burning time, its bursting pressure, its heat resistance and conductivity.

Fins. Fins should be tested for aerodynamic behavior and shear strength.

Diaphragms. Diaphragms should be tested to determine the pressure at which they will burst, and to determine whether they will shatter or melt.

Mechanisms. All mechanical devices must be tested to determine whether they will function under the conditions to which they are subjected, and to determine that they are in working order immediately prior to launching.

Igniters. Igniters must be pretested for their ability to produce sufficient heat, and examined for breaks and short circuits.

Propellants. Propellants must be tested for burning rate, heat of combustion, means of ignition, etc.

Bulkheads. Bulkheads should be tested for shear strength and heat resistance.

Launching Rack. Launching racks should be tested for stability, whip, and accuracy of angle of elevation.

In addition to the above, all batteries, switches, electrical circuits and other electronic devices must be tested initially to ensure that they will perform their assigned functions, and then examined carefully prior to actual use to ensure that they are in operating condition.

Generally speaking, there is a means of testing almost any device in such a manner as to give reasonable assurance that it will function. You may have to use your ingenuity in some instances, but that is part of the challenge. Most tests are based on simulating, as closely as possible, the actual flight to which a part or a device may be subjected. The degree to which this can be done is an important factor affecting the validity of the test, naturally, but there are other ways of compensating for an inability to duplicate operating conditions precisely. Repetition of a test pattern many times over, or correction of test results to allow for differences in conditions are two such methods.

Also, a little thought and imagination devoted to any testing problem will generally result in some method being devised that reasonably meets the requirement. Right at present it is not possible to duplicate the conditions in every respect that the Project Mercury Astronauts will encounter on the first trip into space; but scientists are doing a pretty good job of conditioning them with the centrifuge, pressure chamber, submersion in tanks, etc. You must use similar ingenuity in developing testing procedures.

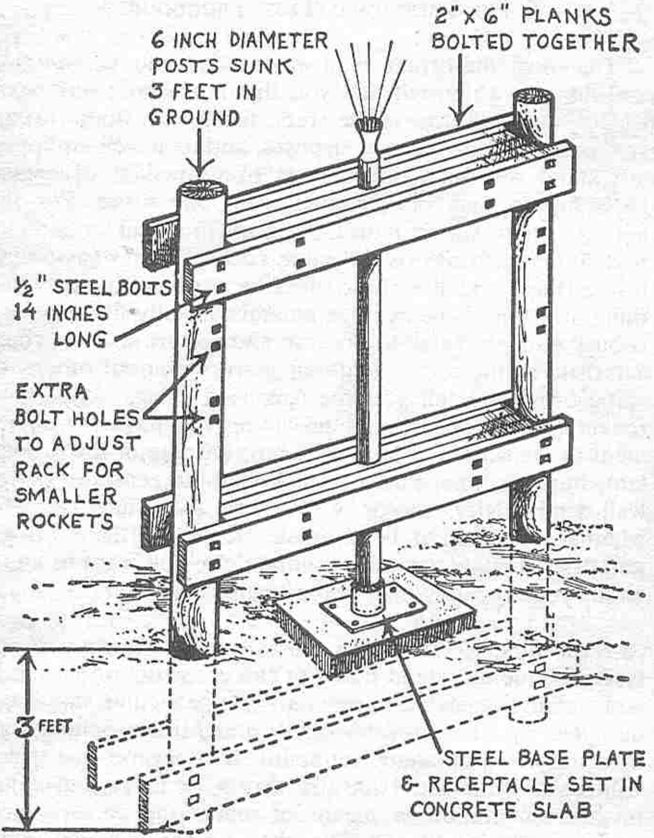
SOME SIMPLIFIED TEST PROCEDURES

The most important type of test for you to conduct, and the one which will tell you the most about how your rocket may perform, is the static firing test. Static firings are conducted for several purposes, and on a well-equipped test stand several measurements of propellant or engine performance may be obtained from one firing. For the amateur, however, it is usually more practical to conduct several static firings of the same rocket engine (assuming it stands up) and attempt to measure or determine only one thing at a time. The average amateur usually finds that he is busy enough trying to observe and record just one characteristic of the rocket, without worrying about others. A static firing can tell you the following things about your rocket (or the propellant) providing you have the equipment to measure and record it: burning rate of the propellant, burning time, thrust, motor wall-temperature, motor wall-conductivity, motor wall-stress, total impulse, and whether combustion is complete. Knowing these things, you can calculate virtually anything else you want to know about your rocket's propulsion characteristics.

A Basic Static Test Stand: Illustration *38* shows you one type of static test stand that you can construct rather easily with readily available materials. This particular stand was designed by The Army Artillery and Missile School staff as a suggested amateur test stand. It is a good one which will easily withstand 1000 lbs. thrust, or more, but it has no instrumentation or means of measuring performance, consequently it will not serve the purpose of determining the thrust of your rocket. Burning time, and burning rate, however, can be determined easily with a stopwatch or

ILLUSTRATION NO. 38

A Basic Static Test Stand



STAND SHOULD BE EMPLACED IN A PIT OR SURROUNDED BY A BARRICADE TO HEIGHT OF ROCKET NOZZLE movie camera, and temperature and strain gauge readings could be taken on this type stand simply by using the equipment shown in Illustration *43*. It is also satisfactory for making tests of diaphragms and igniters, and can be used to observe the burning characteristics of different propellants, photograph exhaust jets, or test the heat resistance of nozzles.

Static tests performed on a stand of this type need not necessarily be done in the wide open spaces. Any reasonably open area will serve as a suitable location for a static test stand, providing the stand is properly revetted or recessed in the ground. Bear in mind, however, that noise and shock waves from even a small rocket engine can cause considerable annoyance and can break windows and dishes in near-by buildings. Wherever you do establish a static test facility, make certain that you have the permission of authorities and the concurrence of near-by property owners.

The stand shown in Illustration *38* should be either emplaced in the ground or a barricade built around it to a height slightly above the nozzle exit of the largest rocket you expect to test in it. Overhead covering is not essential as fragmentation from an explosion is always radial in direction—that is, the force of an explosion is always directed at right angles to the longitudinal axis of the exploding vessel and any fragmentation will follow this path. Of course, there is always the possibility that a nozzle may be blown out of the tube of a test vessel, and in this instance the path of flight would be straight up in the air. For this reason, overhead cover of substantial thickness must be provided on any personnel bunker used for test observation, and such observation should be by camera, periscope or mirrors, only. No direct observation of static tests should ever be permitted, except perhaps through a telescope from a distance of 200 feet or more.

All things considered, this type of test stand is probably the safest that can be devised. Since the direction of thrust is downward into the ground, it is very unlikely that the rocket would do anything but bury itself should anything go amiss. In the event the forward bulkhead, or nose-cap, should blow out, the direction of thrust would be reversed, of course; but unless the nozzle were completely clogged, gas would be escaping at both ends of the vessel and the amount of thrust upward would be considerably reduced. At the very worst, even with full thrust upward, the stand should be able to hold the rocket in place. Another advantage of this type of stand is the fact that the rocket is already in the ideal position for safest loading (See Chapter 8), so that it is unnecessary to move or handle the rocket in any way after loading has been accomplished.

Thrust-Measuring Devices: Several simple thrust-measuring devices are shown in Illustrations *39* through *41*. A great variety of similar designs are possible and are already in use by amateur groups. After a study of the ones presented here you can probably design one of your own which will best suit your purposes. The most commonly used measuring devices are the simple spring scale and a hydraulic system of some sort utilizing a standard pressure gauge. The system is usually designed so that the test engine either pushes against a heavy plate or pulls against a cable to register its thrust. In all cases the rocket engine must be securely lashed to some sort of movable bed. The problem of allowing free movement (within limits) of the rocket is solved by several means. In some cases the engine is mounted on roller skate wheels which move in a track. In others it is mounted on a flat bed which is supported on pivoted legs that allow a certain forward and backward movement of the entire bed. Sometimes the same type of bed is suspended from a beam. Still another type of device allows the rocket to ride free on a taut cable.

Whatever type of thrust device you design, there are two important things to keep in mind. One is that the rocket engine must be rigidly held in place so as to allow it movement in only one direction—forward. No sidewise movement can be permitted, or the rocket is apt to whip around when it meets resistance and tear loose from its moorings. Also, the clamps or other devices which hold the engine in place must be unusually strong and so tightly secured to the engine that there is no play in any direction. A rocket engine under full thrust is likely to develop very severe vibrations and *chattering*—particularly if the nozzle is not well-designed—and when this occurs it will tear itself loose if not securely held in place. The second important thing to keep in mind is that the propulsive force developed by

ILLUSTRATION No. 39

A Simple Thrust Measuring Device
FOR SMALL ROCKETS

THIS TYPE DEVICE CAN BE BUILT
TO ANY SCALE DESIRED ~ SPRING SCALES WITH
CAPACITIES OF 25 TO 100 POUNDS ARE READILY AVAILABLE ~
CONSTRUCTION SHOULD BE
HEAVY AND RUGGED ~

***DON'T** UNDERESTIMATE POWER OF YOUR ROCKET !*

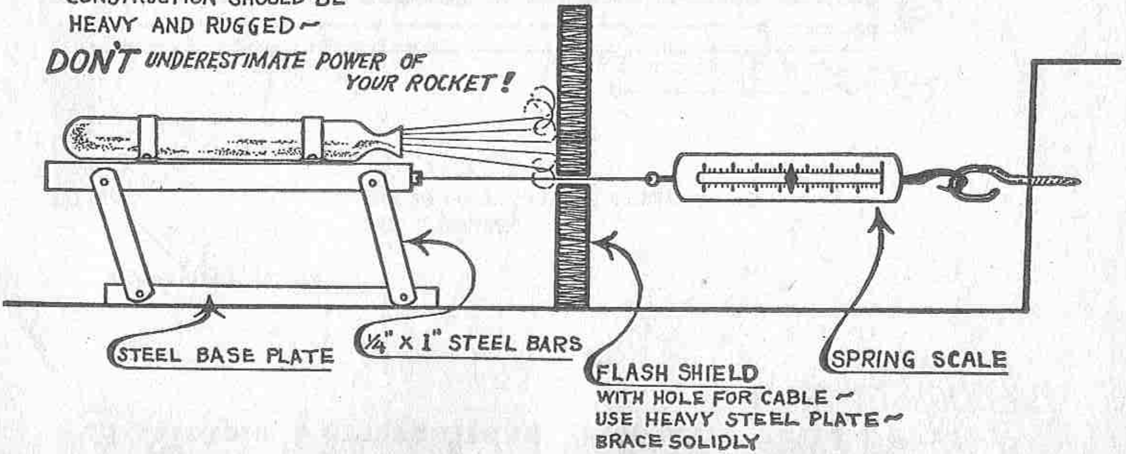


ILLUSTRATION NO. 40

A Simple Thrust Stand With Recording Device
FOR SMALL ROCKETS

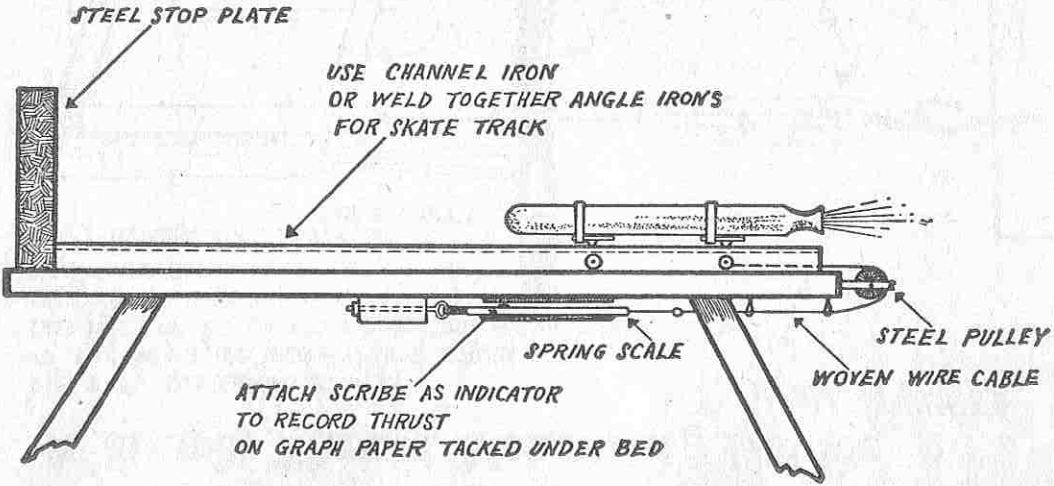
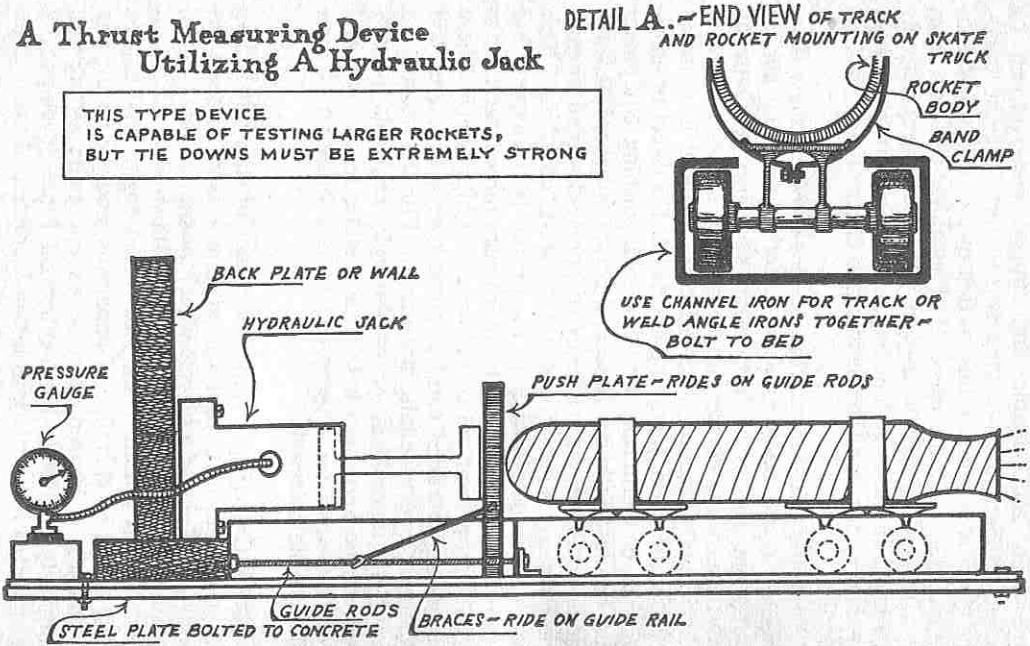


ILLUSTRATION No. 41



A Thrust Measuring Device Utilizing A Hydraulic Jack

THIS TYPE DEVICE
IS CAPABLE OF TESTING LARGER ROCKETS,
BUT TIE DOWNS MUST BE EXTREMELY STRONG

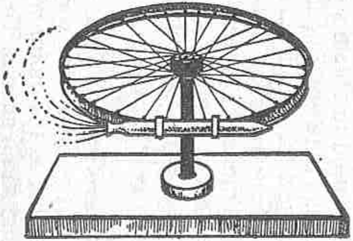
DETAIL A.—END VIEW OF TRACK AND ROCKET MOUNTING ON SKATE TRUCK even a small rocket is about one hundred times as great as you imagine, if you have never seen one fired. Test stands similar to the one shown in Illustration *40* above have been bent double and flipped end-over-end by rocket engines no more than two to three feet in length. The effect is roughly similar to that of a motorcycle crashing into the stand at a speed of about thirty miles an hour. To withstand this terrific impact your stand must not only be rugged in construction, but securely anchored as well. Embedding the stand in a heavy slab of concrete is the best solution.

All of the thrust-measuring devices shown in these illustrations should be housed in a static firing bay similar to the one shown in Illustration *46*. Since virtually all thrust-measuring devices are designed to measure thrust in a horizontal direction, protective barricading is required in every direction, including overhead. No direct observation can be permitted, and fire extinguishing equipment must be close at hand. A second common hazard of static engine testing is the tendency of poorly-designed engines or improperly mixed propellants to start "chunking." This occurs when combustion in the engine is incomplete but pressure in the test vessel is sufficient to force large chunks of solid propellant out of the nozzle at high speed. These still-burning particles can be spread over a wide area and constitute a very definite fire hazard. For this reason, no propellant ingredients or combustible materials of any kind can be kept anywhere near a static testing bay and overhead cover on a personnel bunker must be of non-inflammable material.

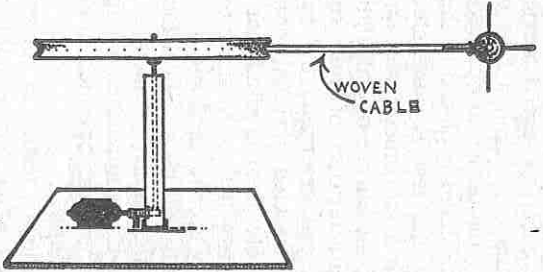
A Rocket Centrifuge: Another means of statically testing the performance of your rocket engine is to strap it securely to the rim of a bicycle wheel, or similar contrivance, mounted as shown in the sketch in Illustration *42*. Naturally, there is a limit to the size rocket engine that can be safely tested on this type of apparatus, and the testing bay in which it is housed must be exceptionally strong and completely enclosed. The centrifugal force developed by the rocket in its revolutions is considerable and the method of lashing the rocket engine to the rim of the wheel must be strong and secure. The axle on which the wheel rotates should be oversized to withstand the outward pull of the

ILLUSTRATION NO. 42

USING A BICYCLE WHEEL AS A CENTRIFUGE
FOR IMPULSE AND AERODYNAMIC TESTS



SMALL ROCKETS MAY BE LASHED TO RIM OF TIRELESS WHEEL FOR TOTAL IMPULSE, VELOCITY & BURNING TIME TESTS ~ BY CALCULATING ANGULAR MOMENT OF WHEEL YOU CAN DETERMINE IMPULSE ~ USE TACHOMETER AND ODOMETER GEARED TO SHAFT TO GET SPEED AND DISTANCE ~



POWER WITH ELECTRIC MOTOR & HIGH SPEED GEARS ~ OR WITH A SMALL ROCKET ~ TO FLIGHT TEST ROCKET SUSPENDED FROM CABLE ~

CONSTRUCTION OF THIS DEVICE MUST BE HEAVY AND RUGGED ~ OPERATE ONLY IN COMPLETELY ENCLOSED AREA, HEAVILY BARRICADED ~

rocket, should have no wobble and be as frictionless as possible.

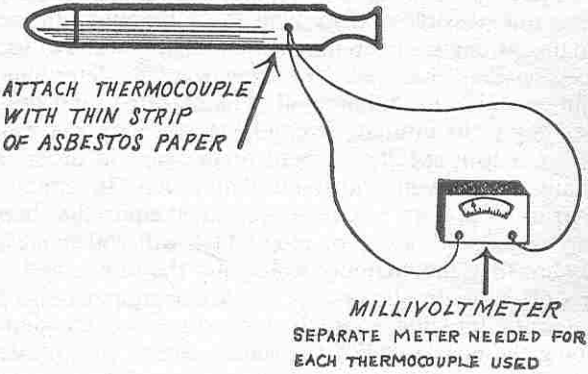
Very little, if anything, can be observed of the character of the exhaust jet with a testing device of this type, and it may not be possible to calculate or record burning time accurately. Even a high-speed movie camera would probably catch little more than a blur of light on its film in photographing the device in operation. But if a clock with a sweep second hand is placed in the field of vision of the camera when the test is conducted, and the device is equipped with a tachometer and an odometer, you have the means of measuring or calculating many of the performance characteristics of your rocket. From the data obtained you can determine the velocity, total impulse, total distance traveled, residual momentum of the rocket after burnout, etc. Bear in mind that the exhaust fume and smoke problem will be something to contend with as far as photography is concerned and the placement of cameras and instruments will be a critical factor as well as proper ventilation of the bunker. Remember, also, that this could be a very dangerous apparatus if improperly used. Such a device should never be operated in any place other than a well-fortified bunker.

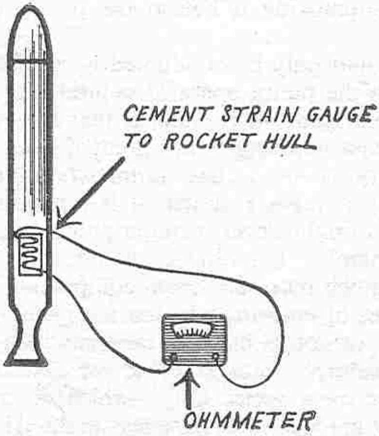
In addition to the testing of rocket engines, this type of device can have other very valuable uses, just as a centrifuge has. Whether powered by a rocket engine or an electric motor the apparatus could be used to obtain some idea of the ability of mechanical devices to perform under acceleration. You can also use it to test the aerodynamic stability of fin designs and hull configurations by attaching your rocket, or scale model, to the rim of the wheel with a short length of cable in order to allow it relatively free flight. This would do as good a job as any wind tunnel you could devise.

Measuring Motor Wall Temperature and Stress: Illustration *43* shows you the method of measuring wall-temperature and stress at various points on the motor wall through the use of thermocouples and strain gauges. The latter can be obtained from any engineering laboratory or supply house. The millivoltmeter and ohmmeter are common items of electrical supply. Wall-temperature changes and the conductivity of the chamber casing can also be meas-

ILLUSTRATION No. 43

MEASURING CHAMBER WALL TEMPERATURE AND STRESS





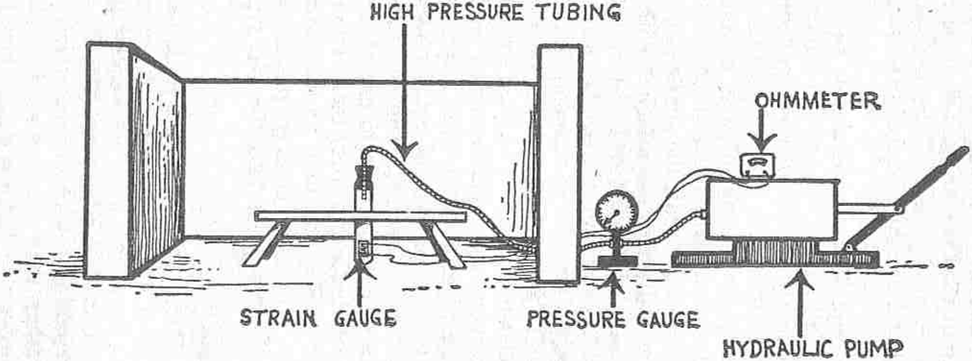
ured to a certain degree through the use of temperature paints. These paints are commercially available and are designed to change color or melt and run at specific temperatures. By establishing a pattern of them along the outer surface of the combustion chamber you can get a pretty good idea of the rapidity with which heat reaches the outer surface and follow the progress of heat transfer as burning progresses longitudinally up the chamber.

A Device for Testing Bursting Strength: Illustration 44 shows one possible arrangement for determining the actual bursting strength of tubing which you may want to use for a combustion chamber. You may want to determine the point at which the tubing will actually burst, and thus get a reading of its ultimate strength, or you may just want to subject it to a specific amount of pressure in order to be certain that it will withstand that much. In conducting either of these tests, of course, you must equip the chamber being tested with a cap or plug which will withstand more pressure than the chamber walls, and the tubing and other parts of the hydraulic system you are using must also have a superior bursting strength. One suggested technique is to plug the nozzle end of the rocket engine with plaster of paris. This would have to be done by immersing the nozzle end in the wet plaster with the hydraulic tube already inserted, and then removing it before the plaster is completely set.

Such a test should only be conducted in a heavily revetted cubicle with the pump operator behind a thick steel plate or similar barricade. It is claimed that the explosion effect when the case ruptures is not great if both the test chamber and the pump system are *completely* full of liquid when the bursting point is reached. It is not practical to achieve this condition, however, without pumping all of the air out of the chamber beforehand, and this is scarcely feasible without much more elaborate equipment. Besides, you have no means of knowing whether the system is completely free of air, or not. A bursting tank can be a dangerous thing. Two soldiers were killed at an eastern Army post one summer by a water tank—which is ordinarily considered a very innocent and harmless thing. They were filling a truck-mounted tank from a water tower when it suddenly exploded, hurling jagged steel fragments in all

ILLUSTRATION NO. 44

DETERMINING BURSTING STRENGTH OF A CHAMBER



PLACE CHAMBER UPRIGHT IN A RACK ~
(FRAGMENTATION FROM A BURST IS ALWAYS RADIAL IN DIRECTION)
PLUG NOZZLE WITH PLASTER OF PARIS ~
COMPARE PRESSURE READINGS WITH STRAIN GAUGE READINGS
ON OHMMETER AS PRESSURE RISES ~

directions. The men had forgotten to remove the bleeder cap which allows air to escape from the tank as water is let in.

If you don't want to put together a piece of apparatus as complex as this, you can still give your rocket engine a pretty good pressure test with an ordinary grease gun of the type used to lubricate machinery. Such a gun will produce pressures up to 10,000 pounds. The same precautions should be taken as in the case of the hydraulic system, though the likelihood of a high degree explosion is less.

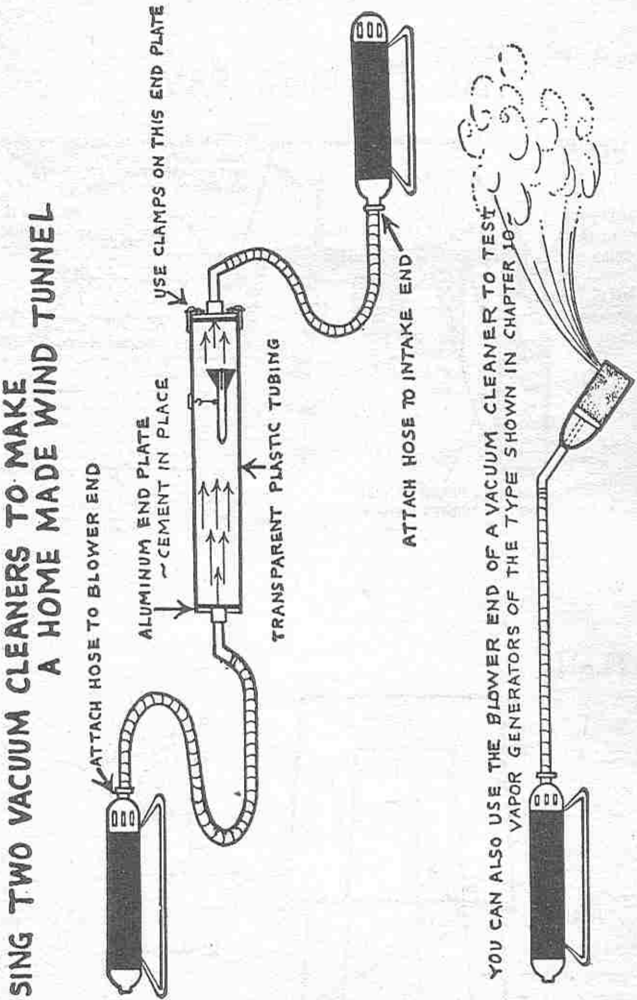
A Home-Made Wind Tunnel: A simple rig for creating a low velocity wind tunnel is shown in Illustration *45*. Plastic tubing of the type shown is now available in a considerable range of sizes. The plates at either end of the tunnel can be made by you out of steel or aluminum, or you may be able to find ready-made discs with the proper size receptacles to accommodate the nozzle of your vacuum cleaner hose. The end plates are attached with a bonding cement. The vacuum cleaner at one end blows the air in and the other one sucks it out of the tube. Scale models of rockets and fin assemblies can be suspended from the hook protruding through the top of the plastic tube.

One vacuum cleaner alone can be used for testing liquid vapor generators such as the one described in Chapter 10.

You can, if you wish, build an even larger wind tunnel by using two window type fans of equal power, and any large cylinder such as a barrel, oil drum or discarded water tank. In this case you would have to cut observation slits in the sides of the cylinder and cover them with transparent plastic. If you are lucky, you may be able to find a very large transparent cylinder of glass or plastic, such as are used to enclose barber poles and the old type gasoline pumps.

A Static Testing Bay: A design for a static testing bay is shown in Illustration *46*. A good deal of the construction can be done with sandbags, as in the case of most of the emplacements described in Chapter 8. Sandbags have the advantage of presenting a wall surface which will absorb fragmentation rather than ricocheting it. Sandbags will catch on fire, however; so that it is a good idea to wet them down thoroughly prior to any test firing, or to treat them

ILLUSTRATION No. 45

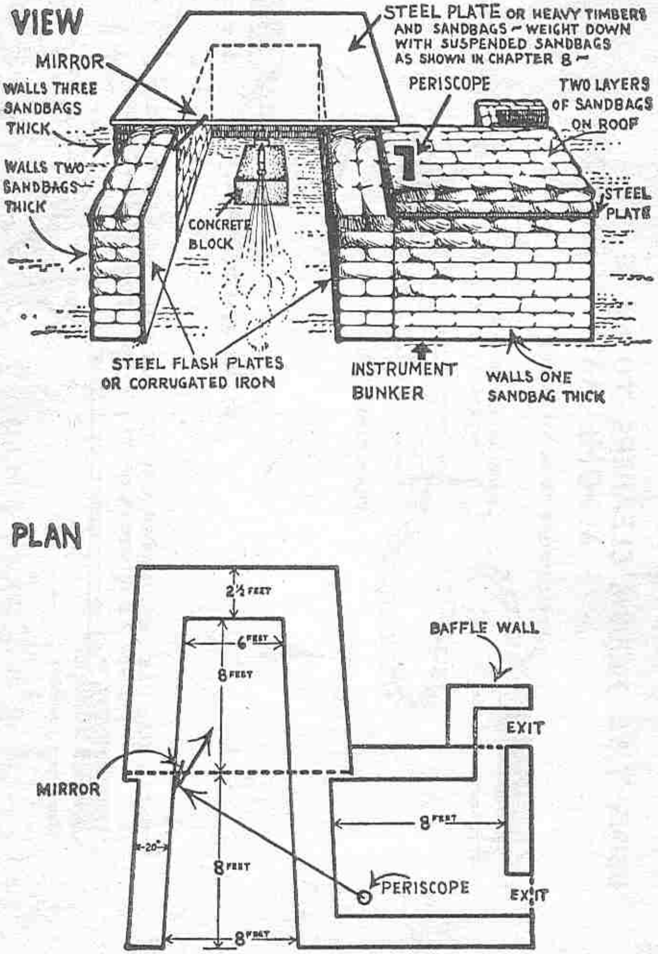


USING TWO VACUUM CLEANERS TO MAKE A HOME MADE WIND TUNNEL

YOU CAN ALSO USE THE BLOWER END OF A VACUUM CLEANER TO TEST VAPOR GENERATORS OF THE TYPE SHOWN IN CHAPTER 10

ILLUSTRATION NO. 46

A SUGGESTED
STATIC TESTING BAY



with some fireproofing compound. A testing bay should be well vented and should always have an open side in the direction that the exhaust gases are propelled. The open side should be on the side of the bay opposite to the prevailing winds so that exhaust fumes are dissipated as rapidly as possible. A baffle wall can be constructed at a reasonable distance from this open side so as to stop any solid object, such as a blown out nozzle, that may fly in that direction.

The rapid dissipation of fumes, smoke and other exhaust products is an important factor in the efficient functioning of any static testing facility. Not only do the fumes obscure observation and make the recording of test data difficult, but they may also be a toxic hazard for personnel exposed to them, and it is even conceivable that a heavy enough concentration of such fumes could result in a secondary explosion of considerable violence. Whenever static firings are in progress it is a good idea to allow a long enough interval between tests to ensure that fumes and tiny dust particles from previous firings are dissipated and have not accumulated in the immediate area of the bay.

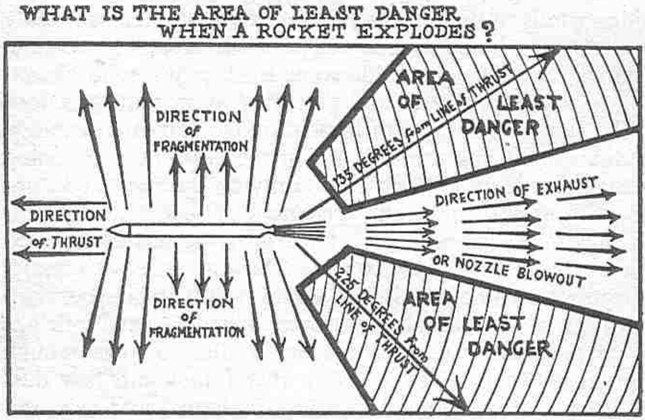
Another important feature of a testing bay is a means of rapid exit for any personnel in the observation bunker. In the event of fire, or sudden concentration of noxious fumes, serious injury may be prevented if all persons are able to leave the area immediately. Never construct any kind of a bunker or shelter that has a bottleneck entrance.

TRAJECTORY CALCULATIONS

After you have designed and constructed a rocket, and then subjected it to some of the tests outlined in this chapter in order to get an idea of how well it will perform, you will probably want to be able to predict how high it will go and what sort of a flight pattern it will follow before you take it out to a launching site to flight test it. You will need to know the approximate maximum anticipated performance of the missile, because many of the actions and preparations you initiate at the launching site are predicated on what you expect your rocket to do. To cite an obvious example, you don't even know how large a launching site is needed until you have some idea of what your rocket's ultimate altitude and range might be.

Chapters 8, 9 and 10, which follow, cover the basic

ILLUSTRATION No. 47



requirements for the design of a good launching site and the procedures you should follow in launching your rockets and in tracking and evaluating their performance. Chapter 8 treats very briefly with the question of the maximum *lateral* range of a rocket and presents a very simple formula for calculating it, as a guide in determining the land area required for launching. But for those of you who would like to know a little more about how the complete trajectory of a free flight missile is calculated, a simplified version of the computations involved is presented here. This version was prepared by the Propulsion Research Division of the Mechanical Engineering Department at the Polytechnic Institute of Brooklyn expressly for students of high school age. It eliminates from consideration some of the factors affecting the flight of a free ballistic missile, and it assumes that the angle of flight (in reference to the vertical) remains constant throughout the powered portion of the flight and that this angle is an extension of the angle of the launching rack.

The following symbols are used in the computation:

c	effective exhaust velocity
g	gravitational acceleration at earth's surface (32.2 fps)

H	Height, or altitude (maximum)
h_b	height at burnout
$\ln$	logarithm
M^*	$\dfrac{\text{initial weight}-\text{burnout weight}}{\text{initial weight}}$
Q	angle of flight at burnout
t	time (in seconds)
t_b	time at burnout, or time of powered flight
v	velocity (fps)
v_b	velocity at burnout
Y	launching angle
cos	cosine
sin	sine
tan	tangent

A SIMPLIFIED METHOD FOR COMPUTING OVER-ALL FLIGHT PERFORMANCE OF SMALL MISSILES

In order to maintain maximum simplicity in the calculation of the missile's trajectory, certain assumptions have been made. First, it has been assumed that the path of the vehicle, up to the instant of burnout, is linear: i.e., this portion of the trajectory may be approximated by a straight line. Secondly, the deviation from the vertical over this path shall not exceed five degrees. Finally, the equations shall not include drag terms.

The entire trajectory assumed for the vehicle is shown by the sketch in Illustration *48*. For the sake of clarity it is broken into three segments, each of which is discussed separately, and then tied together at the end of the discussion.

For the powered portion of flight, if the average deviation from vertical flight is denoted by the angle Y, and if the orientation (flight attitude) of the vehicle at burnout is taken as equal to this angle, then the cutoff, or burnout, velocity at the end of the burning time (t_b) is :

$$v_b = [-c \ln(1-M^*)-gt_b+v_o] \cos Y$$

where: c is the effective exhaust velocity in fps (See Chapter 4 for calculation of this value)

g is the gravitational acceleration (32.2fps^2)
v_o is the initial velocity (fps)
M^* is the ratio $\dfrac{\text{init. wt.—burnout wt.}}{\text{initial weight}}$

If the initial velocity (v_o) is zero, as in the case of unboosted firing, this term is dropped and the equation reduces to:

$$v_b = [-c\, ln\,(1-M^*)-gt_b] \cos Y$$

The height (h_b) at the end of burning can be found by the equation:

$$h_b = \left\{ ct_b \left[1+\frac{1-M^*}{M^*}\, ln\,(1-M^*)\right] - \tfrac{1}{2}\, gt_b^2 + v_o t_b + h_o \right\} \cos Y$$

If all elevations are taken with respect to ground level, then h_o is equal to zero, and again letting v_o equal zero, the equation can be re-written as:

$$h_b = \left\{ ct_b \left[1+\frac{1-M^*}{M^*}\, ln\,(1-M^*)\right] - \tfrac{1}{2}\, gt_b^2 \right\} \cos Y$$

The total horizontal distance traveled during the period of powered flight (x_1) is then:

$$x_1 = h_b \div \tan Y$$

Once these values have been determined, a simple trajectory analysis for a regular projectile is applicable.

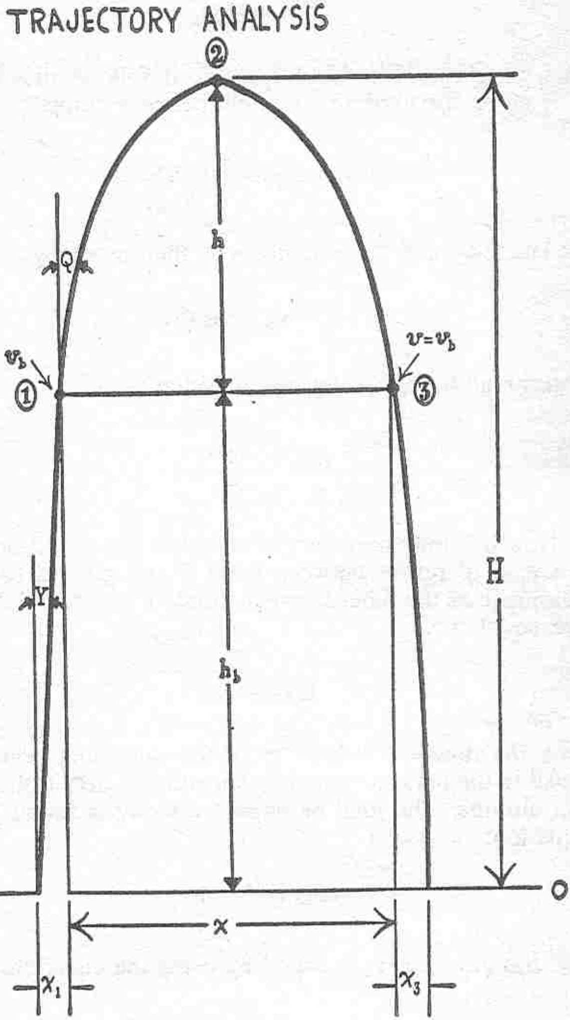
All values are now measured from the instant of burnout. The time (t_2) in which the projectile reaches the apex of its flight is found by the relationship:

$$v_b \sin Q = gt_2$$

During this period the projectile rises to a height *over the altitude at burnout,* represented by h, and given by the relation:

$$h = \tfrac{1}{2}\, gt_2^2$$

ILLUSTRATION NO. 48



The time required for the projectile to reach point 3 in the diagram is given by:

$$-h = \tfrac{1}{2} g t_3^2$$

and since the altitudes are equal, it follows that $t_2 = t_3$. Therefore, the total time of flight between points 1 and 3 is

$$t = t_{1\text{-}3} = 2t_1 = \frac{2v_b \sin Q}{g}$$

The length of the distance x is then given by:

$$x = v_b\, t \cos Q$$

and the altitude, h, may be re-written as:

$$h = \frac{v_b^2 \sin^2 Q}{2g}$$

Now it is only necessary to calculate the conditions over the path of return between point 3 and ground level, O. Inasmuch as the times between points 1 and 2, and 2 and 3 are equal, i.e.:

$$t_{1-2} = t_{2\text{-}3}$$

then the downward velocity of the missile at point 3 is equal to the burnout velocity. The altitude here is the burnout altitude. The *final* or *impact* velocity is found by the equation:

$$v^2_f = v^2_b + 2gh_b$$

and the distance x_3 is found by using the equation:

$$x_3 = h_b v_b \sqrt{\frac{2}{gh_b}}$$

The time required to traverse this final segment is:

$$t_f = \frac{v_f - v_b}{g}$$

and the total time of flight, from the time of firing to impact is:

$$T = t_b + t_{1\text{-}3} + t_f \text{ or } T = t_b + \frac{2v_b \sin Q}{g} + \frac{v_f - v_b}{g}$$

The total range, X, is then found by summing the segments x_1, x and x_3. Thus:

$$X = x_1 + x + x_3$$

or

$$X = \frac{h_b}{\tan Y} + v_b\, t_{1\text{-}3} \cos Q + h_b v_b \sqrt{\frac{2}{gh_b}}$$

Chapter 8

LAYOUT AND CONSTRUCTION OF THE LAUNCHING SITE

Launching is the high point in rocket experimentation, the ultimate thrill for the researcher. There is little sense of achievement to be gained from the design, construction and testing of a rocket which ends up as a static display. For this reason safe proving grounds must be provided where well organized and serious research groups can launch rockets that have passed all preliminary tests.

You have been given some pointers in Chapter 1 on how to go about establishing an authorized launching site, how and where to seek sponsorship and the importance of coordination with the proper authorities. Do not neglect these things. Do not attempt to launch your rockets without adequate facilities, sufficient preparation, proper supervision and official permission.

This chapter and the one which follows are written for those who have met these requirements. They present the best available information on launching techniques and safety precautions for student researchers. Read the chapters carefully, study the drawings closely and follow the instructions given. Reread them frequently to make certain you have missed no important point. Prepare a checklist to make sure you have overlooked no essentials in building your launching site and in the procedures you establish for firing operations.

Remember also that while the launching may be the thrilling climax of your work, it is not the ultimate goal. It is only the final step in reaching that goal, which is to study the behavior of the rocket in flight, to record and analyze the information provided by the instruments you have built into it and then to evaluate what you have learned from the rocket. Take this final step carefully and with deliberate seriousness or it may prove to be your last.

PRIMARY SAFETY CONSIDERATIONS

Before you begin to build a launching site you must think seriously about the dangers involved for yourself and the public, and about how to avoid or minimize them. There are some basic elements which promote safety and reduce the likelihood of accidents. You will find them wherever dangerous conditions require the continuous observance of safety practices—rifle ranges, blasting areas, chemical plants, etc. Learn these safety elements by heart. Get in the habit of thinking in terms of them and of constantly asking yourself whether you are observing them in every phase of your operations. They are:

Remoteness: Be as far from the point of danger as you reasonably can while still controlling the operation.

Cover: This is the military term for any object or condition which provides physical protection for the man exposed to danger. Trees, rocks, gullies, foxholes, bunkers, trenches and sandbags are forms of cover. So is the ability to "hit the ground" automatically when an explosion occurs.

Provide plenty of cover for your group and use it.

Limited Observation: No one should be permitted to watch a dangerous operation whose presence is not essential to its success. Those who *must* watch should do so only from behind protective barricades.

When viewing the launching, cover bunker slits with shatterproof glass or use periscopes.

Assignment of Tasks: Probably nothing is more conducive to safety than orderly procedure. Confusion is the helpmate of disaster.

Make certain that everyone in your group knows his job and knows which jobs are the responsibility of others. Don't permit arguments about assignments. Assign one man to each job and hold him responsible for it. Be sure every job is covered.

One-man Control: It may not be democratic, but it is efficient. On a ship, in an airplane, in almost any military operation, and at professional rocket launchings, one man is boss. His word is law.

Your group must decide who is to be boss at your launching site. Nothing should be done until he gives the order for it. His decisions must be obeyed.

"Scouts Out" Security: Safety for the public demands extra precautions. You must consider the hazard your operations present to other persons.

Put guards at strategic points of observation to warn away passersby and to alert your control center to the presence of aircraft and other possible hazards.

Fire Fighting and First Aid: You must have fire fighting equipment on hand and be capable of fighting fire wherever it may occur. You must have first aid supplies and people who are trained to use them.

Routine: There must be routine in everything you do at a launching site or any other place where there are hazards. Routine means habit. Psychologists know that in emergencies people react according to habit. If your routine is good, your members' habits will be good and accidents can be minimized.

Layout of a Launching Site: Illustration No. *49* shows the recommended layout of a safe launching site which the average rocket group can build and maintain. More elaborate layouts using the same principles can be designed by advanced groups which have the resources.

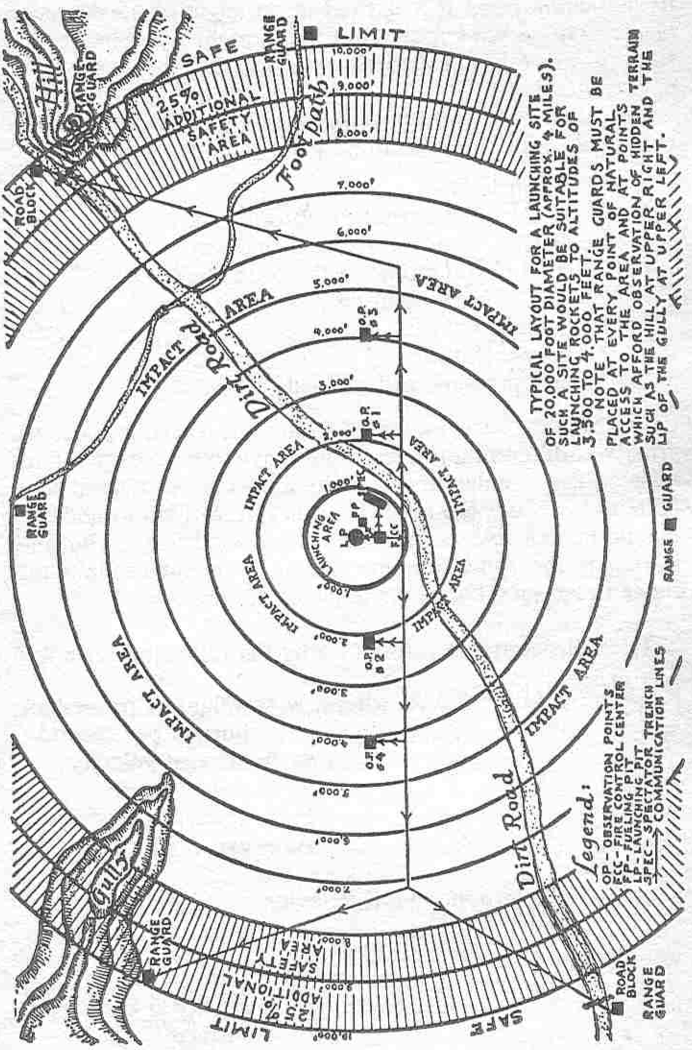
How big a launching area will you need? Its size will, in most cases, be determined by two factors: the size and range of rockets to be launched from it, and the amount of land you can get permission to use.

Very large areas of uninhabited land are found only in the West and Southwest. For rocket groups in other parts of the country it is generally more sensible to ask the question the other way around: what size rocket can you launch safely in the land you have available to you?

Many groups will find that the answer to this question is —none! In this case it is wiser to plan your group's program of activities with major emphasis on design, research and static testing. Then, when your members have enough money saved to travel to a distant launching area, the rockets you have developed will be more likely to perform as expected and you will not have to ask yourselves, "Was this trip really necessary?"

To find out what size rocket you can launch within the land area you have permission to use, you need to know

ILLUSTRATION NO. 49



TYPICAL LAYOUT FOR A LAUNCHING SITE OF 20,000 FOOT DIAMETER (APPROX. 4 MILES). SUCH A SITE WOULD BE SUITABLE FOR LAUNCHING ROCKETS TO ALTITUDES OF 3,500 TO 4,000 FEET.

NOTE THAT RANGE GUARDS MUST BE PLACED AT EVERY POINT OF NATURAL ACCESS TO THE AREA AND AT POINTS WHICH AFFORD OBSERVATION OF HIDDEN TERRAIN SUCH AS THE HILL AT UPPER RIGHT AND THE LIP OF THE GULLY AT UPPER LEFT.

Legend:
OP - OBSERVATION POINTS
FCC - FIRE CONTROL CENTER
FP - FUELING PIT
LP - LAUNCHING PIT
SPEC - SPECTATOR TRENCH
→ COMMUNICATION LINES

not how *high* your rocket will go when launched vertically, but how *far* it will go if launched at an angle of 45 degrees. A rocket, or any projectile, will travel farthest away from its launching point if it is fired at an angle of 45 degrees. Never assume your rocket will go straight up. Always assume it will take off erratically and travel the full length of its potential trajectory.

To calculate the potential trajectory, or maximum range, you need to know the following things about your rocket:

a. its weight loaded.
b. its weight after burnout of propellant.
c. the specific impulse of the propellant.
d. the total burning time of the propellant.
e. the rate of burning in lbs./second.
f. the exhaust velocity.
g. the nozzle exit area.
h. the exit pressure and ambient pressure.

Other factors, such as air drag and the varying effect of gravity at different altitudes would have to be considered in an accurate calculation of maximum range. But since they all tend to reduce the range we don't need them to find the maximum possible range under ideal conditions. The following is the procedure for finding a rocket's maximum range based on a launching angle of 45 degrees.

1. First determine thrust (F) by the following formula.

$$F = \frac{\mathring{w}}{g} v_e + (P_e - P_o) A_e$$

where: $\mathring{w}$ = weight of propellant burned per second
v_e = exhaust velocity
P_e = exit pressure
P_o = ambient pressure
A_e = exit area

2. Next, determine cutoff velocity:

$$v_c = g_e I_{sp} \left(l_n n - \frac{n-1}{\psi} \right)$$

where: g_e = gravity at earth surface
$n = \frac{\text{loaded weight}}{\text{cutoff weight}}$

ψ = initial thrust-weight ratio $\left(\text{or } \frac{F}{w_i}\right)$

l_n = logarithm

3. Then determine range (X)

$X = \frac{V_c^2}{g} \text{Sin } 2\phi$ where: X = range

ϕ = launching angle (in this case 45°)

Illustration No. *49* shows the area needed to launch rockets which are capable of reaching altitudes of 3500 to 4000 feet. Note that the area is circular. Since we do not know in what direction the rocket will fly if it takes off erratically, we must provide a "safe area" in all directions. Always launch your rockets from the center of your launching site, never from the perimeter or anywhere else in the area.

The shaded area in the sketch indicates an additional safety margin provided by extending the radius of the circle 2000 feet beyond the calculated maximum *range* of the rocket. This second perimeter should be the outside safety limit of your launching site. The location of this perimeter is largely a matter of judgment and can be varied according to the type of terrain you are in, observation conditions, and whether the surrounding area is populated or heavily traveled. In no case should you establish the radius of the outside perimeter at less than 125% of the calculated maximum range. Its purpose is to provide an extra margin of safety to allow for minor miscalculations, variations in fuels, strong tail winds, etc.

When you have all the necessary permissions and clearances discussed in Chapter 1, you are ready to determine what you need at your launching site. Before we consider that, however, it is necessary to define a few terms we will be using throughout the rest of this chapter so that you will be certain to understand exactly what is being said, and particularly to avoid confusion as to the ground area being referred to.

Launching Site: The entire area of the launching facility, including the outside safety perimeter. The term "range" may be used interchangeably with the term "launching site" to indicate the same thing.

Launching Area: The immediate working area in the center of the launching site. It includes the launching pit, firing bunker, fueling pit, observation bunkers, etc.

Launching Pit: The actual pit or barricade from which the rocket is launched. It contains the launching rack or platform.

Impact Area: Any area where a rocket lands, or is expected to land. To be realistic you must consider your entire launching site as potential impact area.

Impact Point: The spot at which a specific rocket actually lands.

Impact Zone: The predicted area of impact of a specific rocket or series of rockets launched at the same angle. The size and distance from the launching pit of an impact zone will vary with the type of rocket and the angle of launching. Impact zones will generally be oval in shape with the long axis pointing toward the launching pit. The length of the long axis will vary according to altitude reached and launching angles, with the axis generally growing shorter as the launching angle approaches the vertical.

Road Block: Any barricade, rope, chain, sign or manned post established at a point on a road or path beyond which persons or vehicles are not permitted to pass.

Road Guard: A person assigned to man a road block.

Range Guard: A person assigned to stand at a point or patrol an area on the perimeter of a range for the purpose of preventing access to it.

Countdown: The final safety and operational readiness check prior to launching. It should be highly systematized and proceed on a rigid time schedule, with the final 15 seconds being counted out orally.

Fueling Pit: The pit or barricade within which rockets are fueled. This is not, and should never be, the place where fuel is stored.

"By the Numbers": A method of doing things step-by-step, with each step numbered in sequence to ensure that none is omitted. The numbers are called out as each step is performed. The system also permits everyone within hearing to know what is going on. The countdown is a method of firing missiles by the numbers. In the armed forces every important or hazardous operation is done this way.

Protective Pits and Barricades: A safe launching site is not just an open area out in the country. As Illustration No. *49* shows, it requires intelligent planning, some material and a great deal of pick and shovel work. The more pick and shovel work you do, the safer you will be. The illustrations which follow show you how to construct a variety of emplacements that are needed at a well-equipped launching site. They are not the most elaborate that can be built, nor are they the simplest. They are designed so that they can be built by the average rocket group with easily obtained materials.

For the launching site shown in Illustration No. *49* you need:

a launching pit	(Illustration *53*)
a firing bunker	(Illustration *55*)

The firing bunker should also be the control center. A separate control center may be established but this increases communications problems and the chances of premature firing.

fueling pit	(Illustration *56*)
observation bunkers	(Illustration *58*)
range guard shelters	(Illustration *60*)
spectator shelters	(Illustration *61*)

The most important emplacement is the launching pit. Even if you have nothing else on your site, a properly built launching pit can give a great deal of protection to those participating in the launching.

It is most important that the launching rack be emplaced in a pit or surrounded by a barricade, the top of which is approximately one foot higher than the nose of the rocket as it rests on the rack in launching position. The purpose of this barricade is to absorb fragments which would fly laterally, and somewhat upward, in the event of an explosion. The pit should be at least four feet deep. If your launching site is located in rocky soil you can combine a two-foot deep pit with a partial barricade high enough to extend above the nose of the rocket. You may also use a four- to six-foot barricade built at ground level.

How you build your barricades and emplacements will depend on what materials are available to you. Reinforced concrete would give the greatest protection, but it is unlikely that many groups can afford this type of construction. In any case, it is not necessary, considering the size and power of rockets you will be testing and launching. Plain concrete, bricks, cinder blocks, railroad ties and heavy timbers are excellent. If you are willing to do the shovel work, however, you can do a satisfactory job and provide maximum protection against fragments that fly laterally with nothing more than dirt or sand.

Less than thirty inches of sand will stop a .30 caliber bullet fired from a Garand M1 rifle at a range of 100 yards. The M1 has a muzzle velocity of about 2900 feet per second. It is not likely that fragments from an exploding rocket will develop velocities anywhere near this figure and dirt will give you all the protection you need from them. With dirt as your basic construction material you can build all of the protective emplacements shown in the illustrations. Besides costing nothing, dirt has the advantage of absorbing fragments on impact instead of ricocheting them off as stone or concrete would do.

The material thickness tables in the Appendix show you the types and thicknesses of materials which the U. S. Army has found will stop projectiles and bomb fragments of varying sizes at varying distances. You will note, for instance, that 40 inches of sand or earth in sandbags will protect you from the fragmentation of a 500-lb. bomb which explodes only 50 feet away from you.

With dirt, your basic building block is the sandbag. Shovel the dirt into burlap bags or 100-pound flour sacks. Don't fill the bags too full. Tie the mouth of each securely, leaving enough space at the top so that the bag will lie flat when placed in position. This helps to prevent gaps in a sandbag wall, makes a stronger wall, and keeps the bags from splitting. If you can cover your walls with tarpaulins or any water-resistant covering you will find that they withstand the ravages of weather much better and last longer.

Lay the sandbags so that the long axis is at right angles to the long axis of the wall you are building. This gives you a thicker wall and lets you build to a greater height without danger of the wall collapsing. The rows of sandbags should be laid so that each bag is centered over the crack between the two bags beneath it, the same way a brick wall is built. After a little tamping and with time for the bags to settle, you will have a pretty solid wall. This type of construction is shown in Illustration No. *50*.

An alternative method is also shown, in which the bags are laid crosswise in the first row, lengthwise in the second row, crosswise in the third row and so on. Assuming the bags are roughly twice as long as they are wide, this method usually results in a more stable and better aligned wall, and it is recommended.

Illustration No. *50* also shows another type of dirt construction you can use if you can't get sandbags, but can get timbers or logs. This is called crib construction and consists simply of erecting a framework, or crib, to give basic shape and rigidity to your wall. You fill the interior of the crib with rocks and dirt, the more dirt the better. Walls built this way should be 24 to 30 inches thick and should be buttressed at intervals with diagonal supports if your timbers are not heavy enough to withstand the weight of the dirt and rocks by themselves. Thin branches, matting, wire mesh, chicken wire or canvas placed along the interior of the crib walls will hold the dirt in place. The tops of the walls should be covered to prevent rain from washing the dirt away.

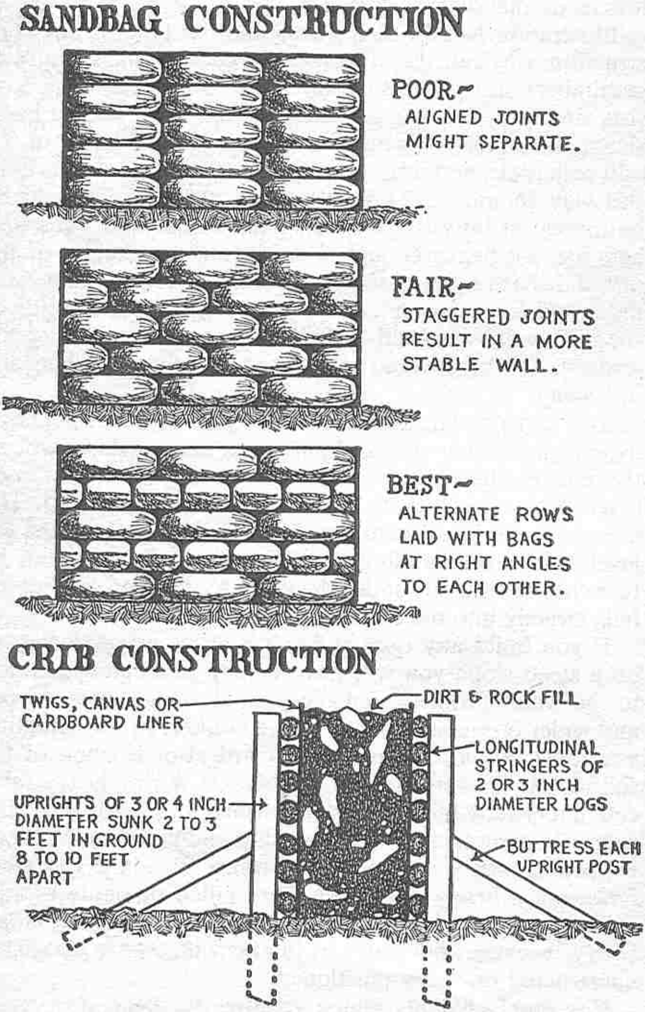
You can prevent flooding inside your emplacements by digging a shallow trench four to six inches deep around the outside edge of each emplacement with a lead-off trench extending a few feet in the direction of low ground. The floor of the emplacement should be slightly higher than the level of the surrounding ground and small holes can be tunneled at intervals under the walls to drain off rain which falls directly into the emplacement.

If you build any type of bunker or other emplacement on a steep slope you will have to pay particular attention to the water problem and dig your drainage ditch deeper and wider on the uphill side of the bunker. In this situation you must be alert to another hazard also. Erosion of the soil on the downhill side of the bunker during heavy rains can undermine the ground on which the walls rest and cause the structure to slide downhill and collapse. This can happen suddenly and without warning, even in dry weather following a heavy rain. Men were killed or badly injured in Korea, where the hills are steep and the rains extremely heavy, because they slept in bunkers that were carelessly constructed or badly positioned.

For emplacements which require overhead cover you must keep a few things in mind:

a. Make certain the walls of the bunker are strong

ILLUSTRATION No. 50



enough and thick enough to support the load of the roof.

b. Be sure the timbers you use for roof beams are heavy enough.

c. Do not try to span too great a distance with a roof consisting of sandbags and timbers. Eight feet is the maximum, five or six feet is preferable. Use posts or sandbag partitions to reduce the length of the span wherever possible.

Roofs can be built simply by laying a framework of timbers across the open area between the walls as shown in Illustration No. *51*. The timbers should be as uniform in girth and length as possible and fairly smooth. The main support beam should be six or eight inches thick and the crossbeams which are laid across the main beams should be three or four inches thick if you plan to put three layers of sandbags on top. Three layers of sandbags on a roof measuring six by eight feet will weigh about 4000 pounds.

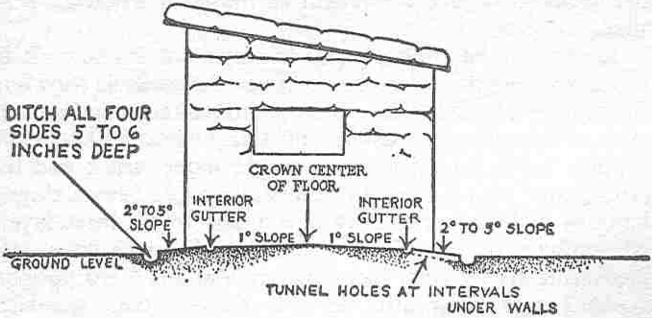
Your roof must also be able to withstand sideways stresses and for this reason the beams should be joined in some manner at the points where they intersect. There are several methods of doing this. If someone in your group is handy with an ax you can notch the beams at all points of intersection so that they nest together evenly. The beam ends which rest on the walls should also be notched so that they present a flat surface to the top of the wall. If notching sounds like too much work the beams can be bound together with baling wire or old electrical cord. Surplus sales stores usually have Army "commo wire" (communications wire) available which is excellent for this purpose. It is a light, tough, pliable wire with a glossy black rubber coating. It is used primarily for stringing field telephone lines, but the American soldier uses it for everything from shoelaces to hanging out wash.

Extra stability can be given to your roof by allowing the beam ends to project beyond the sandbag wall a foot or so (as shown in Illustration *51*) and suspending a loaded sandbag from the butt end of each. This helps to settle the beams in place, prevents side-slippage, and acts as a counterweight to the downward thrust of the roof load in the center.

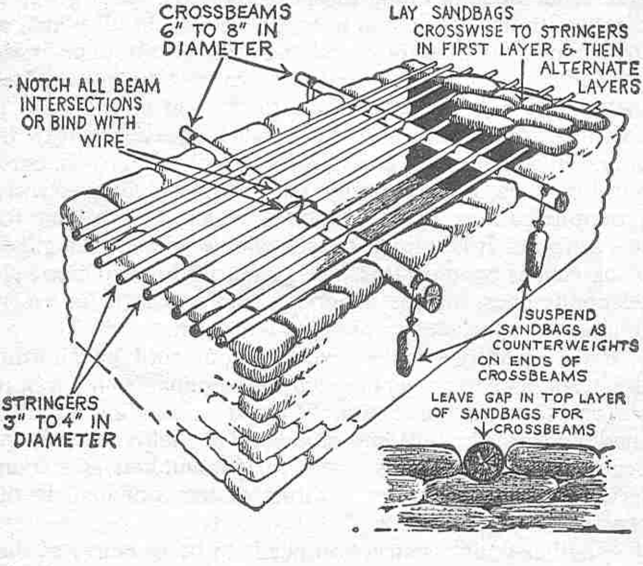
Whether your construction needs to be as heavy as that shown in the illustration is a matter of judgment. The illustrations show the heavy type of construction to emphasize

ILLUSTRATION NO. 51

DITCHING & DRAINAGE



ROOF CONSTRUCTION



the need for safety. You may be able to use lighter construction with complete safety—one or two layers of sandbags on the roof instead of three. You can determine your needs with a little calculation and perhaps a few tests. The primary considerations are the weights of the rockets you intend to launch and the altitudes you expect them to reach.

The altitude is the most important factor because it determines the velocity at which your rocket will hit the ground. Velocity determines depth of penetration, with due allowance for the weight of the object. Did you ever stop to think that the only thing lethal about a bullet is the speed with which it travels? A lead slug tossed across a room at you would do no more than sting you. But when it comes at you at a speed close to 2000 miles an hour it is an entirely different matter. All that has been added to the slug is velocity. But velocity turns it into a killer. The same thing is true of your rocket. If it falls from a great enough altitude it can kill. A rocket which reaches a height of 1000 feet will hit the ground at approximately 175 miles an hour. This is not very fast. It is only a little faster than Pancho Gonzales hits a tennis ball, and twice the speed of one of Herb Score's fast balls. But if you have ever seen a batter "beaned" by a fast pitch you will know that you don't want to be in the way of a rocket falling from 1000 feet. Gauge your construction accordingly.

If your group intends to test rockets capable of reaching 10,000 feet you had better figure on good, heavy overhead protection. From an altitude of 5,000 feet a rocket body will reach a speed of 386 miles per hour by the time it hits the ground: from 10,000 feet, 545 miles per hour. From 20,000 feet your rocket would be hitting the ground at supersonic speed (775 MPH).

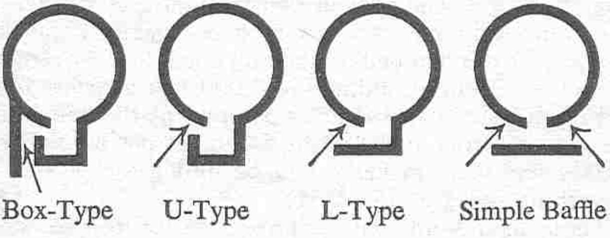
These figures are only approximate, of course, since they do not allow for aerodynamic drag (which would vary for every size and shape of rocket) nor for the fact that the pull of gravity (and consequently the rate of acceleration) varies with altitudes. They are good enough, however, for the purpose at hand. You will find a discussion of how to calculate the velocity of a free-falling body in Chapter 10, and the table of velocities in the Appendix shows the calculations for various altitudes as a ready reference for tracking purposes.

The designs shown for the various types of emplacements in Illustrations *53* through *62* are self-explanatory and there is no need to discuss the construction of each in detail. There are certain important features of each, however, which must be stressed, and some explanation must be given of the purpose of each emplacement, the part it plays in the operation of the launching site, and the equipment needed in it, if any. Let us take them up in the order they have been listed.

The Launching Pit: We have already discussed certain features of the launching pit. You will note that the illustration shows access doors for convenience in entering the pit. It also provides access for wire leads to the launching rack and for the pull wire which is used in the procedure for handling a misfire described in Chapter 9. Details of the launching rack and the platform on which it rests are shown in Illustration *63* which will be discussed later.

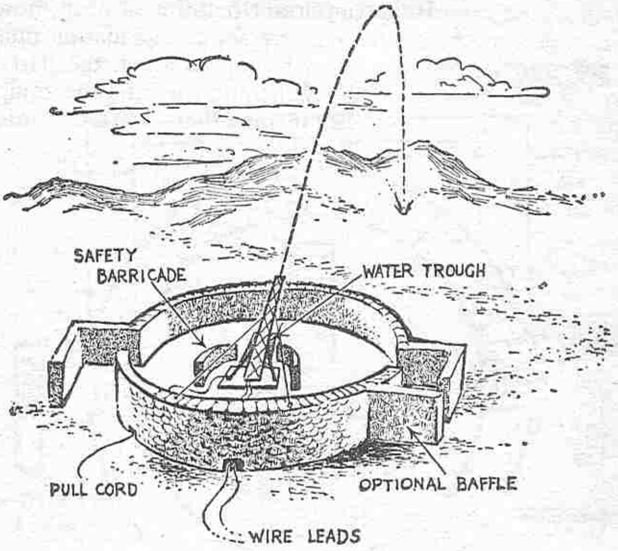
The access door is nothing but a rectangular opening in the wall protected by a baffle. Baffles should be used to close off access doors to all emplacements. They are of four general types:

ILLUSTRATION NO. 52



Note that the baffle should extend far enough beyond the opening so that it is impossible to see into the emplacement from any direction, as shown by the line-of-sight arrows. The baffle, also, must be of the same height as the emplacement wall and of the same thickness. The U-shaped baffle gives the best all-around protection, but it is complicated to build and is not really necessary. It is used by the Army in combat areas where it is desirable to prevent light from showing through a doorway at night.

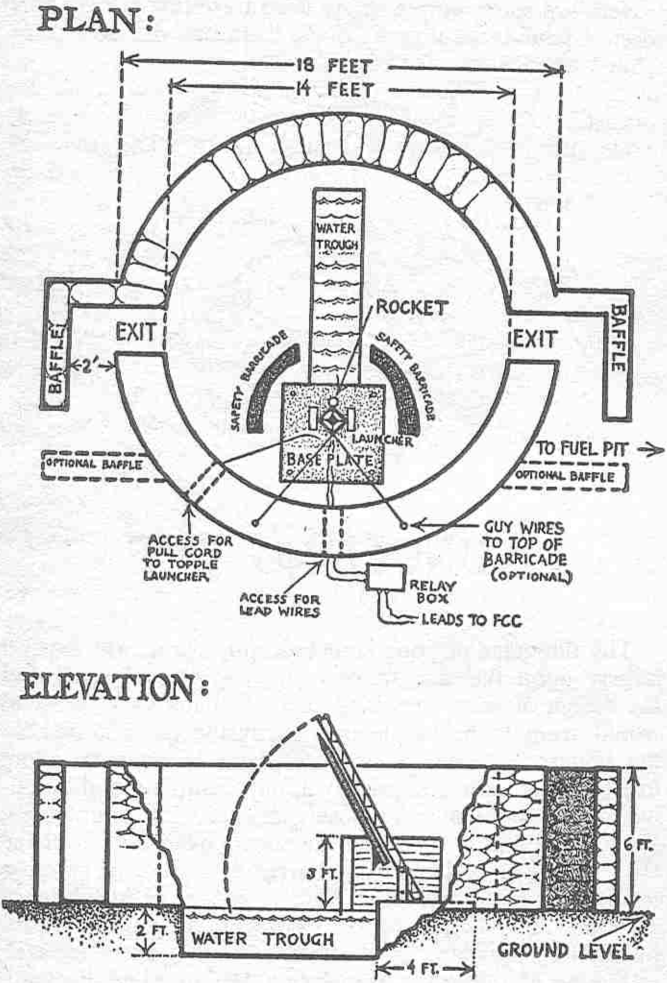
ILLUSTRATION NO. 53



LAUNCHING PIT

The diameter of your launching pit, again, will depend largely upon the size rockets you expect to launch and the design of your launching rack. A diameter of ten feet would seem to be ample in most instances. The smaller the better, however, as long as there is sufficient room to work inside the enclosure without stumbling and bumping into things. The more closely an explosion is contained, the less likely it is to scatter fragments over the top of the barricade. The walls of your barricade cannot be so close to the launching rack that there is danger of interference with the flight of the rocket, however. You must always have what is called "mask clearance." No obstacle, such as the top of a wall, the branch of a tree, or telephone wire, should be in a position to "mask" the line-of-sight which your rocket will follow in flight. You'd be surprised how frequently this important rule is overlooked. The launching

ILLUSTRATION No. 54



pit shown in Illustrations *53* and *54* has an inside diameter of 14 feet. This is ample for launching rockets up to 8 feet in length, and includes a water trough 8 feet long and 2 feet in width.

Here are some simple safety rules to follow in the operation of your launching pit. Type them out and post them at the entrance to your pit.

1. *Nobody whose presence is not essential* should be permitted to enter the launching pit when a rocket is in it. If one man can perform all the necessary setting up operations, then *only one man and a supervisor* should be allowed inside.
2. *Never stay in the pit* longer than is absolutely necessary to set up and perform the necessary safety checks. (This does not mean that you should hurry your work, but get out as soon as possible.)
3. *Never have more than one rocket* in the pit.
4. *If a rocket starts to burn*, or a fuse sputters, *get out*. Throw yourself flat on the ground *outside* the barricade and as close to the wall as possible. Bury your face in the dirt. *Never* attempt to stop the burning, or touch or move the rocket in any way.
5. *Always wear protective* clothing, including helmet, face shield and gloves in the pit. *Do not attempt* to work with the gloves on if it is awkward.
6. *Always sight* along the launching rack to make certain nothing will interfere with the flight of the rocket, *before* you place the rocket on the rack. (Mask clearance) Shout, "Clear!", so that your supervisor will know you have done it.
7. *Always* have a bucket or trough of water in the pit, and a first-aid man on call.
8. *Never* allow fuel to be stored in the launching pit.
9. *Fly a red flag* from the barricade whenever a live rocket is in the pit.
10. *Fly a yellow flag* from the barricade whenever personnel are in the pit.

In regard to safety rule number 4, you might consider providing two access doors to your launching pit in order to provide better means of escape in an emergency. This is not essential, but if you don't mind the extra work it is probably advisable.

The Firing Bunker—Control Center: The firing bunker is the next most important emplacement at your launching site. It should also be your fire control center and the control center for the entire operation of the range. Some groups may prefer to have a firing bunker that is separate from the control center and in which only the firing operation takes place. To do this, however, makes it necessary to have good telephone, or visual signal communication with the control center. Remember that every time you introduce a need for more communications you provide another opportunity for something to go wrong. For this reason it is advisable that the firing bunker and the control center be one and the same place. If the topography of your launching site is such that you cannot get good observation of the entire range from the point at which it is most convenient to locate your firing bunker, then you may be justified in establishing a separate location for the control center. Otherwise keep them together. From this point on we will assume that they are co-located.

The primary functions of the fire control center are to:

a. Maintain visual or wire communications with all parts of the range.

b. Give all procedural directions and orders.

c. Execute all safety checks, or order them executed.

d. Determine that every station on the range is in readiness.

e. Determine when an emergency exists and make all decisions in an emergency.

f. Keep all stations on the range informed of the status of operations at each critical point.

g. Give the order to take cover.

h. Give the order to fuel the rocket.

i. Give the order to fire the rocket.

j. Fire the rocket.

k. Give the "all clear" signal.

l. Take reports and record the data for each flight.

m. Announce the results of each firing.

n. Declare rest periods, or "breaks," when all range operations cease.

REMEMBER THIS:

1. Nobody on a firing range, or launching site, moves from one place to another or takes any action without a specific order from the control center.

2. It is the duty of every person on a range to report any unusual occurrence to the control center immediately, and also to make routine reports upon the completion of assigned tasks.

The emplacement which you build for your fire control center (Illustration 55) should be designed so as to give adequate protection, but at the same time it should afford reasonably good observation of the entire launching *area* and to certain other designated points within the launching site. Consequently the placement of windows and observation slits in the walls of the bunker will be determined by the topography of your particular launching area and the locations of observer bunkers, etc. The arrangement shown in the illustration is not intended to be followed precisely.

Your fire control center will also be the heart of whatever communications system you establish for your range. It must have communication with the launching pit, the fueling pit, observer bunkers and range guards. The section on communications which follows will give you ideas on installing and operating a satisfactory communications system.

There is another important point to remember about your control center. The purpose of control is to eliminate confusion and ensure safe, orderly procedure. If you have confusion in your control center you will have it elsewhere on your range. Keep people out of your control bunker who don't have any business being in there. People naturally like to be at the center of operations. It makes them feel important. But you cannot afford to humor people when you are dealing with danger. Make it an ironclad rule in your group that no one is allowed in the control bunker who does not have a specific job to do. There is a separate shelter provided for spectators.

One final consideration in the construction and location of your control and firing bunker is its distance from the launching pit. There are several factors to be considered in determining this distance (*see* Quantity-Distance Tables in Appendix). But when all these factors have been evaluated, and proper considerations of *safety* and *control* taken into account, it seems most reasonable to establish a distance of 50 yards to 100 yards between launching pit and control bunker. The distance of 100 yards is preferable, of course, for maximum safety; but at this distance you may have difficulty in getting your electrical firing system to operate. If you are firing small rockets (1 foot to 3 feet in length) a distance of 50 yards is adequate providing you have a soundly constructed firing bunker and good range discipline. Generally speaking, the explosive effect of rockets has been over-emphasized; mainly because people who have been injured by them have been foolish enough to be standing right next to them. For purposes of comparison, the Army's 4.2-inch (105MM) high explosive mortar shell (which weighs approximately 25 pounds, is nearly 2 ft. long, and 4.2 inches in diameter) has an *effective* burst radius of only 45 yards, laterally. This projectile was *designed* to kill. It is the product of generations of development work by ordnance experts. It is packed with TNT and has a shell casing designed for maximum fragmentation effect.* It is not likely that amateurs using inferior materials, slower burning fuels and with no ordnance experience, could accidentally produce a more lethal effect. When one considers, in addition, that the launching rack is surrounded by a barricade, and a protective bunker houses the firing personnel, it is obvious that a distance of 50 yards is sufficient.

It never does any harm, however, to provide yourself with an extra margin of safety wherever possible. Therefore, if you are planning to launch rockets larger than three feet in length, and if the topography of your site will permit it, a distance of 100 yards between launching pit and control bunker is recommended. Bear in mind that increased cable length in your electrical system will probably require stepped up voltage, if the system is to be effective.

The Fueling Pit: The purpose of a fueling pit is, of course, to minimize any accident which might occur during the loading process. It is designed to afford maximum possible protection for those doing the fueling, and also to contain any explosion to prevent injury to other persons in the area. The design shown in Illustration *56* is not too difficult

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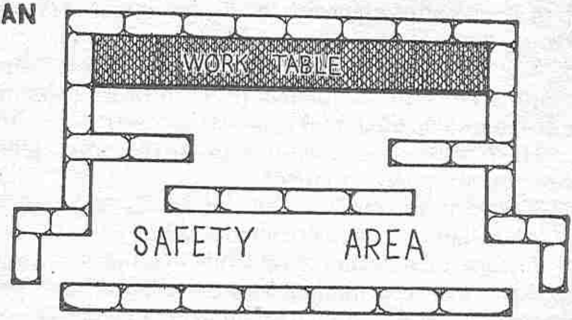
*Army ordnance experts have calculated that a flying fragment must produce a minimum of 58 foot pounds of energy to have a casualty effect. This means that a one ounce fragment would have to travel at a velocity of 246 FPS (166 MPH) to injure severely. You can use your knowledge of basic physics to calculate the possible casualty effect of one of your rockets if it exploded.

ILLUSTRATION No. 55

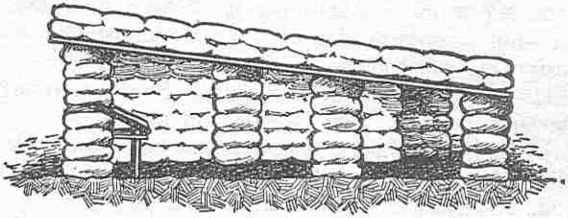
FIRE CONTROL CENTER

OR CONTROL BUNKER

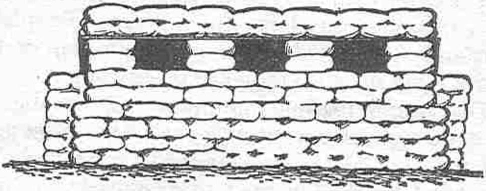
PLAN



SIDE ELEVATION CUTAWAY VIEW



FRONT ELEVATION



to build and will prove convenient to work in. *It is not the place where fuel or oxidizers should be stored,* for obvious reasons.

Here are some points to keep in mind in regard to the location and operation of a fueling pit.

a. Nobody should be allowed in or near the fueling pit during loading operations, except the fueling supervisor and the persons designated to do the loading (normally two).

b. The fueling pit should be remote from other emplacements, *but close to the launching pit* in order to minimize the distance a loaded rocket must be carried.

c. Have only enough propellant in the pit to load the rocket you are going to launch.

d. Keep the fueling area free of debris and return unused propellant to storage immediately.

e. Fly a red flag from the pit while loading is in progress.

f. Have wire communication, or some other signaling arrangement, with the control bunker and notify control when loading is completed.

g. Only the control center should give the order to move the rocket into the launching pit.

h. Naturally, no smoking is allowed near the fueling pit—nor anywhere else on your launching site, except in designated areas during announced breaks.

i. All persons in the fueling pit should wear protective clothing, helmets, face shields and gloves.

j. Fueling should not commence until the order is received from the control center.

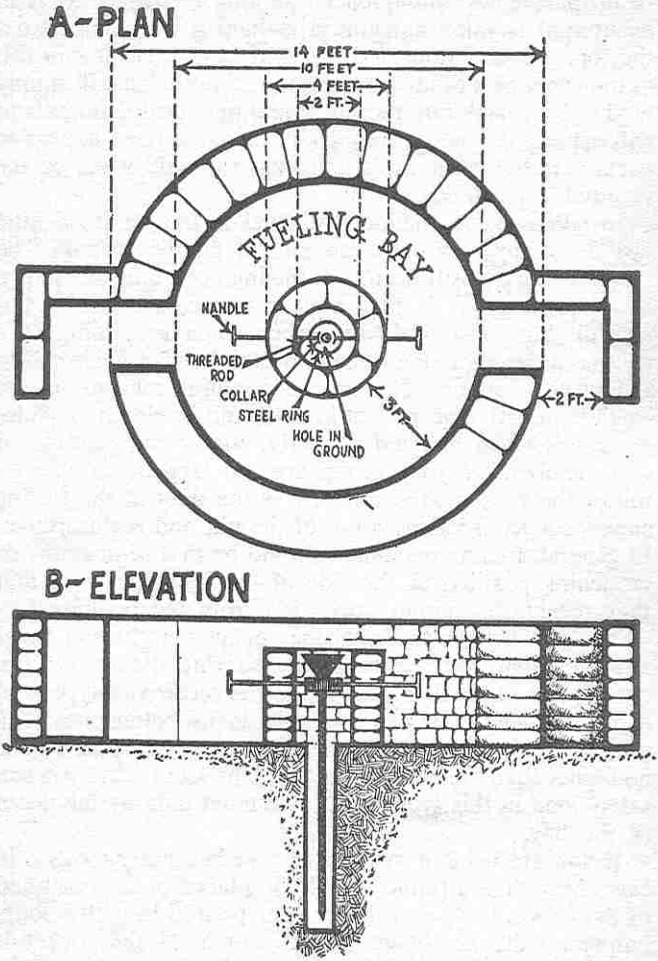
k. Always use a funnel with loose powders.

It is a good idea to have some of these rules posted on signs in and around the fueling area. People need to be constantly reminded of safety regulations or they tend to ignore them because they are inconvenient.

The actual fueling operation will be slightly different for each type of rocket and each type of propellant. You will have to develop a standard procedure of your own. The most commonly used propellant (and apparently the safest one that will give any appreciable amount of thrust) is the combination of zinc dust and sulfur. As indicated in the chapter on propellants it is most widely used in loose powder form and is either poured directly into the rocket

ILLUSTRATION No. 56

FUELING PIT


A-PLAN

B-ELEVATION

chamber and tamped down, or is prepackaged in tubular cartridges. Whichever method is used, the rocket should be placed in an upright position in the revetted fueling bay (Illustration *56*) in the center of the fueling pit, and the powder fed in from the top. Whether your rocket is designed to be loaded from the nozzle end, or the nose, is of no particular consequence. As long as the rocket is in an upright position and the propellant is introduced from the top, the direction of thrust will always be downward, in the event of a premature ignition. The rocket will simply tend to bore itself into the earth, and the burning propellant will expend its energy harmlessly upward. If an explosion occurs, rather than rapid burning, the side walls of the revetted bay will contain it.

In either event, fueling personnel in the pit stand little chance of injury if they remain flat on the ground. The recommended positions for all fueling personnel are shown in Illustration *57*. It may appear unnecessary to be this careful; but most accidents occur when something of a routine nature is being done and people have neglected to follow the routine. The zinc and sulfur mixture is the "safest" effective propellant known, and it seldom explodes or ignites when handled properly. *But it can explode.* If any members of your group are too lazy or careless to follow the proper procedures, it is the duty of the fueling supervisor to order them out of the pit, and replace them. In general, fueling personnel should be in a semi-prone or crouching position at the side of the fueling bay so that they receive maximum protection from the revetment.

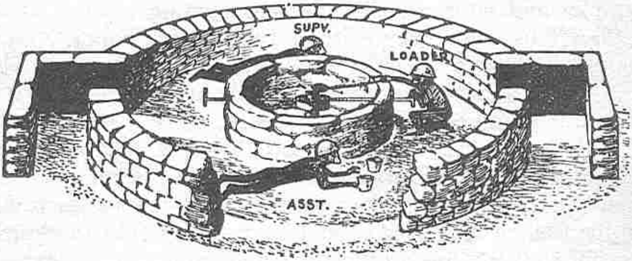
The bracket which holds the rocket upright can be of any type that will accommodate varying diameters. The type shown in the illustration is of the screw-vise-type, and is just one idea. You can probably devise better ones. The rocket should always be inserted so that its upper end is no higher than the revetment wall. The size rocket you can safely load in this type of bay is limited only by the depth of the bay.

If you are using a mixture of powders not packaged in cartridges, then a funnel should be placed in the open end of the rocket body and the powder poured in with a long-handled ladle as shown in the sketch. If the rocket is properly positioned in the bracket the person doing the loading will be able to see the edge of the funnel. In

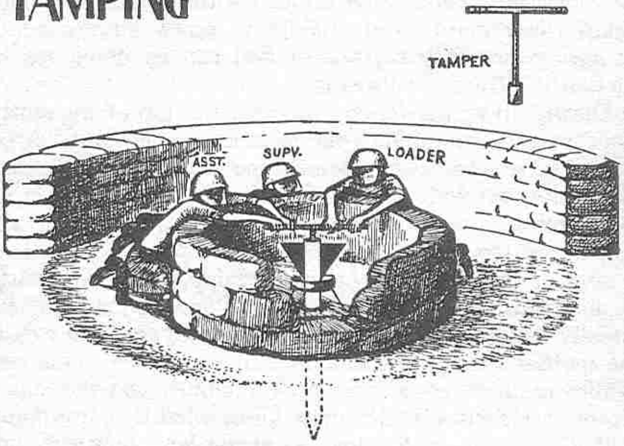
ILLUSTRATION NO. 57

FUELING PROCESS

LOADING



TAMPING



loose-powder loading, the assistant loader is probably best employed in filling the ladle for the loader; or he may do the tamping from the opposite side of the bay. The powder should be tamped down lightly but firmly with a right-angled tamper, similar to the one shown in the sketch, after each ladleful, and settled by vibration.

If your propellant is prepackaged in cartridges, each cartridge should be dropped into the rocket tube by the loader with a pair of long-handled tongs (ordinary fireplace tongs will do) or similar device; and the tamper should simply press each cartridge firmly into place, being careful not to rupture the cartridges. Cartridge loading is generally simpler and safer, and less time-consuming.

Wadding or packing of some type (tissue paper, cotton, wool waste, or even soft wax) may then be inserted with the tongs and pressed down firmly by the tamper, if a burst diaphragm is not being used.

If your rocket is so designed that you have removed either the nozzle or nose cone in order to accomplish the loading, it should now be replaced while the rocket is still in the fueling bay. This should be done carefully, and preferably with the tongs until final tightening is necessary. If your rocket has a threaded section for attachment of the nozzle or nose cone, wipe it clean with a piece of slightly damp waste before you attempt to screw on the nozzle or nose cone. Tiny crystals of fuel can be detonated by friction if left on the threads.

During all of the fueling process, the job of the supervisor is simply to monitor the procedure and make corrections if he sees something being done improperly or a safety precaution overlooked. He should also be responsible for maintaining communication with the control center and relaying orders.

If your group is well enough equipped and supervised by qualified chemists and engineers, it may be that you have already begun to use propellant mixtures that are cast in the molten state in the chamber of the rocket. This procedure requires good laboratory facilities and the supervision of experts who definitely know what they are doing. If the laboratory is not located at the launching site, and it is unlikely that it will be, you then have the nasty problem of transporting loaded rockets over public highways. Bear in mind that you must have a permit to do this and that extreme caution must be exercised in the interests of the public safety. It is a good idea to enlist the aid of some trucking concern or industrial firm that has had experience in the transportation of explosives. Considering all of the things that can go wrong, or cause variations, both in the mixing process and in the behavior of a rocket using a cast charge, it is not recommended for any but extremely advanced groups.

Once the rocket is loaded and ready to be taken to the launching rack the control center must be notified. Do not remove the rocket from the fueling bay until the order to do so has been received from the control center. Remove all excess propellant from the fueling pit and notify control that this has been done. When you do remove the rocket from the bracket, do so very carefully. Do not jar or shake it. Take it immediately to the launching rack and place it in position.

If, for any reason, the rocket should start to burn or sputter on the way to the launching rack, do one of the following (whichever is quickest and most convenient):

a. Immerse it in a trough of water.
b. Throw it back in the fueling bay.
c. Throw it back in the launching pit.
d. Thrust it, nose down, into soft sand.

Whichever you do, throw yourself flat on the ground behind the nearest barricade and keep your head down until the rocket has spent itself. If you have some type of prearranged alarm signal, give the signal so that others may take cover. Do not expose yourself unnecessarily to do so, however.

Observer Bunkers: Usually two observer bunkers are needed at the approximate locations shown in Illustration *49*. These are the points from which sightings of the rocket in flight are made and which have the basic responsibility for tracking. Each should be manned by two men. If desired, two two-man teams can be stationed at each bunker in order to provide comparative information on sightings. If your group is large enough you may want to build additional observer bunkers at other strategic points on the range. They can be useful for two reasons:

a. They can provide alternate data as a check on the accuracy and reliability of data obtained from the two primary observation points.

b. They provide an opportunity to train additional observer teams.

The protective shelters for observers do not have to be as elaborately constructed nor as rugged as the emplacements so far discussed, because they are relatively remote from the launching pit. Since no blast or fragmentation from an explosion could reach this far, there is no real need for lateral protection. An overhead cover is advisable however. The arrangement shown in Illustration *58* should be adequate. The sandbag wall in front of the shelter is intended not so much for protection, but as a convenient resting place for instruments, charts, and sighters' elbows when observing through binoculars.

Since the details of observers' operations are covered very thoroughly in Chapter 10, we will not discuss them here, except to indicate how the observer teams tie in with the operation of the range as a whole. To begin with, it is desirable that there be direct communication with the control center, either by field telephone or visual signal. This is necessary first of all in order to alert the observer teams to the precise time of launching. Secondly, good communications considerably speeds up the reporting and evaluation of observer data. It is virtually essential that the observer teams be able to hear the pre-firing countdown, as they must have their instruments trained on the launching rack and the predicted flight path of the rocket in a state of instant readiness.

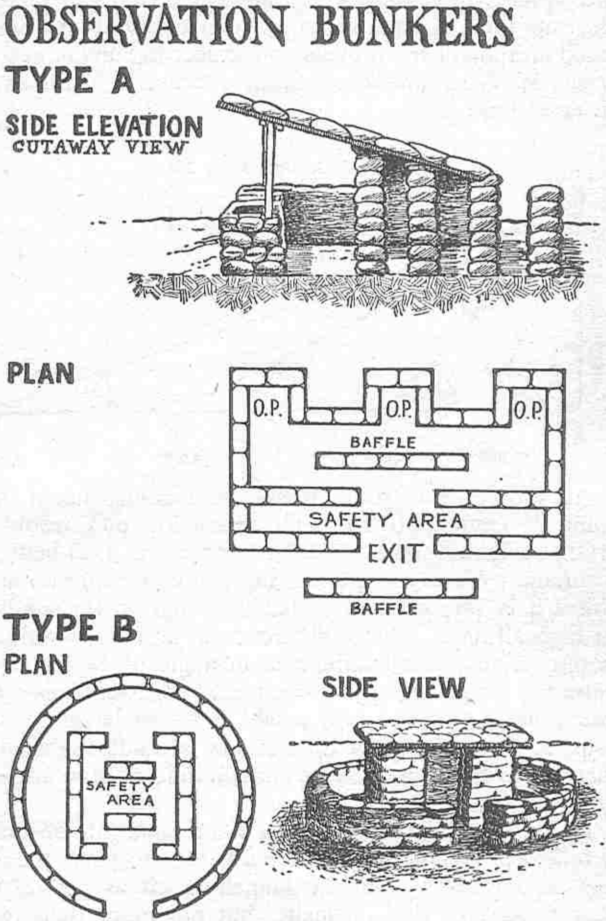
The distance of observer bunkers from the launching pit is determinable by two principal factors, the second of which is the more important:

a. The topography of the particular launching site (i.e., whether line-of-sight observation can be maintained between the observer bunker and the launcher).

b. The anticipated altitude of the rockets you intend to launch.

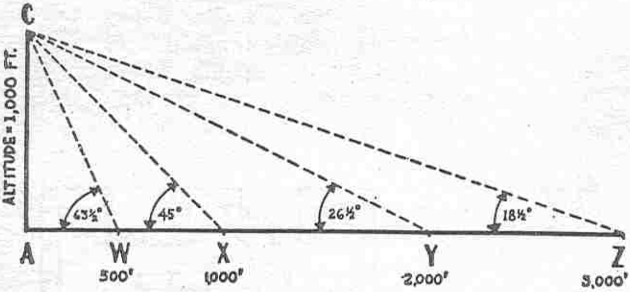
The latter factor is most important because of the fact that visual sightings are only approximate, at the best, and the angle of elevation to be read by the observer should be in a range which will be conducive to the most accurate reading possible. If the angle is too small (20° or less) or too large (80° to 90°) the margin of error is likely to be

Illustration No. 58



greater. Generally speaking, if observer bunkers are too close to the launching pit the angles of elevation to be read by observers will be extremely high (close to 90°) and consequently less reliable. If the observers are too far away, the angles to be read will be correspondingly small and equally unreliable. The following sketch will serve to illustrate this principle for you. (AC represents the anticipated altitude of the rockets you expect to launch, and the points W, X, Y and Z represent alternative locations for observer bunkers):

Illustration No. 59



As you can see from the sketch, readings taken from point W (only 500′ from the launching pit) would be in the neighborhood of 63½°, which is too high for accuracy. (When you are looking almost straight up at an object it is very difficult to tell how high in the air it is. At high altitudes a large difference in altitude is reflected as only a very small difference in angle of elevation because the observer is too close.) Likewise, readings taken from point Z (3000′ away) would be less accurate because point Z is so far away that at low altitudes substantial changes do not cause a large enough difference in angle of elevation readings.

It can be seen from the sketch that a good rule-of-thumb to follow in locating observer bunkers is to place them at least as far away from the launching pit as you expect your rockets to rise vertically, but not more than twice this distance. Obviously, this means that you should construct observer bunkers in several locations if you intend to launch rockets that vary greatly in altitude capability. Simply bear in mind that elevation readings in the neighborhood of 25° to 45° will probably give the greatest accuracy, and locate your observer teams accordingly.

Range Guard Shelters: The construction of range guard shelters, as shown in Illustration *60,* is relatively simple. Such shelters may not even be necessary for range guards located a considerable distance from the launching area. The only important requirement is to provide some type of overhead cover in the event a stray rocket lands near the perimeter of your launching site. If you consider this highly unlikely at your particular site you may want to dispense with range guard shelters altogether. There is no particular objection to this, except that a shelter makes the range guard feel important and he may appreciate it in the event a sudden thunderstorm delays launching operations.

The range guard, of course, must be provided with some type of telephone or visual communication with the control center so that he can give clearances for firing to commence, or stop the launching operations if he discovers someone has wandered into his area. The range officer must complete a check with each of them before starting any of the countdown procedure. Since the job can be boring, and the man acting as range guard is likely to feel left out of the proceedings, the assignment should be rotated frequently among members of the group.

The number of range guards that you need, and the locations at which they should be stationed, are matters that can be determined only by careful analysis of the topography of your particular site and the means of access to it. The arrangement shown in Illustration *49* is only a hypothetical one, of course. Specifically, you must make certain that all "natural avenues of approach," to use a military term, are covered. This means a man must be stationed on, or be in a position to observe, every road, pathway or trail leading into the site. In addition you should provide for the following:

a. Point-to-point visual contact between range guards across unguarded sections of the perimeter.

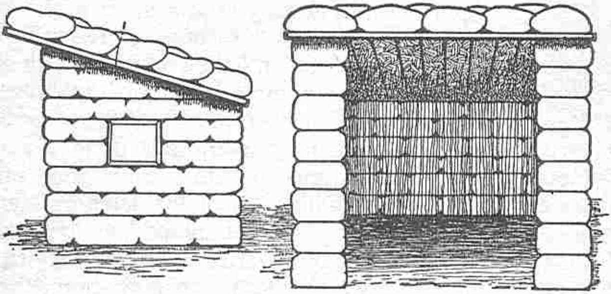
b. Aircraft spotters on prominent terrain features (or up in trees) which afford a commanding view of large land areas surrounding your site.

c. Range guards at intermediate points between the launching pit and the perimeter, for the purpose of relaying

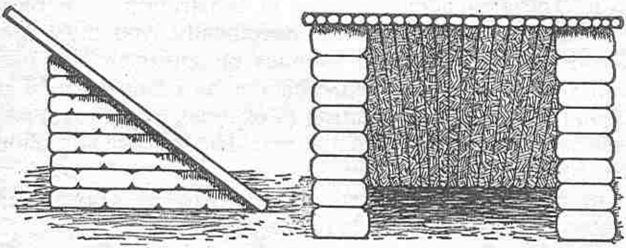
ILLUSTRATION No. 60

RANGE GUARD SHELTERS

TYPE A



TYPE B



signals if you lack telephone communication.

Spectator Shelters: If you are going to allow spectators at your launchings you must provide shelter for them. They should not be allowed in the control center. The type of emplacement shown in Illustration *61* is adequate and should accommodate twenty persons comfortably. A distance of 100 yards to 200 yards from the launching pit is recommended, as spectators will want to be close enough to observe the actual blast off. The bunker should be located close enough to the control center to enable all spectators to hear the countdown and all warning orders issued by control.

Latrines and General Field Sanitation: Since well-organized groups will be using a launching site for extended periods of time some thought must be given to what the Army calls field sanitation. You must provide toilet facilities, water, and rubbish disposal at your site. Two types of latrines are shown in Illustration *62*. The slit-trench type need be dug to a depth of only one or two feet. Regular latrines should be dug to a depth of five or six feet. Both types should have dirt shoveled into them daily and be sprinkled with powdered lime periodically. When half-filled up, they should be covered over completely, marked with a sign, and a new location chosen.

Water is best supplied in the field by a Lister bag. These are generally available at surplus supply stores, as are the five-gallon "jerry cans" usually used by the Army to transport water. A rubbish pit or "sanitary fill" should be dug to take care of all refuse which cannot be burned. Each time refuse is thrown into a pit it should be covered with a layer of dirt and sprinkled with lime.

You can get a good manual on field sanitation which will show you how to live in the field and "keep a good house" by writing to the Superintendent of Documents, Government Printing Office, Washington 25, D. C. Ask for the Army field manual on Field Sanitation.

Communications: Communications in a broad sense is simply a system for "keeping in touch," so that information, orders and reports can be relayed from one person to another. All persons involved in an operation, such as

ILLUSTRATION NO. 61

SPECTATOR SHELTER

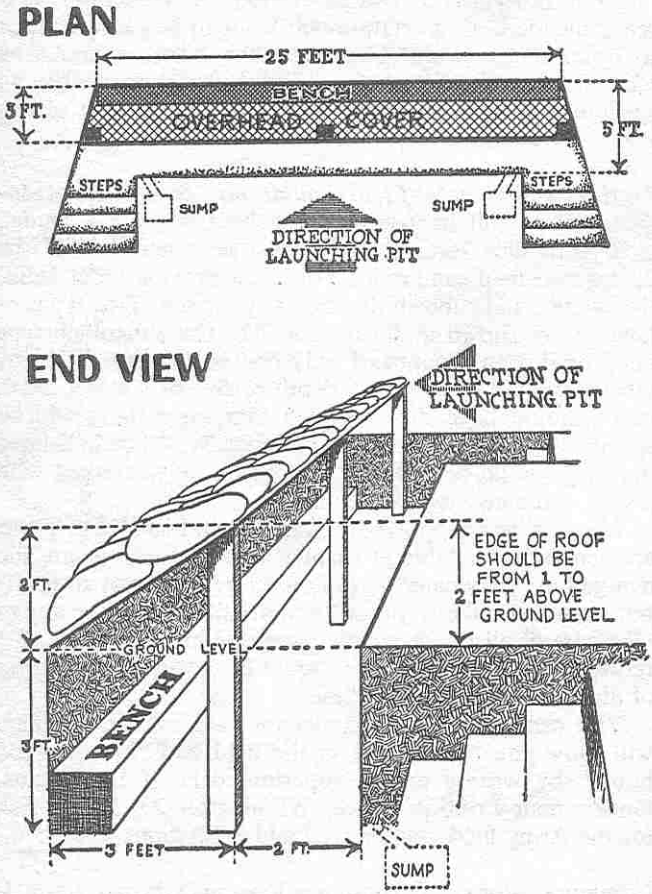
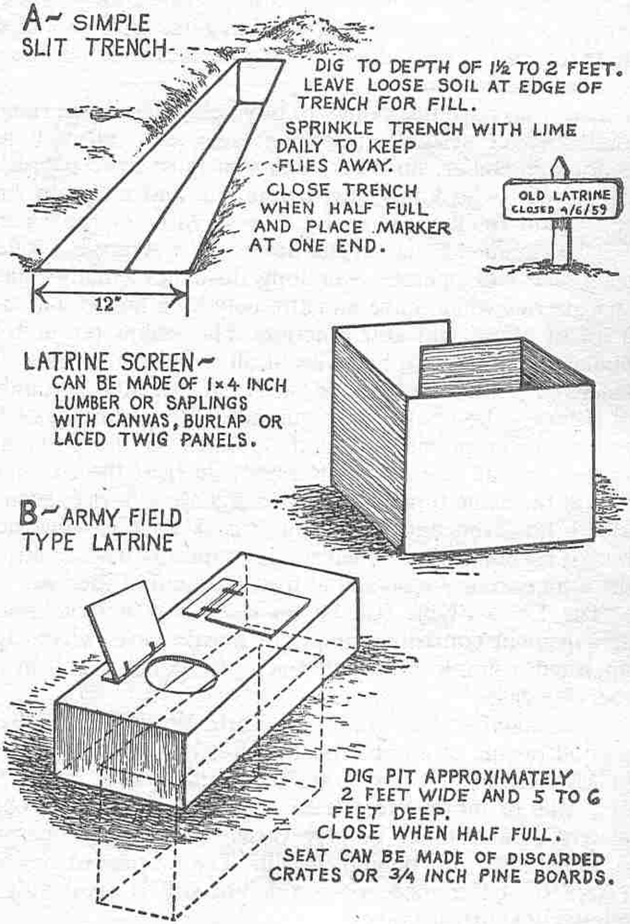


ILLUSTRATION NO. 62

TWO TYPES of FIELD LATRINE



A– SIMPLE SLIT TRENCH–

DIG TO DEPTH OF 1½ TO 2 FEET. LEAVE LOOSE SOIL AT EDGE OF TRENCH FOR FILL.

SPRINKLE TRENCH WITH LIME DAILY TO KEEP FLIES AWAY.

CLOSE TRENCH WHEN HALF FULL AND PLACE MARKER AT ONE END.

LATRINE SCREEN– CAN BE MADE OF 1×4 INCH LUMBER OR SAPLINGS WITH CANVAS, BURLAP OR LACED TWIG PANELS.

B– ARMY FIELD TYPE LATRINE

DIG PIT APPROXIMATELY 2 FEET WIDE AND 5 TO 6 FEET DEEP.

CLOSE WHEN HALF FULL.

SEAT CAN BE MADE OF DISCARDED CRATES OR 3/4 INCH PINE BOARDS.

rocket launching, must know at all times what is going on. Otherwise confusion results, time is lost and costly mistakes can be made. The word "communications" in this era of advanced technology is likely to suggest to the mind elaborate networks of wire, telephone, radios and various electronic gadgets. All of this is impressive, but it is not necessary. Without any of it you can still operate a very effective system of communications if you have imagination and the ingenuity to use everyday signaling devices which are readily available to you.

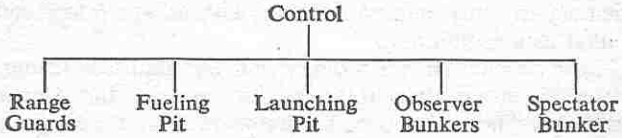
If you do have the money to buy field telephones, radios, loud speaker systems, inter-com sets, etc., all well and good. Remember, however, that you must have people in your group who know how to operate and maintain such equipment for it to be useful to you. Most of these items can be obtained from surplus stores. The Army EE 8 field telephone will operate over long distances (many miles) on batteries which have an extremely long life. It will take a lot of abuse and still function. The sound power telephone which uses no batteries at all, will operate over distances of many hundreds of yards, and an infinite number of them can be hooked into one net. One advantage of the sound power phone is that it operates on the party line system and all stations on the line can hear the conversation at the same time. There is no signaling device, such as a bell, however, and each man must keep his phone near him at all times. A loud whistle is ordinarily used to attract the attention of the person at the other end of the line.

The EE 8 phone can be hooked up in a switchboard arrangement consisting simply of plastic jacks which light up when a crank is turned. Each phone has a bell in the carrying case.

The "handy-talkie" radio of World War II (SCR–6) is a good means of communication but it has its limitations in hilly terrain. It will operate satisfactorily over a distance of a mile or more across level ground, and then fail completely at a distance of fifty yards because one operator is in a ditch or behind a hill. The improved version (ANPRC–6) is more powerful, but still is good only at relatively short distances.

The "walkie-talkies" which are carried on the back are effective at ranges up to several miles. They, too, have their difficulties in hilly country, however. The World War II version is called the SCR–300. The improved model (ANPRC–12) is lighter and more compact and generally more powerful.

Whatever the system of communication you are able to set up on your range, you should design it to include all of the following in the "communications net."



All of these stations must be able to communicate with control, and vice-versa. It is not necessary that any of the stations be able to communicate with each other, however, and it is probably preferable that they do not. You will have better control and discipline if the control center is the one source of information for everyone, and the sole authority for orders.

There are two other important things you should keep in mind about your communications net:

a. Keep it as simple as possible:
The more gadgets you have, the more frequently it will break down.
b. You must always have an alternate means of communication with every station.

The second of these two rules is the more important. It is a basic rule in all military operations, but unfortunately is a difficult one to enforce. People are prone to rely on the wonderful gadgets of modern technology to the point that they are lost and helpless when those gadgets break down and refuse to function properly. When you are conducting an operation which demands close timing and coordination you cannot afford to put yourself at the mercy of mechanical gadgets. You must have a reliable alternate means of getting messages to people.

An Ethiopian lieutenant in Korea once amazed a group of American officers with a demonstration of perfect control over his platoon in a difficult tactical problem. He used none of the ordinary means of communication. None of his squad leaders carried radios. But each squad leader always had a man in visual contact with the lieutenant to relay hand signals. When any man's attention wandered the lieutenant had an infallible alternate means of communication available to him. He would pull a pebble from his cartridge belt, and at ranges of twenty to thirty yards he could hit any man on the head with it. The pebble never failed to get attention.

Just consider, for a moment, all the alternate means of communication that are available to you and you will probably find many uses for them on your range. Just as the cave man, the Indian and the Roman did, you can send messages to people over considerable distances without the use of telephones and radios. Anything that can be heard, seen or felt is a means of communication. Here are some obvious ones:

Bells
Sirens
Megaphones
Drums
Gongs
Whistles
Horns
Reflecting mirrors
Colored flares
Smoke flares
Flashlights
Flags
Hand signals
Runners

You can use many of these means of communication to notify range guards and observers of the exact status of operations at the launching pit as long as you have had the foresight to establish a prearranged set of signals. Range guards can also use devices such as colored flares to notify the control center that it is unsafe to fire.

Illustration *49*, which shows the basic layout of a launching site, also shows a suggested communications setup. There should be a red flag flying at the control center at all times that firing is in progress. This should be replaced by a green or yellow flag when firing is not in progress. Red flags should fly at all entrances to the launching site during the entire time the range is in use. If there is a prominent piece of ground on your site which can be seen from all directions, you can fly one flag from it and dispense with all others.

The Launching Rack: The most important single piece of equipment on your launching site is, of course, the launching rack. Most groups develop racks of their own design after a little experience, and it is obvious that no single design can be considered ideal for all types and sizes of rockets. You will have to adapt the ideas shown in Illustrations *63* and *64* to suit your own particular requirements. The important things to consider in the design and construction of a launching rack are:

a. That it is long enough to give initial stability to the rocket.

b. That it is rigid and firmly anchored.

c. That it can be elevated and depressed to vary the launching angle.

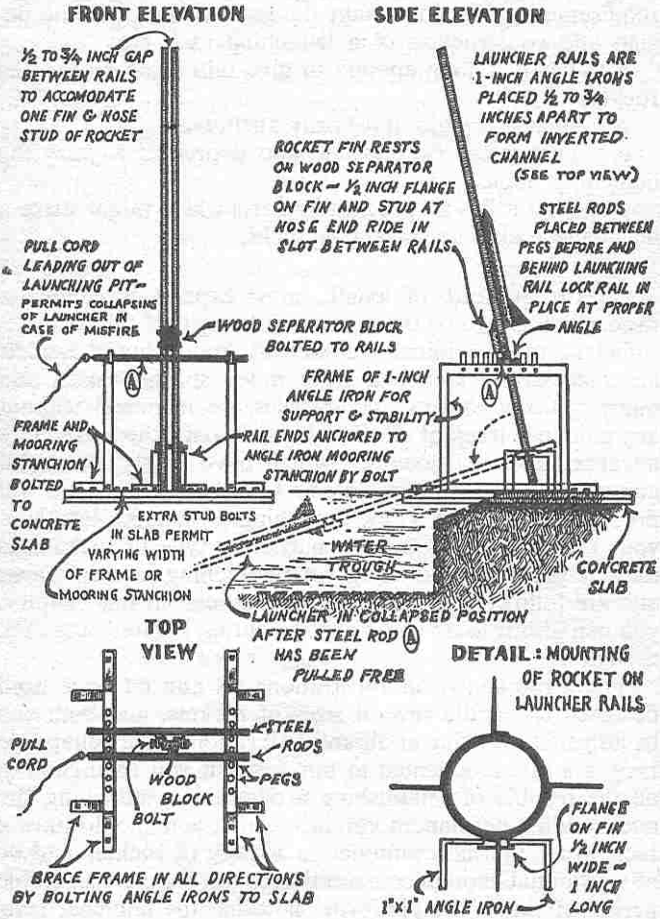
d. That it has no protruding parts which might strike a fin of the rocket and affect its flight.

On the question of length, most experts agree that a rack which is two or three times the length of the rocket is sufficient to give initial stability. Actually, many rockets are successfully launched from much shorter racks, and many military rockets and missiles are launched without any guidance track at all. For the most part, these are more advanced rockets, however, which have highly developed guidance and stabilizing systems built into them. You will probably find, after a few launchings, what the length of your rack should be for any particular type of rocket. As long as you are conducting your launching in a safe area and are following the precautions outlined in this chapter, you can afford to do some experimenting in launching rack design.

The types shown in Illustrations *63* and *64* have been designed to handle several sizes of rockets, and both can be adjusted for firing at different elevations. The collapsible rack is a bit complicated to build, but if you have gone to all the trouble of establishing a permanent launching site and building permanent emplacements, you should have a rack which will accommodate a variety of rockets and be of substantial enough construction to last for a considerable period of time. The platform on which the launcher rests can be of poured concrete, railroad ties or other heavy timbers imbedded in the earth. Perhaps one of your group has a father who is a contractor, or you may be able to get

ILLUSTRATION NO. 63

Rocket Launcher... ADJUSTABLE AND COLLAPSIBLE... FOR ANY SIZE ROCKET.



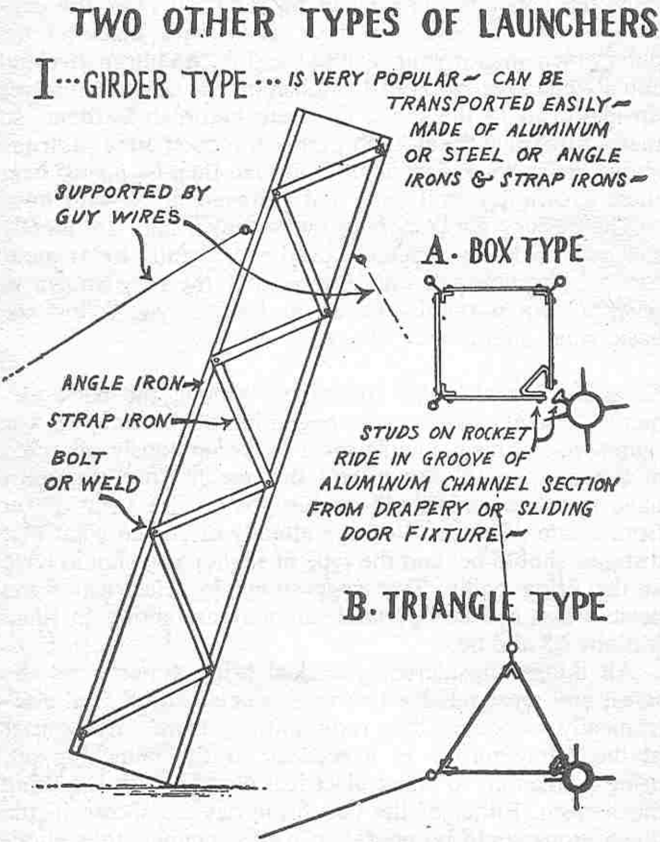
a local contractor to pour this slab for you as a contribution to your project and tap the holes for attaching the angle irons to the concrete. If you pour the slab yourself you can lay pieces of strap-iron in the pit first which have threaded holes tapped in them, the size of the bolts you intend to use. Place wooden pegs upright in these holes when you pour the concrete. These can be removed after the concrete is set, and you then have ready-made holes for the bolts which anchor your rack to the slab. An alternative and equally effective method is to position the bolts themselves upside-down in the moist concrete before it hardens, so that approximately an inch of the threaded ends protrude above the surface. The angle irons can then be placed over these protruding bolt ends and fastened down with nuts.

The designs for launching racks shown here are merely suggestions. Many types are used successfully by amateur groups, and you can improve or alter the ones shown to fit your own particular needs, as long as you follow the basic rules enumerated above.

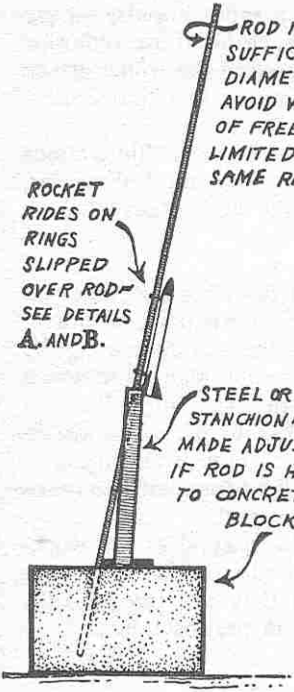
Remote Control Firing Systems: Among the basic elements of safety listed at the beginning of this chapter was *remoteness*. This principle must be scrupulously observed at the moment of firing, and this means that you must have a device which will enable you to fire your rocket from a safe distance. We have already discussed what that distance should be, and the type of shelter you should have at the firing point. Two suggestions for electrical firing devices that can be operated remotely are shown in Illustrations *65* and *66*.

All things considered, electrical firing systems are the safest and most reliable to use. Rockets can be fired electronically, of course, by a radio impulse from a transmitter at the firing bunker to a receiver at the launching pit, using a solenoid to effect electrical contact with the firing mechanism. Either of the two firing devices shown in the illustrations could be operated in this manner, thus eliminating ground wires running to the firing bunker. However, there is no particular advantage to be gained by using a radio impulse (except to be able to say that you have done it) and there is a great sacrifice of safety. Not only do you run the risk of members of your own group accidentally firing the rocket, but you never know when a

ILLUSTRATION NO. 64



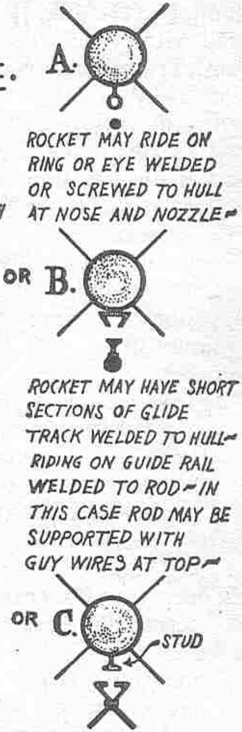
II··· STEEL ROD SET IN CONCRETE·



ROD MUST BE OF SUFFICIENT DIAMETER TO AVOID WHIP ~ LENGTH OF FREE TRAVEL IS LIMITED FOR SAME REASON

ROCKET RIDES ON RINGS SLIPPED OVER ROD ~ SEE DETAILS A. AND B.

STEEL OR IRON STANCHION ~ MAY BE MADE ADJUSTABLE IF ROD IS HINGED TO CONCRETE BLOCK



ROCKET MAY RIDE ON RING OR EYE WELDED OR SCREWED TO HULL AT NOSE AND NOZZLE ~

ROCKET MAY HAVE SHORT SECTIONS OF GLIDE TRACK WELDED TO HULL ~ RIDING ON GUIDE RAIL WELDED TO ROD ~ IN THIS CASE ROD MAY BE SUPPORTED WITH GUY WIRES AT TOP ~

LAUNCHING ROD MAY BE OF ANGLE IRON WITH GLIDE TRACK WELDED TO IT ~

taxicab or police radio, or a ham operator, may start transmitting on the frequency you have selected for your own signals. (*See* Chapter 6)

This may seem hard to believe, but it is cited on good authority: when the Navy first started firing high-altitude Aerobee rockets for the IGY program at Fort Churchill in Manitoba, Canada, it found its radio signals being interfered with. Where do you suppose the interference came from? Taxicab radios in Charlotte, North Carolina—1,800 miles away.

Another disadvantage in using a radio impulse to fire your rockets is that it makes it dangerous to use radio for your communications net, or any type of electronic device for tracking. The best and safest means is a simple electrical system.

You will find the firing devices shown in the illustrations easy to assemble, reliable and safe. You must, however, keep the following rules in mind and observe them scrupulously:

Always include a safety light in the circuit so that you can tell visually whether the circuit is open or closed.

Always have a means of locking the box containing the firing switch, or button, and appoint a guard to watch it when any personnel are in the launching pit.

Only one man should have a key to the firing switch box, and he should keep it with him at all times.

Check your batteries and safety light frequently to make certain they are functioning properly.

An electrical mechanism is only as good as the workmanship you put into it. Make sure that all wire leads are connected securely, that they are free of rust, and that there are no breaks in the insulation.

ILLUSTRATION NO. 65

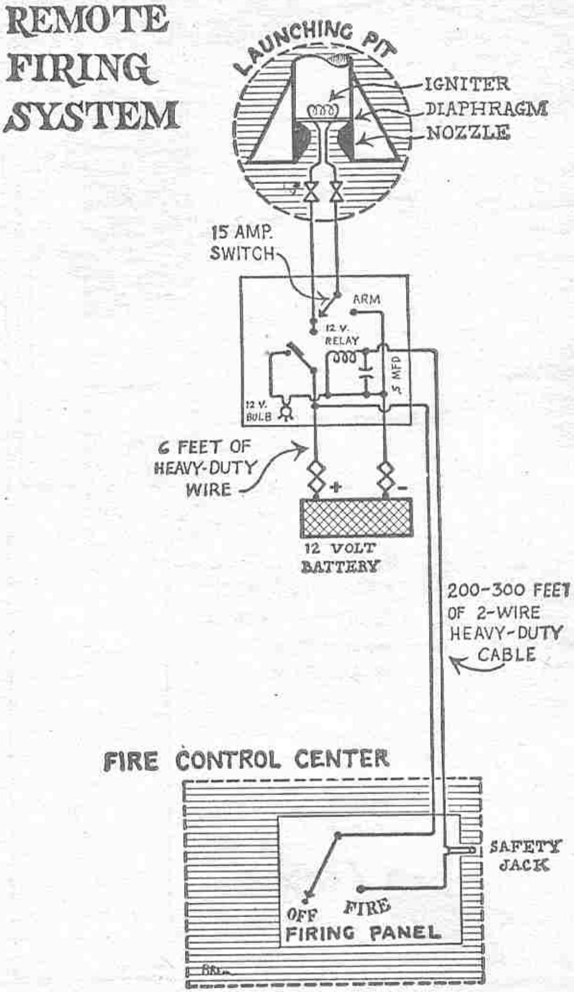
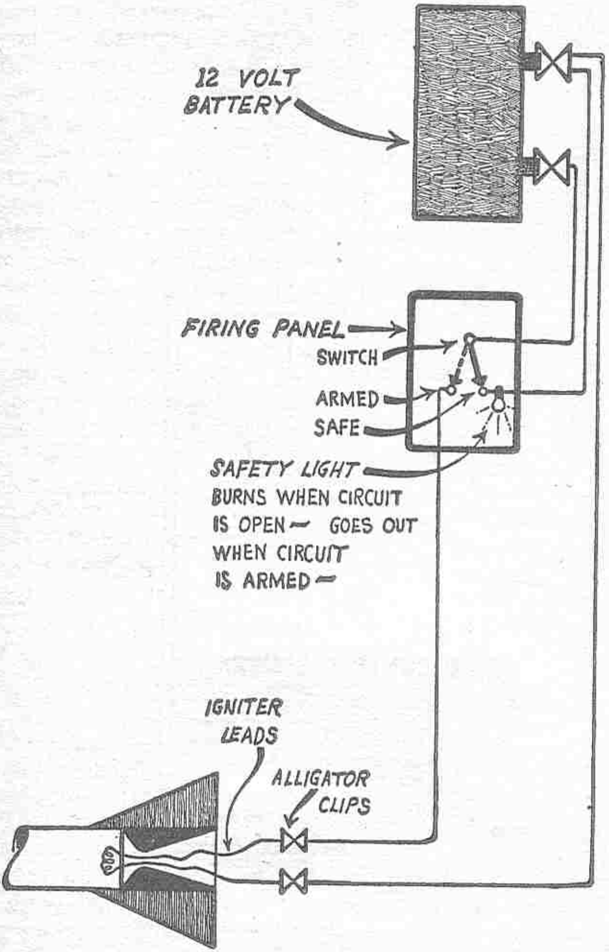


ILLUSTRATION NO. 66

A SIMPLE ELECTRICAL CIRCUIT FOR REMOTE FIRING



Chapter 9

SAFE RANGE PROCEDURES AT THE LAUNCHING SITE

Assuming that you have a properly laid-out launching site constructed according to the principles outlined in the preceding chapter (though not necessarily as elaborate) and you have obtained the proper clearances and permissions of responsible officials, you now must learn how to use it effectively so as to take maximum advantage of the safeguards that have been built into it. You can blow yourself up on a so-called "safe" range just as easily as you can in your own basement, simply through carelessness and failing to establish simple and orderly routines that are easy to follow. Such routines are essential to the safety of all participants in a group project, and every individual assignment must be carried out to the letter, or failure—even disaster—may result. Any high school football player knows the importance of carrying out his individual assignment on every play, no matter how pointless it may seem in a hundred run-throughs. The time always comes when that particular assignment is the key to success or failure of the entire play—perhaps the game. Similarly, a driver, in order to qualify for a license and to avoid having accidents on the highway, must learn certain routines and get in the habit of taking certain actions by instinct, even though they may be wasted effort 99% of the time. As an example, the well-schooled driver automatically gives a signal before making a left- or right-hand turn. Probably only once in a hundred times does this signal serve a really useful purpose. But it is essential that it be given every time, as a matter of habit. For once in ten thousand times it may save the driver's life.

You must establish similar routines for the over-all operation of your launching site and for every individual who has an important assignment. And you must impress upon every member of your group the importance of following these procedures *every time* you conduct a test-firing or launching. What these procedures are, and the reasons they are important is the subject matter of this chapter. A complete operating procedure for conducting firings is outlined here as a model upon which you can base your own range regulations and step-by-step routine for launchings. It is not expected that you will duplicate this model procedure in every detail, for it has been designed for a hypothetical launching site and a hypothetical group. You must modify it to fit your own particular launching facility and the capabilities of your own group. What is important is that you understand the reason for each of the actions and safety checks taken, and follow the same principles in developing your own.

I POSITIONS AND RESPONSIBILITIES

Following are the positions and responsibilities to be assigned to individuals in your group. These are the essential positions necessary to assure the smooth operation of an "ideal" firing range. Your group may not be large enough to staff all of these positions. Your launching site may differ substantially from the one described in Chapter 8. Therefore, the organization of your range operation may be considerably different. Again, the important consideration is not whether you have supplied a man to fill each of the positions listed, but whether you have arranged to take care of each of the functions shown.

Range Officer—He is in complete charge of the launching site. No action is taken without his direction. He gives all orders, makes all decisions. His place should be at the control center.

Safety Officer—He is responsible for checking all critical points of the operation in advance to make certain that safety regulations are being followed. Responsible for instruction of all personnel in safety precautions. No firing takes place until he has given his clearance to the Range Officer.

Fueling Supervisor—He is responsible for establishing the procedures to be followed in the fueling pit and for supervising the actual fueling operation. Certifies the fueling area as clear before firing can proceed.

Spectator Control Officer—He is responsible for clearing the launching area of all personnel not assigned to specific posts and seeing that they are behind proper shelter before he gives his clearance to the Range Officer. If your group is short of personnel, this assignment may be handled by the Safety Officer.

As previously stated, the positions shown above are considered to be essential. If your group is small you must combine responsibilities wherever possible to ensure that every assignment is properly covered, with due regard for the fact that you cannot give one person too much to do. If you have a very large group, you may want to establish additional positions, such as a communications supervisor, photographic supervisor, etc., in order to give all members of your group something to do on each firing. All of these positions, of course, are either *supervisory* or *control* jobs. In addition you will have the people who perform the actual launching operation, and those who have a specific duty to perform not supervisory in nature. These are:

Key Man—He carries the key or the safety jack for the firing mechanism, and consequently is the only man on the range who can fire the rocket.

Fuelers—They perform the actual fueling operation.

Pit Men—They mount the rocket on the launcher in the launching pit under the supervision of the Safety Officer.

Range Guards—They are responsible for keeping bypassers out of the area, scanning the sky for aircraft, and certifying to the Range Officer that it is safe to fire.

Observers and Trackers—They are responsible for tracking the path of the rocket, taking observations on the azimuth and angle of elevation at the peak of trajectory and reporting them to the control center for plotting.

Recorders and Computers—They are responsible for recording all data received from observers and/or mechanical tracking devices for each firing, and for computing the path and performance of the rocket. They should be located at the fire control center.

First-Aid Man—A very important man who should have qualified for his job by completing a Red Cross first-aid course, or similar training.

The number of persons you choose to assign to each of these jobs in the second category will vary, of course, with the size of your group. It is important, however, that there be only one key man and only two fuelers and two pit men. Two men are sufficient to handle the fueling and the positioning of the rocket on the launcher. These are the most delicate operations, and any more than two people in addition to the supervisor would tend to create confusion and increase the likelihood of a mishap. Furthermore, and most importantly, if you are going to have an explosion it is far better to injure only two persons, rather than three or four.

Naturally, you should rotate assignments among the members of your group as frequently as possible. This is important, not only to relieve the boredom of always having the same job to do, but also from the standpoint of training the maximum number of people in each job. There are certain assignments, of course, requiring special skills which only a few members of your group will have. There also are people who like to do only one thing—such as photography or telemetering. But to the greatest extent possible, try to change the assignment of each individual on each firing and the group as a whole will become more proficient as a result.

II RANGE PROCEDURE

In setting up the procedures to be followed on your range, or launching site, you must be systematic and you must be logical. But above all be as simple as possible. Complicated procedures and unnecessary regulations only serve to increase the likelihood of a mishap. Simplicity is a basic rule of tactical planners in the Army, and very frequently maneuvers that are tactically sound in themselves are rejected because military men know that large groups of people in a coordinated effort become very easily excited and confused; and if the plan they are following is not the soul of simplicity itself, it will fail, no matter how well-conceived a plan it may be. If, after you have established a working procedure and tested it, you find that certain features of it are not really necessary, and serve no useful purpose, eliminate them. Nothing is more destructive of morale and efficiency among the personnel of an organization than regulations which appear to have no purpose. Eventually people will eliminate them or violate them on their own initiative. When this happens, and nothing disastrous occurs, they begin to have less respect for all regulations and procedures, and soon you will find that they are violating vitally important ones, because they think that they have discovered none of them are really necessary. At this point the whole fabric of your system of procedure will be threatened with collapse and you will find the morale of your organization very poor. If you would be a successful organizer and "run a tight ship," as they say in the Navy, then you must learn to apply two very simple, but inviolable rules:

Never establish a rule or regulation that is not entirely necessary.

Never establish a rule or regulation *which you cannot enforce*, no matter how necessary you feel it is.

The firing procedure which follows is intended to be comprehensive and all-inclusive. For that reason you may find it unwieldy, too elaborate, and much too ambitious for your group. Again, you must use your own judgment in determining which procedures are best suited to your own particular group and launching facility, using this procedure as a guide to ensure that you are not overlooking anything important. In a sense, you are a pioneer, and you must work out for yourself the procedure that is best and safest for *you* to follow. Amateur rocket groups have not been operating long enough for hard and fast procedural patterns to be established, and scarcely anyone is an authority on the subject.

But there is one consideration which you must always bear uppermost in your mind, and from which no deviation can be allowed. *You must base your firing procedure on the assumption that the rocket is going to explode.* To proceed upon any other assumption is foolhardy and an invitation to disaster. No person on earth can possibly predict what a specific rocket will do when it is ignited. It is therefore safer to pretend that you are setting off a bomb or a charge of blasting dynamite, and proceed accordingly.

Range procedure is divided into four separate operations. They are: *prefiring procedure, firing procedure, in-flight procedure* and *postfiring procedure*. Each of these periods has a definite end and a definite beginning. The *prefiring* period ends when all preparations for the launching have been made and all personnel are under cover ready for the blast off. The *in-flight* period ends with impact of the rocket on the ground. The *postfiring* period ends when all data have been reported and evaluated and a critique of the operation has been concluded. The step-by-step procedure for each of these four phases of a launching is provided for you in the following outline. The outline for the postfiring procedure includes the alternate patterns of action to be followed for successful and unsuccessful firings.

PREFIRING PROCEDURE

1. *Briefing:* Every group operation must start with a period of briefing, or orientation, in which the conduct of the operation is outlined to all participants, each individual is given his instructions, special actions involving a departure from normal procedure are explained, and questions of participants are answered. The Range Officer conducts this briefing and makes individual job assignments at this time. He may also call upon other members of the group, such as the Safety Officer, to explain certain phases of the operation, or to give emphasis to a particular phase. Every member of the group must attend this briefing, and every person who has a question about the procedure to be followed must be encouraged to ask it at the briefing. Once the operation has started, questions cause delays and it is frequently not possible to ask or answer them.

The briefing should be held on a prominent piece of ground from which the salient features of the launching site are visible to all members of the group. If such a piece of ground is not available, then the logical place to hold the briefing is at the fire control center. The Range Officer should have a blackboard available on which he can diagram the launching site and give graphic illustrations of points he wishes to cover. If a blackboard is not available, he should be provided with a suitable pointer and a sand table, or a sandy area, on which he can illustrate important points. The length of the briefing is entirely dependent upon the complexity of your launching procedure and other factors which will vary with each group. It will require at least fifteen minutes, however, and perhaps as long as an hour.

2. *Firing Stations—Scouts Out:* Immediately after the briefing is concluded all personnel move to their assigned stations. (Since range guards must normally traverse a considerable distance to their posts, and since fueling the rocket may sometimes be a time-consuming process, the fueling operation may be started as soon as all personnel in the immediate vicinity of the launching area have

reached their positions. Range guards at the most distant locations may not be able to report in to Control until second reports are called for in step 9.) The yellow range flag should be run up at this time.

3. *First Reports:* As each person reaches his assigned station he must report in to the fire control center that he is in position and ready to perform his assignment. The method of reporting is dependent upon the type of communications you have, naturally. If you are not using a telephone or radio net, the report may be in the form of a signal, flare, hollering through a megaphone, or simply running up a small flag on a pole that can be seen from the fire control center. The Range Officer and his assistants must systematically check off each station on a chart as its report is received and initiate follow-up action in the case of stations not reporting in. Again, if you are not using telephones or radio, runners must be assigned to the Range Officer for the purpose of checking on delinquent stations.

4. *All Clear in the Launching Area:* When all stations except the more distant range guards have reported in the Range Officer announces, "All clear in the launching area," and gives the order for the fueling operation to start. "All Clear" in this instance means that all persons in the launching area are at their assigned stations, spectators are clear of the area and in a trench or behind barricades, only two persons are in the fueling pit with the Fueling Supervisor, and two pit men are in the launching pit. The only person who may move about at this time is the Safety Officer who must check the fueling pit, the firing mechanism, the position of the key man, the first-aid man, etc.

5. *Fueling:* Upon receiving the order to fuel the rocket the fuelers and Fueling Supervisor first run up a red flag in the fueling pit. This serves to warn all persons in the launching area that fueling is in progress. When fueling has been completed, except for insertion of the ignition device, the Range Officer at the fire control center (Control) is notified that the rocket is ready to be moved to the launching pit. This signal may consist of lowering and raising the red flag two or three times if other means of communica-

tion do not exist. When the signal is received from the fueling pit the Range Officer gives the order to clear the fueling pit of all unused fuel, and the fuelers and Fueling Supervisor retire to the spectator trench or other positions that have been assigned to them. The Safety Officer inspects the fueling pit to certify to the Range Officer that it is clear of unused fuel. The Range Officer then gives the order for the rocket to be moved to the launching pit.

6. *Positioning:* The rocket is moved to the launching pit by the pit men and the Safety Officer. The Safety Officer has the ignition device in his possession at all times. The red flag is lowered at the fueling pit and one is raised in its place at the launching pit. At the same time, the yellow flag on the main flag pole for the range is changed to a red one. The rocket is positioned on the launcher by the pit men and a length of wire long enough to reach outside of the barricade is attached either to the rocket or the launcher, depending upon the type of launcher you are using. (*See* Illustrations *54* and *63,* Chapter 8.) This wire is to be used to topple the rocket to the ground or into a water trough in the event of a misfire. The ignition device is then inserted. The Safety Officer makes a final check of the launcher and rocket, orders the pit men out of the pit, and sees that the wire leads to the ignition device are strung to the relay box which should be located *outside* of the pit or barricade. He checks to make certain the circuit is shunted at the relay box before he permits the wire leads to be connected to it. Leaving the relay box shunted he orders the pit men to the spectator trench, or to other positions assigned to them, and reports, "Ready in the launching pit!" to the Range Officer.

7. *Take Cover:* Upon receiving the "ready" report from the Safety Officer, the Range Officer announces, "Ready in the launching pit!" and "Take cover!" With this announcement all persons are required to get behind the protective barricades provided for them and stay there until the "All clear" signal is given by the Range Officer. This is the end of the prefiring procedure, and assuming that all personnel are accounted for and in protected positions, the firing procedure is about to start.

8. *Safety Check—Second Reports:* The Range Officer calls for a final safety check and second reports from all positions. It is not assumed that anyone is in a safe position simply because he cannot be seen. Positive reports are required from all stations by visual signal or telephone and each is checked off on the fire control chart by the Range Officer's assistants. By the time second reports are called for the more distant range guards should be in position and are included in the check-off procedure. Range guards carefully scan their areas of responsibility for persons or aircraft that may be within the limits of the range and report whether their sectors are clear for firing. Observers and trackers report that they are in position with instruments trained on the launching pit and that they are ready to track the path of the rocket. The Spectator Control Officer, or Safety Officer, certifies that all spectators are behind cover in the area designated for them.

9. *Ready on the Right—Ready on the Left:* When reports have been received from all stations on the right of the fire control center the Range Officer announces, "Ready on the right!" When all reports have been received from stations to the left of the fire control center the Range Officer announces, "Ready on the left!" When reports have been received from all points in the immediate vicinity of the fire control center and launching area, he announces, "Ready on the firing line!"

10. *Prepare to Fire:* The Range Officer then instructs the key man to check the firing panel. The key man checks to make certain that the firing panel switch is locked (or the safety jack is out) and reports, "Firing panel clear!" (This means that the circuit is open, the rocket cannot be accidentally fired, and it is safe to remove the shunt to close the circuit at the relay box.) The Range Officer then gives the command, "Prepare to fire!"

11. *Safety Officer Clears:* On the command, "Prepare to fire!" the Safety Officer proceeds to the relay box located outside of the launching pit barricade and closes the shunting switch. This closes the firing circuit so that the rocket

may be fired by the switch at the fire control center. He then returns to the control center or the spectator trench, whichever is his assigned station, and informs the Range Officer that it is clear to fire. The Range Officer announces, "Clear to fire!" and, "You may fire at the count of zero!"

12. *Countdown:* The Range Officer then announces "Fifteen seconds to blast-off!" The key man may then insert the key, or safety jack, after making sure that the firing switch is still open. At ten seconds the Range Officer begins to count down the seconds remaining until firing time, using the public address system or megaphone. "Ten seconds. . . .nine seconds. . . . . .three seconds. . .two seconds. . .one second. . .Fire!" At the command "Fire!" the key man closes the firing switch.

(NOTE: If at any time during the firing procedure or countdown a range guard, or any other member of the group, becomes aware of the presence of an aircraft or persons approaching the range area he should immediately halt the procedure by means of a prearranged signal, such as a flare or a blank cartridge being fired. Upon receipt of such a signal the Range Officer will immediately command "Hold! Cease firing!" until the reason for the interruption can be determined. If a considerable delay is to be involved, he must order the key or safety jack removed and the firing circuit shunted again at the relay box. When the range has again been cleared for firing, the firing procedure must be repeated, commencing with step number 8 (Safety Check —Second Reports), since many persons may have moved from their assigned positions during the delay.)

IN-FLIGHT PROCEDURE

13. *Maintain Cover—Open Firing Switch:* From the time of lift-off to the time of impact of the rocket onto the ground, all persons on the range must maintain their positions behind protective barricades, and, where provided, under overhead cover. (If you have ever seen an unbalanced rocket zig-zagging wildly through the air a few feet above the ground you can appreciate the reason for this. And such a flight is possible, even with well-designed rockets, due to slight variations in the density of the propellant and the resultant erratic burning.) Observers and trackers,

of course, must remain partially in the open to do their jobs (*see* Illustration No. *58*, Chapter 8) but they are generally more than a thousand feet away from the launching pit. As soon as the rocket has left the launcher, the key man opens the firing switch to prevent unnecessary drain on the battery.

14. *Observation and Tracking:* Observers and trackers, who have had their eyes and instruments trained on the launching pit since the beginning of the countdown, now follow the flight of the rocket. Methods of doing this are discussed in Chapter 10. Generally speaking, the trackers are responsible for obtaining elevation and azimuth readings at the peak of the trajectory; and the observers are responsible for timing the flight, noting the general behavior of the rocket, recording time of burn-out, if possible, and obtaining azimuth readings to the point of impact.

15. *Impact Observation:* Impact of the rocket on the ground should be observed and noted by all who are in a position to see it, since the point of impact is frequently a very difficult thing to pinpoint. It is primarily the responsibility of the Observers at the tracking stations to attempt to fix this point as accurately as possible and report the azimuths from their stations to the fire control center when reports are called for. Methods of increasing the accuracy of impact observations are discussed in Chapter 10.

POSTFIRING PROCEDURE

A. For a Successful Firing

16 A. *"All Clear."* Once the rocket has impacted on the ground the Range Officer announces, "All clear! Cease Firing!" Persons in the spectator trench may now leave the trench if they desire. Personnel at Observer and Tracker stations remain in position, however, to give required reports and to recheck data observed during the flight. Range guards should remain at their posts unless called in by the Range Officer, or unless firing has been completed for the day.

17 A. *Reset Safety Devices:* The Range Officer now orders, "Reset safety devices!" The key man (who has

already opened the firing switch immediately after lift-off) removes the key, or the safety jack, and reports this fact to the Range Officer. The Safety Officer proceeds to the launching pit and moves the shunting switch to the safe position, thus opening the circuit at the relay box. He reports to the Range Officer, "Relay box safe!" He then removes the wire leads and the spent igniter left behind by the rocket.

18 A. *Reporting of Data:* After the firing mechanism has been reset the Range Officer calls for reports from the Observation-Tracker stations. These reports are sent in telephonically or by runner, depending upon your communications, and are received and recorded by the Recorders and Computers at the fire control center. (Chapter 10 covers the details of this process.) From these reports the altitude, flight time and velocity of the rocket are calculated; and impact observations are reconciled to determine the probable point of impact.

19 A. *Recovery of Rocket:* After the probable path of the rocket and its impact point have been computed, the Range Officer dispatches a recovery team to the impact area while the recording and analysis of other data on the rocket's performance continues. It is best to attempt recovery of each rocket immediately after firing for many reasons discussed in Chapter 10. If and when the rocket is brought back to the fire control center, valuable additional data concerning its performance can be determined, which will be of interest during the critique which follows.

B. For an Unsuccessful Firing

An unsuccessful firing (firing in which there is no actual lift-off, or flight of the rocket) may result from any one of several causes. There may be a failure in the firing mechanism, a failure in the igniter, failure of the propellant to ignite after the igniter has burned out, failure of the rocket to develop sufficient chamber pressure, failure of the diaphragm to burst, etc. Whatever the reason may be, and whatever you may assume the cause to be, it is safest and wisest to follow the same procedure in all cases. Do not jump to conclusions as to the cause and expose yourself needlessly to danger. The procedure which follows is simple to put into effect, and provides maximum safety for you and your group, considering the fact that you have a potentially explosive article to deal with. It requires some prior preparation which should be a normal part of your firing procedure no matter how many successes you may have to your credit. (*See* step number 6, page 266.)

16 B. *Handling a Misfire or "Dud" Rocket:* If your rocket should misfire, do these things in the order indicated and at the times indicated. This procedure assumes that you have taken the precaution (step number 6) of attaching a length of piano wire to the rocket or launcher for use in toppling the rocket to the ground, or into a water trough. It also assumes that the type of launcher you are using, and the method of attachment of the rocket to it, will permit toppling to the ground. You must make one assumption yourself. You must assume that the propellant *is* burning slowly inside your rocket and that it is likely to explode at any moment.

All times are expressed in minutes. "0" represents the intended time of blast-off.

– 0 – Attempt to fire the rocket. If it fails to fire, open the firing switch after a few moments, wait about a minute.

0 + 1 Close the firing switch again. If rocket still fails to fire the firing circuit may be checked by simply bridging the lead wires from the panel with a light bulb assembly. This can be done at the fire control center. (This test is unnecessary if your firing circuit includes a light on the panel which lights up when the circuit is closed and current is flowing through it.) If the firing circuit functions and the rocket has still failed to fire, the Range Officer instructs all personnel to remain under cover and suspends all operations for fifteen minutes. The key or safety jack is removed from the firing panel at this time.

0 + 15 At the end of the fifteen-minute waiting period, the Safety Officer, or other person designated by the Range Officer, takes a length of wire or rope and *crawls* from the fire control center to the point outside of the launching pit barricade where he placed the end of the piano wire which is attached to the rocket, or launcher. He should be wearing a protective helmet, and it is important that he remain flat on the ground at all times. He first moves the shunting switch on the relay box to the safe position, then he attaches the end of the rope to the end of the piano wire. He then crawls back to the fire control center. (NOTE: If the piano wire is attached to the launcher itself, it obviously is not necessary for anyone to crawl out to the launching pit, because the wire or rope can be strung all the way to the Control Center initially (*see* Step No. 6). Crawling out is eliminated if your launcher is of the type shown in Illustration No. *63,* Chapter 8).

0 + 20 When the Safety Officer has returned to the fire control center the rope is pulled sharply in order to topple the rocket onto the ground. (This is done to precipitate an explosion or ignition of the rocket, if possible, while it is within the enclosure of the launching pit.) If no detonation takes place, the Range Officer orders all personnel to remain in position for another five minutes. If your launching pit is equipped with a water trough, of course, this procedure is much safer.

0 + 25 At the end of the five-minute waiting period the Range Officer designates two persons to disarm the rocket. The persons designated should be equipped with heavy padded clothing (preferably fire-proofed in some fashion), asbestos gloves, face shields and helmets. If the launching pit has been constructed according to the plan shown in Illustration *54* in Chapter 8, the entire rocket and launcher will have been plunged into the water. Care must be exercised by the two men to avoid exposing any more of their bodies than is absolutely necessary at any time. They should lie flat on the ground throughout the disarming operation and should make certain that the nozzle end of the rocket is completely immersed in water while the igniter is removed.

17 B. *"All Clear":* Once the igniter has been removed from the rocket the Range Officer announces, "All Clear!"

Following a misfire, however, nobody is permitted to enter the launching pit until the rocket has been removed from it.

18 B. *Reset Safety Devices:* The safety devices have already been reset during the process of handling the misfire. However, in order to ensure that there has been no slip-up, the Range Officer now orders a complete recheck of the firing mechanism.

19 B. *Reporting of Data:* Obviously no reports are required from Observer and Tracker stations following a misfire, but useful data may be obtained from examination of the igniter, the rocket itself after it has been rendered safe, and from persons who may have been in a position to observe the behavior of the rocket on the launcher. Any scrap of information which may be helpful in determining the reason for the malfunction should be recorded for later analysis.

20. *Critique and Evaluation:* Following each firing, whether successful or unsuccessful, there must be a critique of the operation and an evaluation of the performance of the rocket and the performance of the group as a team. Range guards may or may not be brought in for these critiques, depending upon their distance from the launching area and whether or not they are to be rotated. They should attend the final critique, however, at the end of the day's firing. The Range Officer conducts the critique, presents the data on the performance of the rocket, and calls for comments from other members of the group in supervisory assignments. At the conclusion of the critique new job assignments for the next firing are decided upon, and the briefing for the next firing begins.

Using the foregoing procedure as a basis you can develop your own system for controlling the activities of your group at the launching site. You may find that certain steps can be eliminated or that others may have to be added because of the type of equipment you are using, the composition of your group, or the physical layout of your launching site. Whatever procedure you eventually develop, go over it very carefully, discuss it thoroughly with all members of your group, and actually rehearse it in a dry run several times. You do not have to be at the launching site to conduct these rehearsals. They can be held in your living room, if necessary, and you will be surprised to find how many defects in your procedure will be exposed when the members of your group actually go through the motions of conducting a firing.

When you are satisfied that you have a workable, foolproof procedure that gives maximum assurance of safety, you should prepare a master check-list which outlines the entire procedure and includes every important step, order and safety check that must be made. A copy of this check-list should be furnished to the Range Officer prior to *each* firing so that he and his assistants can physically check off each step in the procedure as it occurs. Nothing should be left to memory or supposition. This check-list should become a part of the permanent record of each firing, and you can include space in it for written comments of the Range Officer so that he can make note of unusual occurrences or departures from the normal procedure.

Correct range procedure is important and vital to your safety. Do not neglect it or minimize it. No matter how good your equipment may be, no matter how expert the members of your group, you can still have an accident. For the greatest single cause of accidents is human error; and procedures are established for just one reason—to reduce human error to a minimum.

Chapter 10

TRACKING

HOW TO TRACK YOUR ROCKET HOW TO EVALUATE ITS PERFORMANCE

Tracking your rocket, once it has left the launcher, is not easy. A frequent comment of amateurs, when asked how their rocket performed, is, "It went out of sight!" or, "We don't know where it went!" When this is the case, most of what you have been working toward is lost. For the behavior of your rocket throughout its entire trajectory, and the recovery of it, if possible, constitute your entire source of information. Virtually nothing can be told from the launching itself, except the fact that sufficient lift did, or did not, develop. For this reason there is really no point in observing the blast-off, except to experience the thrill that all rocketeers feel at the sight. If you are to gain the most from your experimentation with rockets, you must develop a reasonably efficient system for observing as much of the flight path as possible, and recovering the spent hull. It is the purpose of this chapter to help you develop such a system.

There are many techniques and methods used by amateur groups in tracking rockets, and many others that have been suggested. Some methods are workable, others are not. A great many of them appear to be sound in concept, but prove to be ineffective when put to a practical test. But no matter what methods you use, you must train yourself to use them effectively. No method will work automatically and without effort on your part.

For instance: it is possible for a man to follow the flight of a 155mm. artillery shell with the naked eye from the time that it leaves the muzzle until it impacts on the target —*but he must train himself to do it*. Such a shell travels at a speed close to 2000 mph and is even smaller than many amateur rockets, so you can see that it is entirely possible for you to track your own rockets visually.

Also, it is possible for a man to estimate ranges (longitudinal distances on the ground) with the naked eye and with reasonable accuracy, after he has practiced the technique long enough. Similarly, he can learn to estimate lateral distances and elevations, once the range is known, with even better accuracy.

All of this means that you can not only follow the flight of your rocket without the aid of expensive and delicate instruments, but you can also make a reasonable evaluation of its performance without all of the intricate equipment used by the military services and research agencies. The material which follows is designed to help you learn how to do this using only elementary equipment which should be available to any group. This equipment includes your eyes and fingers, binoculars, a simplified theodolite, home-made alidade, protractor, ruler, compass, drawing boards, graph paper, and telescopes (if you can use them effectively). Some of this equipment is optional.

First we will discuss a basic system for tracking which should form the basis for all of your tracking operations. Once the basic system is understood thoroughly, you can simplify it or elaborate upon it as you see fit, depending upon the capabilities of your group, the type of equipment you have at your disposal, and the physical characteristics of your particular launching site. Following that, we will discuss a variety of methods and alternate types of equipment that can be employed to improve your chances of reasonably accurate tracking.

The term "reasonably accurate" is used because there is no such thing as *absolute accuracy,* even in the professional field. If such were the case, many military and scientific development projects in the missile field would have ceased long ago, because the engineers and scientists concerned would have reached one of the objectives they are striving toward. A guidance systems engineer in a leading industrial firm once told me that in order to be certain of hitting a specific target the size of a city block at intercontinental ranges, they must have an accuracy in their calculations equivalent to one-hundredth part of the thickness of a piece of paper. Since the globe has not been mapped to anywhere near this degree of accuracy as yet, and probably never will be, you can appreciate the magnitude of the problems involved. Perhaps this will give you some idea of what the term *absolute accuracy* means, and what the chances are of achieving it.

Another point to consider on the question of accuracy is that the degree of accuracy you need must be related to the objective you have in mind. If you are trying to hit an intercontinental bomber which represents an almost imperceptible speck in the sky at an altitude of 60,000 feet you need one type of accuracy. If you are trying to put a satellite in orbit around the moon, you need another type. But if you are merely trying to measure the altitude reached by a rocket and determine its time of flight and point of impact, you can do with a much more rudimentary, and less demanding, type of accuracy. By and large, the requirements of amateur rocket groups for performance data on their rockets can be satisfied much more simply and easily than professional rocket experts realize; and although the more complex and comprehensive calculations of the professional will produce a more accurate result, it is questionable whether the degree of accuracy involved is of any significance. For instance, it is not important to the average amateur group to know whether the rocket they have just fired reached an altitude of 5,200 feet or 5,208 feet. What they are interested in knowing is whether it went up only 2,000 feet or as much as 10,000 feet!

For this reason, and for another which will be discussed shortly, the charts, diagrams and methods of computation contained in this chapter have been simplified in the interests of making them readily understandable, and in order to permit the rapid calculation of performance data. They are not intended to give highly accurate results which would conform to professional standards, and it would be misleading to present them in that light.

A third, and most important, point to be considered in determining the degree of accuracy which is valid and appropriate in your work is that the degree of accuracy you use in your computations must be related to the accuracy of the basic data with which you are working. If your basic data is only approximate, your answer, or end result, can only be approximate; and it is a waste of time to try and improve its accuracy by more refined computation. If you continue the study of mathematics in college (and you most certainly should), you should include some statistical analysis in your program. The study of statistical methods and their application to the evaluation of data will give you an understanding of the theory of significant numbers and of absolute and approximate quantities. You will learn and appreciate, for instance, that the result of any mathematical computation can only be as accurate as the basic data on which the computation is based. It cannot be *more* accurate (except by accident), and it is usually *less* accurate. In fact, when you are working with approximate basic data, it is even possible for a simple and short-cut method of computation to produce a result that is closer to the true answer.

A simple example will serve to illustrate this point. Let us assume that two men are asked to calculate the circumference of a circle which they are told measures 3 inches in diameter. The first man, striving for accuracy, multiplies by 3.1416 and comes up with an answer of 9.4248 inches. The second man, noticing that the diameter of the circle has been measured with a common ruler that could not be expected to give an accurate diameter, multiplies in his head by 3.1 and gives the answer of 9.3 inches. He then asks that the diameter of the circle be measured accurately and it is found to be not 3 inches, but only 2.97 inches. This means that the actual circumference of the circle is 9.330552 inches, and the second man has come closer to the true answer simply because he recognized that he was working with an approximation in the beginning.

This example is cited, not to discourage you from taking the pains to be accurate in your work, but simply to emphasize the importance of recognizing the nature of the information with which you are working, and the futility of trying to get highly accurate results through laborious computation from very questionable basic data. To relate this lesson specifically to the subject at hand let us take the case of calculating altitude by the method of triangulation. The method itself is one hundred per cent accurate. But we must allow for the fact that the initial data on which we base the calculation is not one hundred per cent accurate. Therefore the altitudes themselves will only be approximate—but they will be within reasonable proximity to the true answer. As an example, an elevation reading must be taken from a visual sighting of the rocket as it reaches the peak of its trajectory. At a horizontal distance of 5000 feet a reading of 70 degrees gives an altitude of 13,737 feet. However, an error of only one degree in the elevation reading means a corresponding error of over 700 feet in the computation of altitude. This is a considerable amount; and it is very easy for an observer to make an error of one or more degrees in his reading. Given this great a possibility for error in the original data used for calculation, you can see how ridiculous it would be to waste time and effort in trying to calculate altitude to the nearest tenth of a foot —or even to the nearest hundred feet. At altitudes over 10,000 feet you are doing very well, indeed, if you can get an answer that is within 500 feet of the actual altitude. And in the final analysis, what purpose would be served by being any closer?

A BASIC SYSTEM FOR TRACKING

The system of tracking outlined in this chapter is based on the use of three charts shown in Illustrations *67*, *68* and *69*. Charts A and C are actually used continuously in the Fire Control Center for determining the altitude and impact point of the rocket. Chart B is a three-dimensional diagram illustrating the principle of triangulation as it is employed in this system. The method employed requires the stationing of at least two observer teams at points which are a known distance from the launching pit. What this distance should be has already been discussed in Chapter 8. The observer locations shown in Chart A (Illustration *67*) are equidistant from the launching pit. This is not necessary, but if it is topographically possible to do it on your particular launching site you will probably find it more convenient and less confusing when it comes to plotting and computing the performance of your rocket. Additional observer stations may be established if desired and if you have the personnel to man them. They can be useful in training additional observer teams and also in providing a check on the accuracy of readings taken from the two principal, or base, observer stations. These additional observer stations may be located at any point on the launching site that commands good observation, as long as they are located a safe distance from the launching pit and far enough away to enable the observers to get reasonably accurate readings, as pointed out in Illustration *59* in Chapter 8.

There is another advantage to be gained from establishing a third or fourth observer station. You will note on Chart A, Illustration *67*, that the point on the ground over which peak altitude occurs, and the impact point, can be determined by intersection of azimuths as long as these points do not fall on the base line which runs through the launching pit and the two observer stations. If you locate a third observer station at any point which is not on this base line then you can always get an intersection of azimuths from two observer stations no matter where peak altitude and impact occur. While we are on this subject it may be well to point out that it is not essential for the locations of the two observer stations and the launching pit to form a straight line. They are shown that way on the chart for the sake of clarity and simplicity. No matter where the two observation points are located, however, you will always be able to draw a straight line between them; and it is impossible to determine the location of any point on that line by intersection unless you have a third point from which to take readings.

Chart A illustrates the method of determining the location of specific points on your launching site, or range, by taking azimuth readings from two or more points of observation. An azimuth is simply a compass reading or a *line of direction* from one point to another expressed in terms of degrees, or in *mils* if you prefer to use the Army mil scale. We will discuss both the method of determining, or measuring, azimuths and the use of the Army mil scale in a moment. Chart A also functions as a small-scale map or diagram of your launching site. You will find such a map, or diagram, extremely useful for a great many purposes, and it will be your principal working tool in your fire control center.

To make up such a diagram of your launching site, get yourself as large a piece of graph paper as you can conveniently mount on a board in your firing bunker. The larger the better, generally, but the size you need for your particular operation will be determined somewhat by the size of your launching site and what you want to include on it. A piece of cross-sectional graph paper 36 by 48 inches mounted on a standard drawing board will probably prove adequate for most groups. If you want to be very fancy and professional, however, you can cover one entire wall of your firing bunker with graph paper and do your plotting there. The larger your diagram is, naturally, the greater the accuracy of your plotting will be. The paper you choose should be 10 or 20 squares to the inch.

Paper that is only 5 squares to the inch will give you less accurate results. Some graph paper is graduated in centimeters, so make sure you know what type of paper you are using. Chart A can conveniently be plotted on paper that is 20 squares to the inch and a scale of 1 inch = 1000 feet used. Such a scale used on paper that is 36 inches wide would enable you to plot peak altitude and impact points on a launching site 36,000 feet in diameter. This size launching site is adequate for rockets reaching 7000 to 7500 feet in altitude, but not much more.

From this point on we will refer to Chart A as the *plotting board,* because that is what it actually is. It is the chief tool which you will use to determine where your rocket went and to compute the details of its flight path.

First of all, plot the location of your launching pit in the exact center of your piece of paper (which is the point where it should be located in respect to the launching site itself, as pointed out in Chapter 8). Using this point as the point of origin for all your measurements, you can then indicate on your diagram the relative positions of the firing bunker, the fueling pit, the fuel storage shelter, the spectator shelter and any other facilities you care to, according to the scale you have determined to be most useful in your particular case. The facilities themselves do not have to be drawn to scale, naturally, as this would not be feasible on a small-scale diagram. Their relative positions, however, should be indicated as accurately as possible. In the case of the observer stations, the distance to them from the launching pit should be measured as accurately as possible on the ground and indicated on the diagram. This distance should be measured to the actual point from which readings of azimuth and elevation are to be taken, and not just to the nearest corner of the observer bunkers. This is important because all of your subsequent calculations will be predicated on this distance, which in Chart A has been labeled the *base line.* Similarly, the measurement should extend to the center of the launching rack itself, and not just to the wall of the launching pit.

Once you have plotted in the positions of the principal installations on your launching site you might then consider indicating also the locations of certain prominent terrain features, such as definable crests of hills, prominent trees on the horizon (or elsewhere), rock piles, scars on

ILLUSTRATION NO. 67

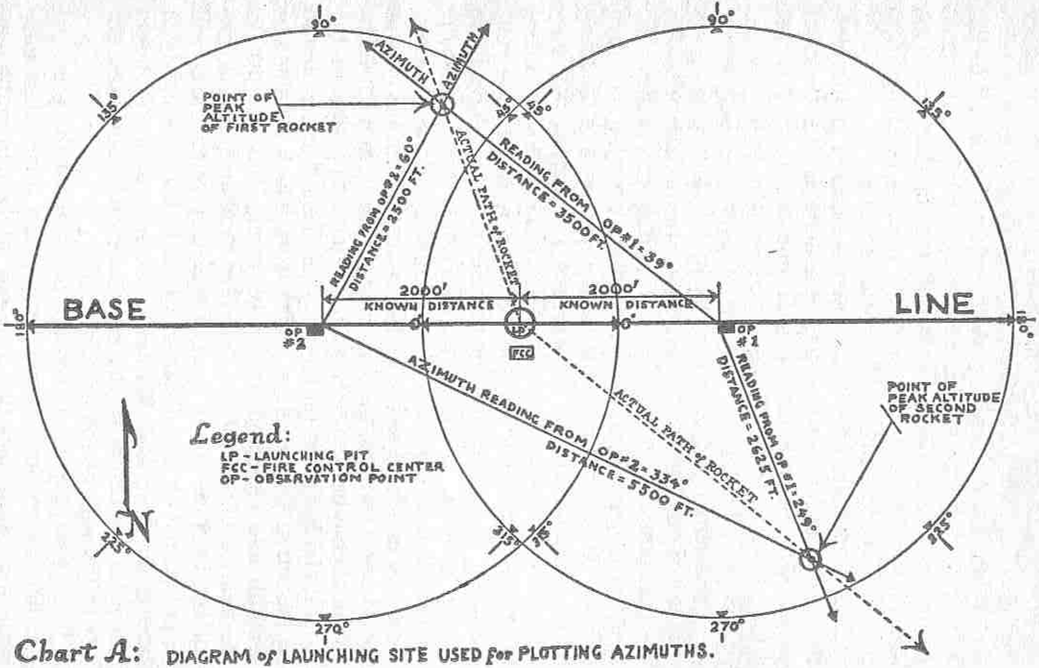


Chart A: DIAGRAM of LAUNCHING SITE USED for PLOTTING AZIMUTHS.

Theodolite at OP#2 is oriented so that zero or 360° points east toward the launching pit.

It is not necessary that OP#1, the launching pit and OP#2 be in a straight line, but if they are not, your diagram must reflect their relative positions.

Theodolite at OP#1 is oriented so that zero or 360° points west toward the launching pit.

Explanation: The chart shows the method of determining the location of point X on the ground by intersection of azimuths taken from two observation points equidistant from the launching pit. X represents the point on the ground over which the rocket reached its highest altitude (Z). The first rocket fired went to the north, the second to the south-east. All angles are measured from the base line which equals zero degrees. OP#1 reads angles clockwise, OP#2 reads them counter-clockwise. Intersection can not be used, of course, if peak altitude should happen to occur at a point directly over the base line.

the sides of hills, gullies, roads, paths, fences, telephone poles, distant water towers, or anything else that might serve as a useful reference point. The features selected for plotting, of course, should be observable from several points on the launching site, but most importantly from the firing bunker and at least one observation bunker. These reference points can serve several useful purposes, but their chief value lies in the fact that accurate azimuths and distances to them can be measured from each observation station and from the firing bunker. With this information indicated on the plotting board, the computers and recorders have a very good means of checking the accuracy of readings reported in from the observer stations, and of determining where the fault may lie in cases of readings from two different observation points which cannot be reconciled on the plotting board. The reference points selected can also be useful in visually estimating ranges, lateral distances and elevations. Their use in these operations will be discussed later in the chapter.

Once the basic information pertaining to the physical locations of permanent fixtures and landmarks on the launching site has been entered on the plotting board you may want to add certain refinements which can be of assistance in locating points rapidly and in speeding up the process of calculating performance. One thing that should certainly be included is a scale of distance in feet. This scale will prove most useful if it is superimposed on the base line which runs through the observer stations and the launching pit. It should be so devised that it is possible to measure distances either to the right or to the left, using either one of the two observer stations as the point of origin for the measurement. (*See* Illustration *70*.)

Another useful refinement is to devise a system of labeling the horizontal and vertical lines on your diagram so that you can identify any point on your launching site by coordinates. This is called a *grid system* or a *system of coordinates,* and it is the same system that is used on ordinary road maps to help you in locating towns from the index. Several systems of coordinates are used by mapmakers, depending upon how accurately points must be located. If you simply want to know the general area within which a specific point is located, you can identify only the heavy horizontal lines running across your paper by placing letters of the alphabet opposite each one down the left-hand margin of the paper. Then number the heavy vertical lines consecutively across the bottom. This will enable you to identify any large square on your paper enclosed by heavy lines (e.g., C10, or F11). If you want to be able to identify points more closely, such as the point of intersection of any two *fine* lines on your diagram, then use arabic numerals to number both the vertical and horizontal lines, and number all of them. When you use this method of numbering you must remember to always read the coordinate of the vertical line *first* by reading to the RIGHT across the scale at the bottom of the sheet. Then read UP the scale on the left margin of the paper to determine the horizontal coordinate. Always read the numbers off in this order with a dash inserted between them to avoid confusion between yourself and another person to whom you are trying to indicate a specific point on the plotting board or launching site. You can remember this rule by always repeating to yourself the phrase, READ RIGHT—UP, whenever you are reading coordinates off of your plotting board. (*See* Illustration *70*.) As an example, let us assume you are using a piece of graph paper 36 inches by 48 inches, 10 squares to the inch. There would be 480 vertical lines numbered across the bottom from left to right (it is sufficient to number every tenth line, actually), and 360 horizontal lines numbered up the left margin. The coordinates designating the center of your launching pit (which should be in the center of your paper) would then be 240-180—READING RIGHT and then UP. Assuming that your plotting board has a scale of 1 inch = 1000 feet, then an observer station located 4000 feet to the left of the launching pit, and on a line with it, would be designated by the coordinates 200-180—again READING RIGHT UP. A rocket which is observed to impact at a point 2000 feet in front of the launching pit and 1000 feet to the right of it, can be recovered by sending a search team to coordinate 250-200. If key members of your group, such as observers and range guards, are supplied with smaller-sized copies of the diagram used on the plotting board you can easily see how it would be possible to simplify many operations, and particularly the communication of information, by adopting a system of coordinates for designating specific points on your range.

A third refinement which should be added to your plotting board, by all means, is a method for readily plotting in the azimuths reported from each observer station to the point of peak altitude and the point of impact of the rocket. This can be done most simply by describing a circle of generous radius about the location of each observer station, as shown in Illustration *70*. This circle should be drawn accurately using the actual point of observation (as closely as it can be determined) as the center of the circle. Degrees from 0 to 360 can then be marked off around the perimeter of the circle (or mils, if you prefer) using a protractor of the same radius for the purpose. This will enable the plotter in the Fire Control Center to plot azimuths directly onto his board as they are reported in without the use of anything but a straightedge or a string. Naturally, these circles and the degree markings on them must be oriented in reference to the base line exactly as the alidade or theodolite of each observer is oriented. (Alidades and theodolites are both instruments for measuring angles.) This is not difficult to do, but it must be done carefully. It is not necessary that measuring instruments at different observer stations be oriented in the same direction (although it is obviously simpler and less confusing if they are), but it *is* essential that the orientation of each one be accurately reflected on the plotting board.

Use of the Plotting Board: You can, if you wish, plot azimuths and other data directly onto your plotting board in ink or pencil so that the sheet can be kept as a permanent record of firings. If you do this, however, you are faced with the problem of making up a new plotting diagram after every few firings. If you do not want the plotting diagram itself as a permanent record, you can place a sheet of pliofilm or other plastic covering over it and mark in the data with a grease pencil. Probably a better method, however, is to tack a sheet of tracing paper as an overlay on your plotting board and use a fresh sheet for each firing. This gives you a permanent record without destroying your permanent diagram. Also, you can do away with straightedges and pencils entirely and use string and thumbtacks for laying in azimuths. This is a very good method and it also simplifies measuring. Simply place a thumb tack in the center of the circle at each observer point and attach

ILLUSTRATION No. 68

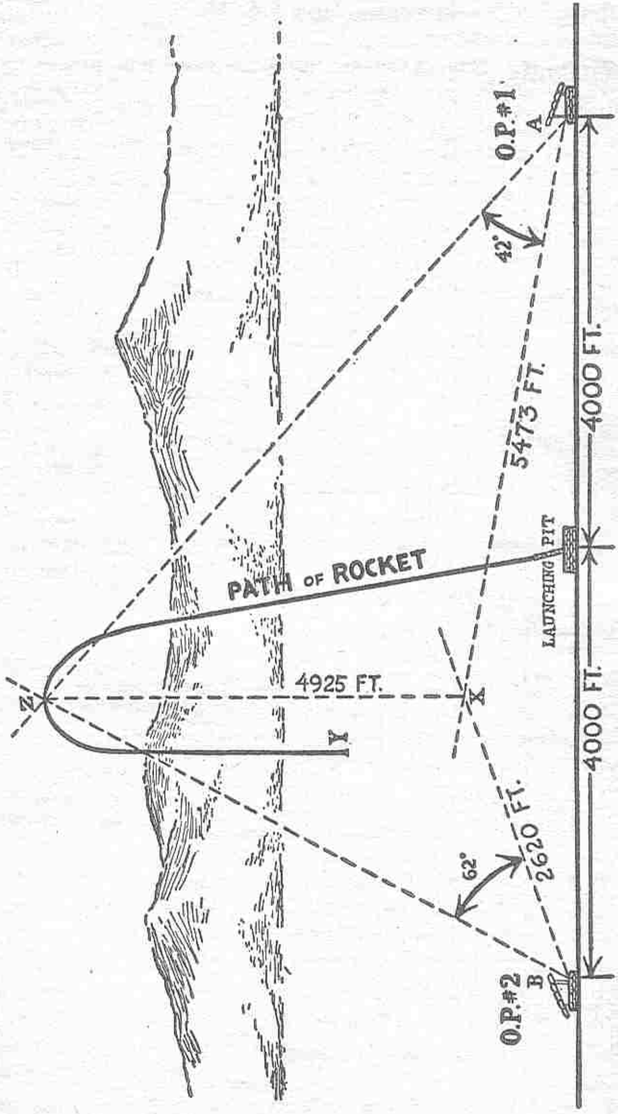


ILLUSTRATION NO. 69

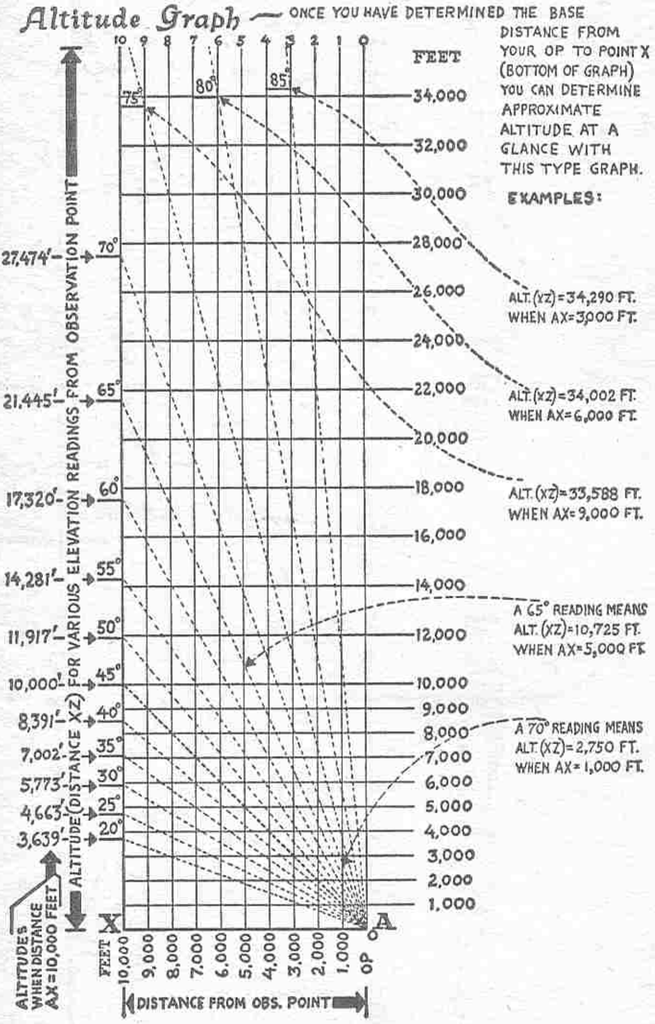
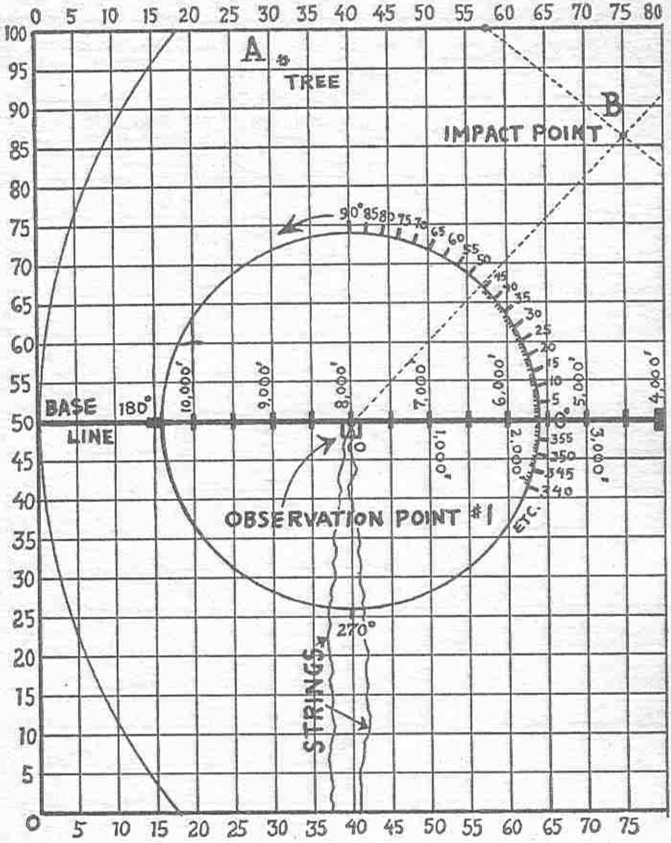
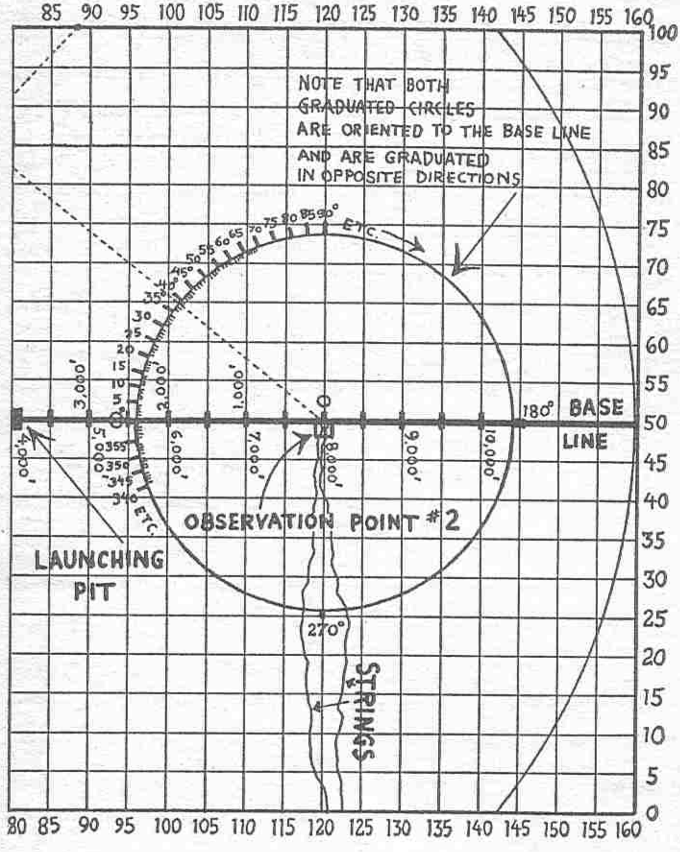


ILLUSTRATION NO. 70



Point "A" shows the location of a prominent tree which has been plotted on the board at coordinates 32-96. This means the tree is located on the ground 4600 feet in front of, and 800 feet to the left of observation point #1 which is located at coordinates 40-50. The location of this tree is determined first by ground measurement and then checked by shooting azimuths to it from each OP.

Point "B" shows the plotting for the impact of a rocket (coord. 75-86) which landed 3600 ft. in front of, and 500 ft. to the



left of the launching pit (coord. 80-50). The location of this point was determined by intersection of the azimuth readings from OP#1 (46°) and OP#2 (38°). The strings tacked to OP#1 and OP#2 are used by the plotter to lay in the azimuths reported to him and then to measure the distance to the point of intersection by using the distance scale which is indicated on the base line extending to the right of OP#1 and to the left of OP#2. A measuring string may also be tacked to the launching pit location.

three pieces of fine waxed string or thread to it. The strings should be long enough to reach the edges of the plotting board. When the azimuth to the point of peak altitude is reported in, simply extend one of the strings through the degree mark on the circle corresponding to the azimuth reported and tack it to the board at a point near the edge. Do likewise with a second string to represent the azimuth to the point of impact of the rocket. The third string is used for measuring the distance from the observer point in question to each of these two points, but the location of these points cannot be known, of course, until the azimuths are reported in from a second observer station. We will come back to the measuring process later.

The Principle of Intersection: It is possible to determine the location of any point on the ground if it can be observed from two other points whose locations are known. This principle is of definite use to rocket experimenters and forms an integral part of the system of tracking to which this chapter is devoted. The method involved is called *intersection* and consists simply of taking azimuth or compass readings from the two known points to the point in question. When these azimuths are plotted on a map or diagram of the area, the point where they intersect is the location of the unknown point. This principle is illustrated in Chart A (Illustration *67*) and in Chart B (Illustration *68*). Specifically, the method is of use to rocket experimenters in determining two things: the point where a rocket impacts on the ground, and the point on the ground over which it reaches its greatest altitude. Knowing the first of these is obviously useful in recovering the rocket. The second point must be known in order to determine the altitude which the rocket reached.

The plottings shown on Chart A (Illustration *67*) are typical azimuths that might be reported from observer stations 1 and 2 (shown as OP#1 and OP#2 on the chart) for two firings. The first rocket fired fell to the north of the base line, and the second fell to the south. This illustration is designed to impress upon you the fact that your observer stations, your plotting board, and indeed your entire launching site, must be so designed that you are capable of tracking rockets and plotting their flight paths in every direction of the compass. The observers at OP#1 and OP#2 merely measure the angle of deviation between the base line and the line of sight from their positions to the point on the ground over which the rocket reached its greatest height and report this angle to the Fire Control Center. They also measure the angle between the base line and the point where the rocket impacts on the ground and report this. (Actually, the angle may be measured from magnetic north with a compass, or with an alidade from any reference point on the horizon which is selected in advance. It makes no difference as long as the plotters in the firing bunker are aware of what point the angle is being measured from and have the graduated circle for that observation station oriented to that reference point. All measurements of angles at one station must be made from the same reference point, however. In the illustration the observer stations are oriented to measure from the base line because it is simplest and least confusing.) The observer teams also measure the vertical angle from ground level to the peak of the rocket's trajectory and report this angle, but we will consider this part of the operation later.

When both azimuths have been reported from both observer stations they are plotted on the plotting board in the firing bunker by one of the methods previously described. Each pair of azimuths intersects, thus determining the locations of points X and Y. (X representing the point on the ground over which peak trajectory occurs, and Y representing the point of impact. *See* Illustration *68*.) The plotter can now measure the distances to these points from each observer station.

Measurements can be made with a ruler if desired; but if the azimuths have been plotted with string, as suggested, the third length of string can be used to measure the distance from the observer station to each of the two points by simply extending it to the point of intersection of the azimuths and then lowering it to the base line where the distance in feet can be read off on the scale provided on your diagram. (*See* Illustration *70*.) You can also use a narrow tape instead of the third string for measuring these distances. The scale can be marked off on the tape, thus eliminating one step in the measuring process. One of these tapes should be tacked to the point on the plotting board representing each observer station, and one should be tacked to the point representing the launching pit. The latter is used by the plotter to measure the distance from the launching pit to the point of impact (which gives him the total horizontal distance traversed by the rocket), and also the distance from the launcher to point X. With these two distances he can reconstruct the entire trajectory followed by the rocket, once the altitude has been computed.

The Principle of Triangulation—Chart B: Computing the altitude reached by a rocket is actually very simple. The difficulty lies in obtaining accurate data on which to base the computation. The method used involves a simple problem in geometry known as the solution of a right triangle when only one side and one angle are known. The vertical distance traveled by the rocket from ground level to the peak of its trajectory represents one leg of this triangle, and the leg whose length we are to determine. (*Vertical* in this instance means the distance on a line drawn from the peak of the trajectory which will form an angle of 90 degrees with the ground. It is *not* the distance from the launching pit to the peak of the trajectory.) In order to determine this distance we must know two things about the triangle formed by:

(1) the ground,
(2) the line of sight from the OP to the rocket, and
(3) the vertical distance from the rocket to the ground.

(*See* Chart B, Illustration *68*.) These two things are: the distance from the OP to point X, called the base distance; and the size of the angle formed by the line of sight to the rocket and the ground. The base distance from the OP to point X is measured by the plotter in the firing bunker after the location of point X has been determined, as explained previously. The angle from ground level to the line of sight to the rocket is measured by the observers at the OP and reported to the plotter. With these two values known, and knowing that the triangle he is dealing with is a right triangle, the plotter can then apply the equation for the solution of a right triangle which will give him the distance from point X to the peak of the rocket's trajectory:

h = base distance X tangent of vertical angle

where:

h – is the vertical distance from point X on the ground to the peak of the trajectory (distance XZ in Illustration 65)

or

h = height

The *tangent* of an angle is one of the trigonometric functions of an angle and is defined as *the ratio of the side opposite to the side adjacent*. Expressed simply, it means that the tangent is a constant mathematical value which can be determined by dividing the side opposite the angle by the side adjacent to the angle. In the illustration below, the tangent of angle BAC is equal to side BC divided by side BA.

$$\text{tangent BAC} = \frac{\text{BC}}{\text{BA}}$$

Obviously, we can solve this simple equation for any one of the three terms if we know the values of the other two. For instance, if we know the length of side BA and the size of angle BAC we can write the equation this way and solve for the length of side BC:

$$\text{BC} = \text{BA x tangent BAC}$$

In the following illustration, if we assume that point C represents the peak of a rocket's trajectory and that side BC represents the vertical distance to the ground, we can find this distance by sighting to the rocket from point A and measuring the size of the angle formed by sides BA and AC (the vertical angle). We have then simply to multiply the value for the tangent of angle BAC by the length of side BA (which we shall call the base distance) and the answer will be the length of side BC (or the altitude). We have already stated that the tangent is a constant mathematical value. It is always the same for a given angle no matter what the lengths of sides BA and BC may be. You can find the tangent for any angle in a table of natural trigonometric functions. A complete table giving you the values for the tangent, cotangent, sine and cosine of every angle from 1 degree to 89 degrees is included in the Appendix.

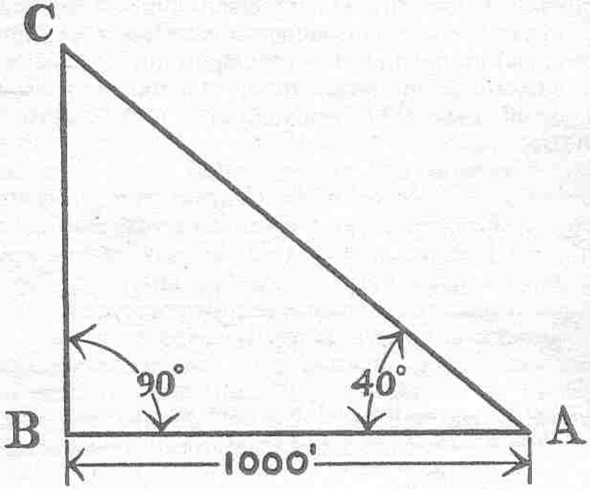
Substituting the values shown in the illustration for angle BAC and side BA in our equation, we can make a simple calculation of the length of side BC:

$$\text{BC} = 1000 \text{ ft.} \times \tan 40 \text{ degrees}$$

Consulting the table of trigonometric functions we find that the tangent of an angle of 40 degrees has a value of .8391. Therefore:

$$BC = 1000 \text{ ft.} \times .8391$$
$$BC = 839.1 \text{ ft.}$$

ILLUSTRATION NO. 71



This is all that there is to the process of triangulation. As stated earlier, it is simple and it is accurate; but the base distance (BA) and the vertical angle (BAC) must be accurate to begin with, or you cannot expect your answer to be.

To relate the simple diagram above directly to the problem at hand we can say that if the vertical angle measured to the peak of a rocket's trajectory from a point 1000 feet away measures 40 degrees, then the rocket has risen approximately 839 feet from the ground. If the vertical angle measured 45 degrees, it would mean that the rocket had risen 1000 feet, for the value of the tangent of an angle of 45 degrees is 1.

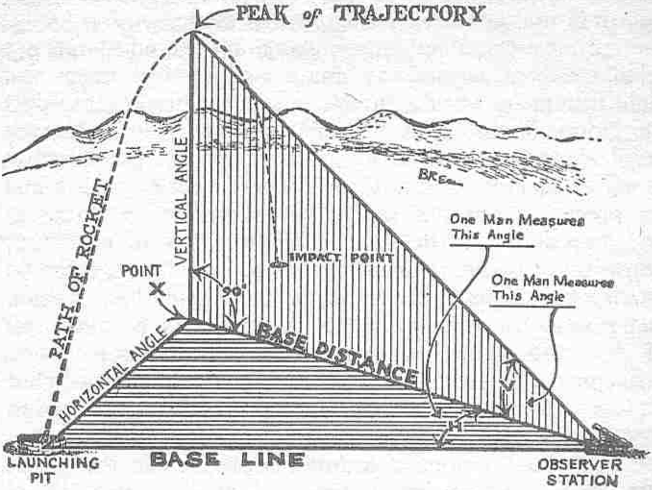
Chart B, Illustration *68*, illustrates this principle for you in perspective in order to show you how the triangle used in solving the problem would appear if you were to visualize it on your launching site. The most important thing to make note of in Chart B is that the base of the triangle (base distance) is *not* the distance from the observation point to the launching pit. It is *the distance from the observation point to point X*. Point X, in turn, is the point on the ground from which a *perpendicular* line can be drawn to the peak of the rocket's trajectory; for we must have a right triangle to work with. We have already discussed how the plotter in the firing bunker determines the location of point X, and consequently the *base distance* from point X to each observer station. In order to do this he must know the precise location of each observer station (its distance and direction from the launching pit), and he must also know the *horizontal* angle to the point where peak trajectory occurs as well as the vertical angle. Both these angles must be measured by the observer teams. It is possible for both angles to be measured by one man on one instrument, but for greater accuracy it is recommended that separate observers with separate instruments be assigned to measure each angle. The instrument used to measure a horizontal angle is normally called an *alidade*. The instrument used to measure a vertical angle is called a *theodolite*. A surveyor's transit can usually measure both horizontally and vertically. We will discuss these instruments, and how you can make them in your own workshop later in the chapter.

Illustration *72*, at the top of the next page, may help you to visualize these angles as they would appear on the ground at your launching site.

So much for the process of triangulation. We will discuss the role of the observers in this process, and the methods they may use to measure the angles required, as soon as we have considered Chart C (Illustration *69*) and its use by the plotter.

Determining Altitude from Reported Data—Use of Chart C: As previously mentioned, in order to determine the altitude your rocket has reached you need to know two things: the distance from the observation point to Point X (base distance) and the size of the vertical angle measured to the peak of the trajectory. Through the use of Chart A (the plotting board) the location of point X and the base distance to each observer station can be determined. It remains, then, only to apply the formula for triangulation in order to determine the altitude your rocket has reached.

ILLUSTRATION No. 72



The calculation involved is simple, as already demonstrated in the discussion of Chart B. You can make it even simpler, and eliminate the need for the plotter to do any calculating, by devising a graph for his use similar to that illustrated in Chart C (Illustration *69*). As an additional aid, you can provide him with a copy of the Table of Altitudes shown in the Appendix. Either of these aids will enable him to read altitudes readily, based on the data reported from the two observer stations. It should be borne in mind that you need data from only one observer station, actually, to calculate the altitude. The data from the other observer station is used primarily to determine the locations of point X and the point of impact; but as long as you have two observer stations you can use the angle of elevation reading from the second one to check on the accuracy of the reading obtained from the first. It is highly unlikely that the elevation readings from two independent observer stations will result in altitude readings which will coincide, because neither can be presumed to be wholly accurate. Therefore, it is probably best to calculate the altitude as observed from each station independently, and then use the average of the two altitudes obtained for recording purposes. Remember that the base distance from each OP to point X is different, as is the size of the vertical angle. In calculating the probable altitude as observed from each station, be careful to use only the data received from that station.

Chart C shows in graphic form the altitudes that are obtained from various combinations of vertical angles and base distances. The horizontal axis of the graph represents the base distance from the OP to point X. In using the chart, O represents the location of the OP (observation point, or observer station) and the distances in feet marked at intervals proceeding to the left, represent the distances to point X. The vertical axis represents elevation readings in degrees (vertical angles), from zero to 75 degrees. To the right of the chart is a scale of altitudes in feet. As you can readily see by studying the chart for a few moments, all that has been done is to *extend* various angles of elevation to a distance of ten thousand feet, so that altitudes subtended by these angles at increasing distances from zero to 10,000 feet can be determined at a glance. With such a chart in the fire control center the plotter can determine the proper altitude for a given elevation reading in an instant by simply reading up the vertical line which corresponds to the base distance to point X, until it intersects with the dotted line representing the angle of elevation reported by the observer. The altitude represented by this intersection can be read in feet from the scale on the right.

You can construct such a chart for your own use which is fitted to the requirements of your own launching site. It is probable that you will not have to extend it as far as ten thousand feet; and it is also likely that you will find little need for measuring angles of elevation beyond the range of twenty to sixty-five degrees, if your observer stations are properly placed in relation to the launching pit. The larger you make the chart, the easier it will be for the plotter to read altitudes from it accurately. The chart shown in Illustration *69* can be drawn on graph paper measuring ten squares to the inch, and on a scale of one thousand feet to the inch. Consequently, each vertical and each horizontal line would represent a distance of one hundred feet. This scale makes it relatively easy to interpolate distances which are not expressed in even hundreds of feet; but you can make it even easier for the plotter and enable him to read altitudes with fairly close accuracy if you use paper with a cross-sectional marking of five squares to the inch, and use a scale of 100 feet to the inch. This would make each square on your graph paper equal to 20 feet on the ground. For a chart with base distances up to 5000 feet you would need a piece of paper only fifty inches wide, which would not be too large.

It will probably prove most convenient to mount your altitude chart on a wall of the firing bunker directly over the plotting board. As recommended for the plotting board itself, you can use a piece of string tacked to the zero point of the horizontal scale at the bottom of the chart to plot the angles of elevation reported by the observer teams, thus eliminating the dotted lines shown in the illustration. The plotter, then, can merely extend the string to the point on the vertical scale to the left representing the proper vertical angle and read off the altitude for any base distance.

If you will study Charts A, B, and C (Illustrations *67*, *68*, and *69*) carefully, and the auxiliary Illustration *70*, you will see that they represent an integrated system for tracking which will give you most of the information you need to evaluate the performance of your rocket. From the basic information provided by this system you can calculate many other performance factors (e.g., total flight time, time of powered flight, time of ascent, time of descent, etc.); and by adding certain refinements, which we will discuss, you can determine much more useful information, or at least provide a means for checking performance calculations by direct observation. The entire system, of course, depends largely on your ability to *visually* track the rocket throughout its entire trajectory. In the event you are unable to do this in every case, there are methods that you can use to help you reconstruct the missing portions of the trajectory. There are also many methods you can employ to increase your chances of visual observation of the entire trajectory, and we will discuss these next, together with the functioning of the observer teams.

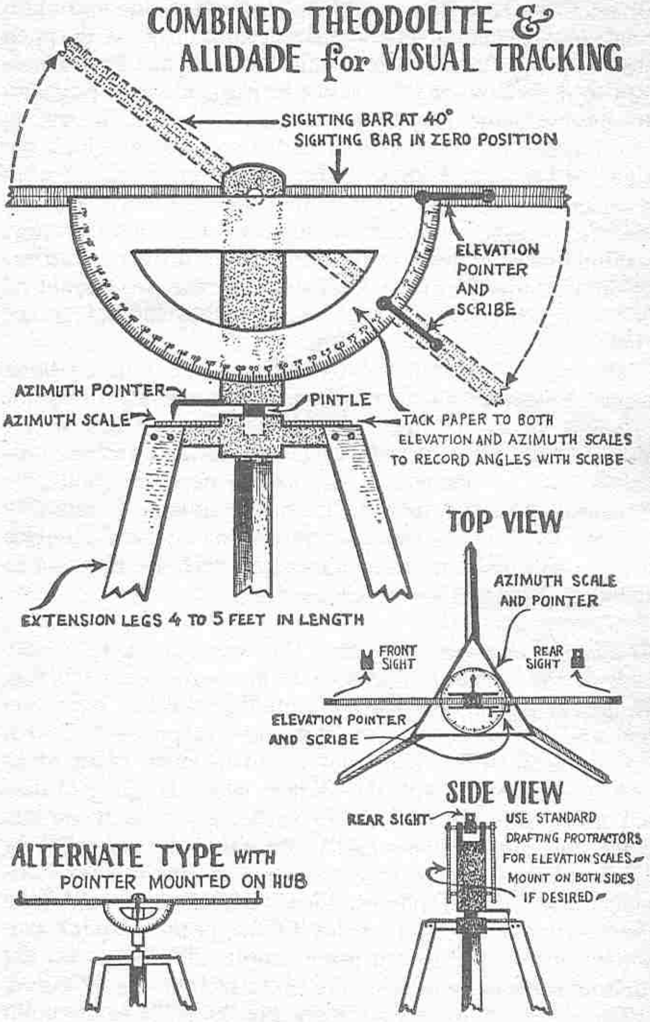
OBSERVER METHODS AND TECHNIQUES

The methods and techniques of measuring your rocket's performance which we will discuss from this point on do not necessarily apply only to the observer teams which it is recommended you establish at permanent observer stations. A great many of them can be employed by anyone in a position to observe the flight of the rocket, and the resulting data obtained can be used either to confirm observations of the observer teams, or to supplement their information. Likewise, all of the techniques described do not necessarily form a part of the system of tracking which has been presented. Many of them can be used in conjunction with such a system, or used independently if you do not establish such a system.

Measurement of Angles. The horizontal angles to the point of impact of the rocket, and to the point over which peak trajectory occurs, can be measured by observers using a simple homemade alidade. An alidade is simply an instrument consisting of an indicator mounted on a swivel which can be swung through an arc of 360 degrees. If the base of the alidade has a circle inscribed on it with degree markings indicated, you have an instrument with which you can measure horizontal angles by sighting along the indicator to the object, or point on the horizon, whose azimuth you are trying to measure. To construct such an instrument in your own home workshop which will give you reasonably accurate readings, is a simple matter, using a square piece of plywood for a base and a sighting bar for an indicator. There are many refinements which you can incorporate in this basic design, if you choose, to increase the accuracy of the instrument and make it easier to use. But it is a practical instrument even in its simplest form.

The alidade should be mounted in a permanent position on the parapet of an observer bunker or on the ground, so that it is oriented in the same direction every time it is used. If it is oriented to the base line, the 0 or 360 degree mark should be pointing directly at the launching rack. Since it may be difficult for one man to measure both of the horizontal angles shown in Chart A, you may want to provide two such instruments at each observer station. Measurement to the point of impact is relatively easy, providing the impact of the rocket is observed. But the measurement of the horizontal angle to the point of peak trajectory takes a little practice. The observer assigned this job must train himself to track sideways while following a more or less vertical flight path with his eye. He must also be able to visualize a perpendicular line from the peak of the trajectory to the ground, and must be adept at "freez-

ILLUSTRATION NO. 73



COMBINED THEODOLITE & ALIDADE for VISUAL TRACKING

ing" the indicator in position once he has determined that the rocket has reached its greatest altitude. To help in locking the indicator in place at the proper point, you might perforate the base board at each degree marking and place a nail in one end of the indicator which can be dropped into the proper perforation when the angle has been measured so that the indicator cannot be joggled out of position. Another refinement which you can add is a vertical sighting bar mounted on an extension of the spindle on which the indicator revolves. This additional sighting bar is not used to measure a vertical angle, but it will probably help the observer to follow the path of the rocket more accurately. It should be mounted so that it can move through a vertical axis independently of the indicator, but the two should be locked together on the spindle so that they move together horizontally.

The observers assigned to the measurement of horizontal angles should be taught to make maximum use of reference points on the launching site as an aid to the correct reading of azimuths. The azimuth to each prominent terrain feature within view of the observer should be measured and noted on the base of the alidade. Familiarity with the locations of these reference points and the angles to them will assist him in estimating angles rapidly and in checking the accuracy of his readings.

Measuring Vertical Angles: The vertical angle to the peak of the rocket's trajectory is measured with the theodolite. A true theodolite will actually measure both vertical and horizontal angles, and you will probably find it most convenient to construct an instrument which does both, and dispense with the alidade which is really of limited usefulness. Illustration *73* shows a simple theodolite which you can construct easily. Note that the indicator, or sighting bar, must be able to move freely in both horizontal and vertical planes. One man can measure both horizontal and vertical angles to the point of peak trajectory. Another man can use a simple alidade just for the horizontal measurement to the point of impact, if desired.

The observers assigned to measure the angle to the point of peak altitude must train themselves to track quickly and surely, and to hold the instrument steady after they have aligned it on the point which represents the apex of the rocket's flight path. This point is not difficult to fix if you have been successful in keeping your eye on the rocket from the time it left the launcher, for the rocket slows perceptibly at the point of burnout and continues to decelerate, as its momentum upward is overcome by the pull of gravity, until it reaches zero velocity (vertically) at the peak of the trajectory. This constant rate of deceleration, which is calculable and predictable, makes it possible for a trained observer to anticipate, or sense, the point at which the missile will nose over and begin its downward flight. After a little practice you will find it relatively easy to "lock" your instrument on this point, providing the rocket has not gone out of sight, or been lost in a cloud. The difficulty in vertical tracking comes at the beginning rather than the end. It requires a decided knack to catch sight of the rocket at all as it leaves the launcher, unless there is a heavy exhaust jet that is readily visible. The tracker must learn to sweep his eyes upward rapidly as the rocket takes off. *Do not* try to train the sighting bar of the theodolite on the launcher and attempt to follow the initial phase of the flight in this manner. If you do you will almost certainly lose track of it. Instead, you should observe the start of the flight by direct observation with the naked eye, holding the sighting bar of the theodolite in a position of readiness, until after the point of burnout. When the upward flight of the rocket has begun to slow perceptibly it is time to train the sighting bar on it. If you attempt to use the sighting bar while the exhaust jet is still visible, you will probably lose sight of the rocket when the jet disappears.

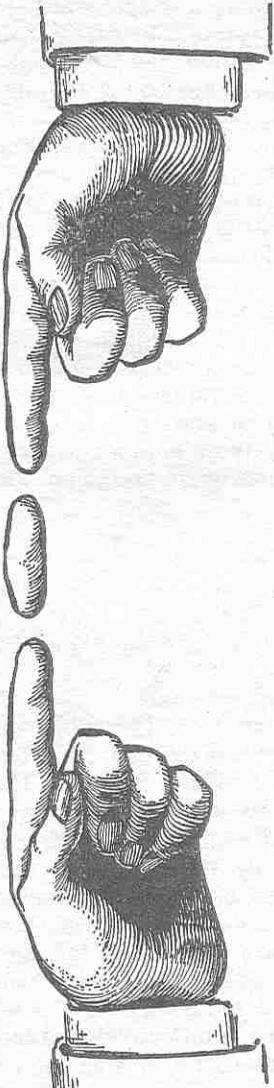
In observing with the naked eye you may find it helpful to make use of a technique which military observers discovered long ago. It is a curious fact of nature that it is difficult to discern the movement of an object when you are looking directly at it. Particularly is this true at night or under conditions of reduced visibility such as are produced by mist or a cloudy background. It can be demonstrated scientifically that the human eye is much more sensitive to movement in the peripheral area surrounding the field of vision than in the center of the field of vision itself. For this reason Army scouts and observers are taught to look slightly to one side or the other of an area in which they are trying to pick up signs of movement of personnel or equipment, and they are also trained in the technique of *unfocusing* their eyes in order to increase sensitivity to movement. With a little practice you can become adept at unfocusing your eyes quickly, and at will, by what is known as the "sausage method."

Hold the index fingers of both hands about twelve or fourteen inches in front of your eyes so that they are pointing toward each other and are horizontal to the floor. Move them slowly toward each other while you stare intently between them at some object which is ten or twelve feet from you. When the tips of your fingers are approximately one inch to one-half inch apart you will notice that you can see three things. The tip of each finger, and a "sausage" in the blank space between them. By moving your finger tips up and down slightly you can make this sausage wiggle; and by changing the depth of focus of your eyes, or by varying the distance between your finger tips, you can make the sausage appear longer or shorter. Once you change the focus of your eyes so that you are looking directly at your finger tips, the sausage disappears. Practice this until you are able to unfocus your eyes at will and at varying depths of vision. But don't practice it so long that you induce an undue strain on your eyes.

Once you have mastered this technique you can apply it to the problem of trying to catch sight of a moving object in the sky. The principle involved is really very simple. When you look up into the sky, normally, you are actually looking at only a very small part of it, and you have to keep shifting your eyes from one place to another in order to observe all of it. When you unfocus your eyes, you are looking at the whole sky at once (or at least a much larger area of it), and you are looking at it with the part of your eye which is most sensitive to movement. Once you have caught sight of the object you are seeking, you can then look directly at it and follow its path. If you lose sight of it, unfocus your eyes again until you pick it up.

Use of the Army Mil Scale in Measuring Angles: If you wish, you may use the Army mil scale for measuring both vertical and horizontal angles, rather than degree markings or points of the compass. The Army mil scale simply divides a circle, or an observer's field of vision, into 6400

ILLUSTRATION No. 74



BY FOCUSING YOUR EYES ON A DISTANT OBJECT YOU CAN MAKE A "SAUSAGE" APPEAR BETWEEN THE TIPS OF YOUR FINGERS. USE THIS METHOD TO TRAIN YOUR EYES TO UNFOCUS RAPIDLY IN ORDER TO DETECT MOVEMENT MORE EASILY.

parts rather than only 360. The figure 6400 is used because it closely approximates the relationship between the radius of a circle and the length of any subtended straight line tangent to the circumference of that circle. If this doesn't seem clear, perhaps it will after you have studied the accompanying diagram. The mil system is used by the Army for several important reasons:

a. It permits a finer and more accurate measurement of angles, or azimuths.

b. It enables the observer to measure the length of objects, or the lateral distance between two points which are a considerable distance away.

c. It enables an observer to estimate the *range* to an object of known length, or width, such as a car, a tank, a ship, or a standard type building.

A mil is defined as the angle which subtends a width of 1 yard at a distance of 1000 yards. In other words, 1000 yards away from the point at which two straight lines intersect at an angle of 1 mil, those lines are 1 yard apart. At 2000 yards, they are 2 yards apart, and so on. This relation may be expressed as a formula:

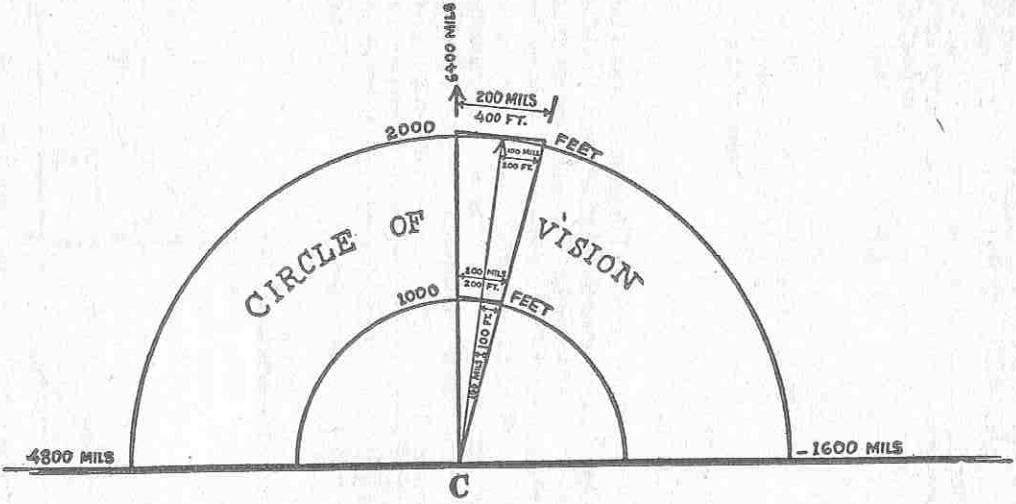
$$\frac{W}{RM} = 1 \text{ or } W = RM \text{ or } R = \frac{W}{M} \text{ or } M = \frac{W}{R}$$

where: W represents *width* in yards
R represents *range* (or distance) in *thousands* of yards
M represents angle in *mils*

The symbol used for the mil is m. The mil formula can be easily remembered if you will think of the word *WORM* (Width Over Range times Mils or W/RM). The diagram on the next page illustrates the mil system for you.

The mil system can be useful to you for the same reasons that it is useful to the Army. If you graduate the scales on your angle measuring instruments in mils rather than degrees, you not only have a more accurate method of measuring angles; but you have a means of measuring lateral distances on your launching site, and vertical heights under certain conditions. Even if you do not use it as the primary means of angle measurement, a knowledge of the mil scale and how to use it can be useful to you for a variety of purposes. If you can obtain a set of surplus Army binoculars (M13A1) you will find that the left telescope of the

ILLUSTRATION No. 75

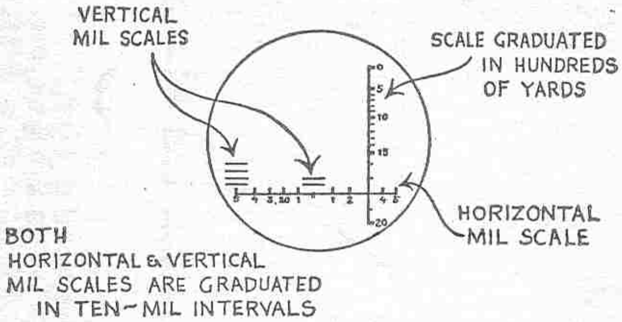


THE MIL SYSTEM OF MEASUREMENT...

FROM POINT C, ONE MIL EQUALS ONE INCH AT ONE THOUSAND INCHES,
ONE FOOT AT ONE THOUSAND FEET, ONE YARD AT ONE THOUSAND YARDS, ETC.

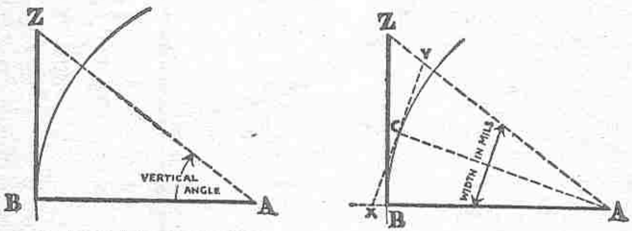
binoculars contains a reticule with a mil scale that looks like this:

ILLUSTRATION NO. 76



With this scale you can measure lateral and vertical distances (if you know the range to the object you are measuring) by use of the mil formula. You must bear in mind, however, that this is not the same thing as determining altitude by triangulation, and you cannot depend upon the mil method to be accurate for measuring vertical distances which are perpendicular to the surface of the earth, except for short distances. The reason is that the mil formula gives you the length of a line that is *tangent at its midpoint* to your circle of vision. It will not give you the length of *any* tangent. The following diagram may serve to clarify this for you:

ILLUSTRATION NO. 77



TRIANGULATION MEASURES THE DISTANCE BZ

MIL FORMULA MEASURES THE DISTANCE XY

As you can see from this diagram, the base distance used for triangulation is the distance AB; whereas the base distance, or *radius*, used in the mil method is the distance AC, and the ends of the line being measured must be equidistant from point C. Calculation by triangulation gives you an actual vertical height from point B to point Z. Measurement by the mil method gives you the *width* of the angle (distance XY), which, as you can see from the diagram, is only an approximation of the perpendicular vertical distance. This approximation is good enough for many practical purposes, such as estimating the height of a cliff, a tree or a water tower. But it is also obvious that as the vertical angle increases the distortion will increase proportionately, until the method is no longer accurate enough.

Use of the M13A1 binoculars does, however, give you a quick and easy method of estimating heights where extreme accuracy is not required. When sighting with the binoculars, cup your hands around them and press the edges of your thumbs against your temples to shut out light. You will see more clearly if you do not try to press your eyes up against the lens of the eyepieces. Hold them a short distance away. Prop your elbows on a parapet or some other firm base for greater steadiness.

You can also measure mil distances on the horizon with nothing more than your fingers, and with a little practice you can become fairly proficient at estimating lateral and vertical distances by this method. The average-sized finger will blot out approximately 30 mils from your field of vision when you hold it at arm's length from your eyes. Since 1 mil equals 1 yard at a thousand yards, this means that your finger can cover an object which is thirty yards long, if the object is a thousand yards from you. If the object is only one hundred yards from you, your finger will blot out one-tenth as much, or about three yards. At one hundred *feet* it will blot out about one yard. Naturally, the size of people's fingers and hands varies. But with a little practice on objects of known size, at varying distances, you can soon determine how many mils you can measure with your own fingers. All four fingers together will blot out about 125 mils from your field of vision, when held at arm's length from your eyes.

Other Methods of Estimating Altitudes: There are two other methods for making a quick estimate of the height your rocket has reached if you do not wish to bother with triangulation or measurement by the mil method. One is by timing the total flight of the rocket, or the time of descent from the peak of the trajectory to the ground, with a stop watch. The other is to visually estimate it by using some object of known height, such as a tree or a telephone pole as your unit of measurement. The latter is the crudest and least accurate of all methods, of course, but it may be useful if you are firing a series of small rockets of similar design with a view to comparing their performance. It obviously is not practical for altitudes of more than a few hundred feet.

To estimate altitudes visually, simply station an observer at a distance approximately equal to the average altitude you expect your rockets to reach. The tree or telephone pole which is used as the unit of measurement should be the same distance from the observer that the launching pit is. The observer equips himself with a piece of cardboard or a stick which, when held at arm's length, equals the height of the tree or pole. When the rocket is fired he can quickly measure against the sky the number of tree or pole-lengths that the rocket rose. To facilitate fixing the point in the sky at which the rocket reached its greatest height he can use a tall pole or surveyor's stick held by an assistant. By positioning himself the same distance from this pole each time a rocket is fired he can observe the point on the pole which is in line with the peak of the rocket's trajectory and mark it with a pencil immediately. He can then measure the distance to that point with his measuring stick, or cardboard, using as his starting point the point on the pole which represents the line of sight to the launcher. It remains then only to multiply the number of units measured by the height of the object which is being used as the unit of measurement.

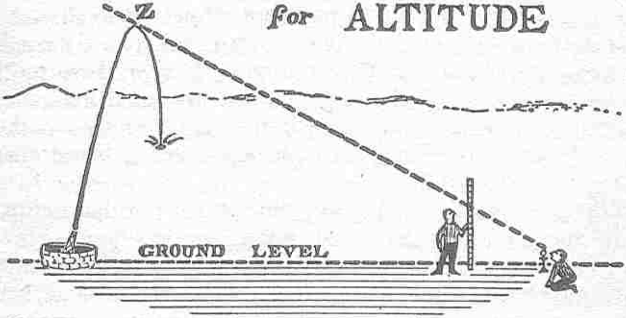
A further refinement of this system, which can actually be developed into a fairly accurate method of tracking, is to station the observer behind a net or a section of Cyclone fence. From this position he can observe the entire flight path of the rocket just as it would appear if plotted on a piece of cross-sectional graph paper or a radar scope. The squares of the net or section of fence, in this instance, can represent the unit of measurement. By simple mathematical computations already discussed in this chapter you can calculate what that unit of measurement will represent in feet, according to the distance that the observer is from the net and the distance from the net to the rocket. Obviously, this system of calculating altitudes will be effective only if the flight path of the rocket is in a plane approximately parallel to the net, but you can compensate for deviations from this plane in your calculations. Illustration *78* shows the relative positions of the observer, the net and the rocket when this system is used. You can readily see that the closer the observer is to the net, the greater are the altitudes which he can sight; but there is a practical limit to how close he can be. You must also recognize that there is an increasing degree of distortion introduced as the line of sight to the rocket diverges from the horizontal, just as there is distortion in the size of the grid squares in a Mercator projection of a map of the globe. In other words, a square at the top of the net will represent a greater distance in the sky than will a square at the observer's eye level. But if you really want to use a system similar to this, you can easily compensate for this distortion in your calculations.

One method of employing this system of visual sighting is to build a permanent observer bunker with an oversized window in the side facing the launching area. (Or, if you wish, the entire side of the bunker can be open.) Cover this open area with large mesh screening of the type that is used to sift gravel or to cage small animals. One-half inch mesh, for instance, might be a practical size. This will represent your grid screen, and you can place a permanent eyepiece on a pedestal inside the bunker to ensure that sightings are always taken from the same position. Such a bunker could serve as an auxiliary observer station, and it might be interesting to compare the sightings obtained from it with the data obtained from your regular observer stations using the triangulation system.

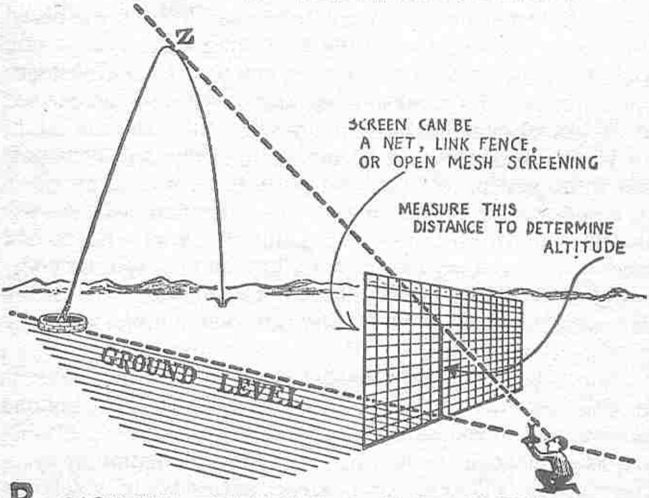
Measuring altitude by timing the flight of your rocket is feasible, and reasonably accurate, providing the rocket can be observed throughout its entire flight path. It is probably just as accurate a method as shooting a triangulation when you consider the many small errors in basic data which can have an effect on the ultimate answer obtained by the triangulation method. We have already discussed this earlier in the chapter. Also, calculating altitude by clocking elapsed time of flight is simple, it gives an answer quickly,

ILLUSTRATION No. 78

OTHER METHODS of VISUAL SIGHTINGS for ALTITUDE



A. SIGHTING PAST A GRADUATED POLE TO DETERMINE ALTITUDE



B. SIGHTING THROUGH A GRID SCREEN TO DETERMINE ALTITUDE and a very minimum of equipment is required. All that you need is a sharp eye, one thumb and a stop watch.

When any projectile is hurled into the air it rises for a certain time until the pull of gravity has overcome its initial velocity, then it falls to earth for a roughly similar period of time until it strikes the ground. If we assume that the direction of flight is exactly vertical, and that initial, or starting, velocity is all that has been imparted to the projectile, then: the time of flight upward will exactly equal the time of flight downward, and the velocity of the projectile upon impact with the earth will exactly equal the initial velocity with which it left the earth. In other words, the upward and downward flight paths are identical if no other factors intervene.

The height to which the projectile will rise is determined by its initial velocity (again assuming a vertical flight path); for the pull of gravity overcomes this velocity at a constant rate, and the projectile loses velocity at the rate of 32.2 feet per second for each second of its flight. On its downward flight it gains velocity at the same rate. (*See* Illustration *79.*) If your rocket has a short burning time, and its trajectory is roughly vertical, you can determine the altitude that it attained by simply timing its entire flight, and using half of this value to represent the time of downward flight. This is assuming that upward and downward flight time are the same. Amateur rockets tracked by radar at Fort Sill in Oklahoma have been found to approximate this flight pattern very closely because their burning time is short.

However, you will obtain a better approximation of altitude if you can observe the point at which the rocket reaches the peak of its trajectory and time only the downward flight. Since we know that the rocket has zero velocity at the point where it stops climbing and accelerates at a constant rate ($32.2\ \text{ft/sec}^2$) until it hits the ground, we can determine both the altitude from which it fell and the velocity with which it hit the ground by two of the formulas derived from Newton's laws of motion:

To calculate the terminal velocity use the formula,

$v = gt$ where: v—is velocity
t—is time in seconds
g—is the rate of acceleration of gravity ($32.2\ \text{ft/sec}^2$)

To calculate the total distance the rocket has fallen, use the formula,

$S = \frac{1}{2}gt^2$ where: S—is the total distance or altitude

The table in Illustration *80* gives you the values for the velocity and distance traveled by falling bodies for each second from 1 second to 25 seconds, and from zero to 10,000 feet. With such a table at your launching site you can dispense with calculations and determine approximate altitudes readily. Even if you use a triangulation system at your regular observer stations, you can appoint other individuals to clock the flight time of your rockets for comparative purposes. The more data you have, the better. The table in Illustration *80* is based on a value of 32 feet/sec./sec. for the quantity g. This is only an approximate value for g, but it is the most widely used. A value of 32.2 ft./sec./sec. is sometimes used. Europeans use a value of 980 cm./sec./sec. which works out to 32.1538 ft. The actual value of g at sea level is supposed to be 32.172 ft./sec./sec., but it varies in different parts of the globe and at different altitudes. You can construct a table similar to the one in Illustration *80* using a more exact value for g, but it is doubtful whether it would give you appreciably more accuracy in your calculations considering the altitudes with which you will be working most of the time. If you do not have a stopwatch with which to time the flight of your rocket you can get a good approximation of the time by a simple time count such as is used by football teams in timing plays. It takes approximately one second for a person to say "one thousand and one" at normal conversational tempo. If you will practice counting "one thousand and one, one thousand and two, one thousand and three, etc.," you will find that you can count seconds quite accurately.

Diagram on the opposite page shows the theoretical trajectory of a bullet fired straight up into the air from a high powered rifle with a muzzle velocity of 3000 feet per second, assuming no wind and no air drag. Compare the distance traveled during the first 20 seconds of flight with the distance traveled during the last 20 seconds of upward flight to get an impression of the slowing effect of gravity. The downward flight of the spent bullet would exactly duplicate the time and distance pattern of the upward flight in reverse. Theoretically the bullet would impact on the ground 187.5 seconds after firing and with a terminal velocity equal to the initial velocity of 3000 ft. per second.

ILLUSTRATION No. 79

EFFECT OF GRAVITY ON BULLET TRAJECTORY

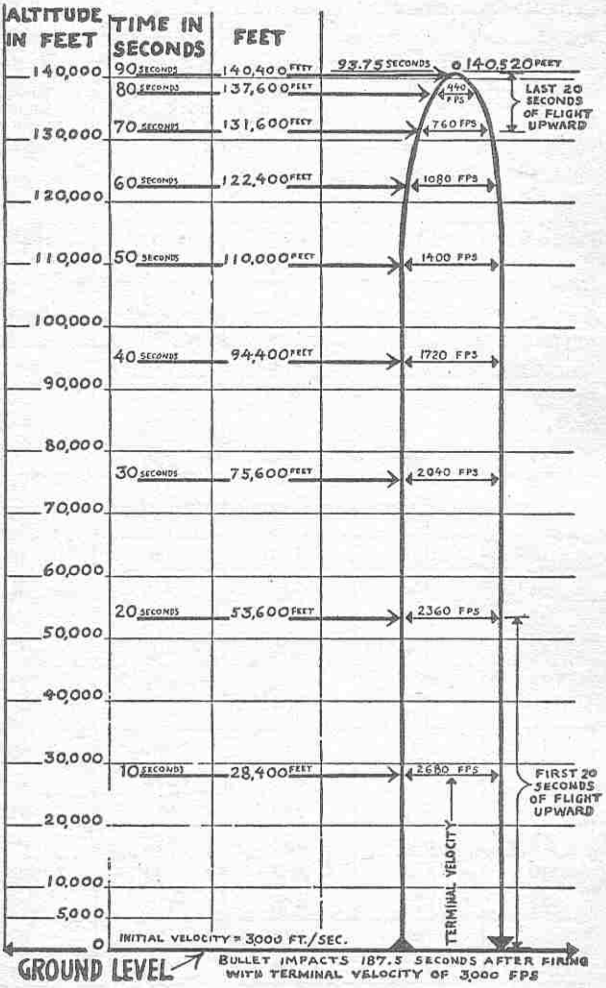


Illustration No. 80

TABLE OF VELOCITIES AND DISTANCES ACHIEVED BY FREE-FALLING BODIES
1 TO 25 SECONDS

t	V	v	s	S
—TIME— AT END OF	TERMINAL VELOCITY IS	AVERAGE VELOCITY DURING LAST SECOND WAS	DISTANCE TRAVELED DURING LAST SECOND WAS	CUMULATIVE OR TOTAL DISTANCE TRAVELED IS
$t=\frac{V}{g}$	$V=gt$	$v=gt-\frac{g}{2}$	$s=1v$	$S=\frac{1}{2}gt^2$
SECONDS	FPS	FPS	FEET	FEET
1	32	16	16	16
2	64	48	48	64
3	96	80	80	144
4	128	112	112	256
5	160	144	144	400
6	192	176	176	576
7	224	208	208	784
8	256	240	240	1024
9	288	272	272	1296
10	320	304	304	1600
11	352	336	336	1936
12	384	368	368	2304
13	416	400	400	2704
14	448	432	432	3136
15	480	464	464	3600
16	512	496	496	4096
17	544	528	528	4624
18	576	560	560	5184
19	608	592	592	5776
20	640	624	624	6400
21	672	656	656	7056
22	704	688	688	7744
23	736	720	720	8464
24	768	752	752	9216
25	800	784	784	10,000

Use of the Camera: Cameras can be used for several purposes in rocket experimentation, both in static testing and flight testing. We have already considered their use in recording various performance characteristics in the static testing bay. At the launching site a movie camera can be used both to record the lift-off from the launcher, and as an aid to tracking if you can develop expert enough cameramen in your group. If you are successful in getting a photographic record of the entire trajectory of one of your rockets, you have a valuable document for subsequent study and analysis. Since you know the speed at which your pictures have been taken (e.g., 32 frames per second) it is possible to reconstruct the entire trajectory of a given flight with considerable exactitude. From this photographic record you can determine the exact burning time of the fuel, the exact time of flight to various points in the trajectory, and the rate of acceleration or deceleration of the rocket through various segments of the flight path. This information can then be plotted on a graph, and if you wish, you can even reconstruct a photographic record of the flight in graph form. Considering the many things that can be done with a photographic record to enhance your knowledge of the performance of your rocket, it is worth going to considerable pains to try and obtain such a record.

Generally speaking, tracking with a camera is difficult; but with constant practice, intensive training of camermen, and the exercise of a little ingenuity and inventiveness, you may very well succeed. It is doubtful whether any cameraman, no matter how expert, can successfully track a rocket using the regular eyepiece, or viewfinder, with which the camera is normally equipped. You can increase his chances of success, however, by fitting the camera with an eyepiece and viewing frame similar to that used on press cameras for covering sporting events. And you can do even better, perhaps, by lashing the camera to a sighting bar mounted on a pivot in the same manner that your theodolite is mounted. This will enable the photographer to swing the camera through a wide arc very rapidly, and if the lens of the camera is properly aligned with the sighting bar sights you should have no difficulty in getting good pictures. A little thought, coupled with experimentation, will readily suggest other methods to you which will increase your chances of getting a good photographic record of your rocket's flight.

Tracking by Radio: If your group includes members whose primary interest is in the field of electronics and you have sufficient money to purchase and develop the necessary equipment, you can, of course, develop a method of tracking by radio signals. A typical system includes a transmitter in the payload of the rocket, a ground receiver, a directional beam finder, and an instrument for recording on graph paper the path of the rocket as it is tracked by the beam finder. In addition to determining the flight path of the rocket, a radio communication system can be elaborated to include the reception of many other types of information from the rocket, such as rate of acceleration, altitude, temperature readings, attitude of flight, spin, etc., that can add to your knowledge of the rocket's behavior in flight and the conditions to which it is subjected during its flight. You can also use radio to send instructions, or *commands,* to the rocket. But radio should not be used in connection with any explosive charge or ignition system.

It is not within the scope of this volume to treat in detail the many possibilities of telemetering techniques as they can be applied to the flight-testing of rockets, nor to give specific instructions on the methods and types of equipment employed. The possibilities should be obvious to any person genuinely interested in the field of electronics, and a knowledge of the techniques employed and the equipment needed can be gained from any one of a variety of magazines devoted to electronics for the "do it yourself" home hobbyist.

Aids to Visual Tracking: There are several methods you can use to increase your chances of tracking your rocket visually. These include:

Distinctive markings on the hull
Fin markings
Use of smoke or vapor trail
Use of lights
Use of opalescent, or reflector type, paints.

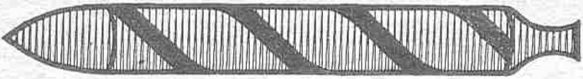
Distinctive markings on the hull of your rocket which provide good contrast can be very helpful in making the rocket stand out against the background of the sky. In general you should avoid the use of neutral colors, particularly grays and light blues, which will tend to blend with sky and clouds. Some designs for hull markings which are used widely by amateur rocket enthusiasts are shown in Illustration *81*. A frequently used combination of colors is bright yellow and dark blue; but most any combination of colors which will provide bright contrast is suitable. Silver, bronze and gold gilts are popular, because of their reflective qualities. Many rockets are simply painted black on one side and silver or white on the other. This has also been done on the Explorer satellites launched by the Army, as an aid to visual observation. As the rocket rotates, the reflection of light from its surface is more intense when the lighter side is exposed to the sun, and the result is a flashing or pulsing effect which is relatively easy to pick up with the naked eye. There is a great deal of room for effective experimentation in the choice of designs and the types of paints that you use. The paints must be highly heat-resistant, of course, and should have good light-reflecting qualities.

Markings on fins may be even more effective aids to visual tracking than hull markings because of the large surface area exposed and the fact that rotation of the rocket (if any) causes a movement of the fins at right angles to the line of flight, thus increasing the chances of observation. Suggested fin markings that you might experiment with are shown in Illustration *82*. Another thing that you might do with the fins on your rocket is to experiment with conformations which will produce an audible sound as the rocket travels through the air. The famous "screaming meemie" used by the Germans in World War II relied on vanes for producing the morale-shattering sound for which it was named. Properly placed perforations or attachments to the fins of a rocket, while they might contribute appreciably to air drag, might also produce a piercing sound which would assist an observer in locating the rocket in the sky.

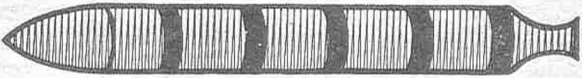
Lights, Smoke and Vapor Trails: Many amateur groups have experimented with various types of light-flashing devices and smoke or vapor generators to increase the chances of good observation of the rocket throughout its trajectory. Generally speaking, light-flashing devices are more difficult to design and fabricate and are sometimes

ILLUSTRATION NO. 81

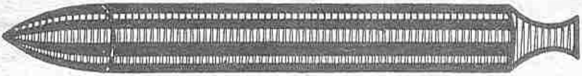
TYPES of ROCKET MARKINGS
USED TO INCREASE VISIBILITY



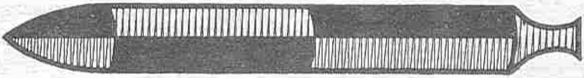
BARBER POLE



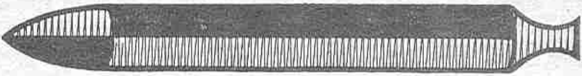
HORIZONTAL STRIPES



VERTICAL STRIPES



HALF HARLEQUIN



HARLEQUIN

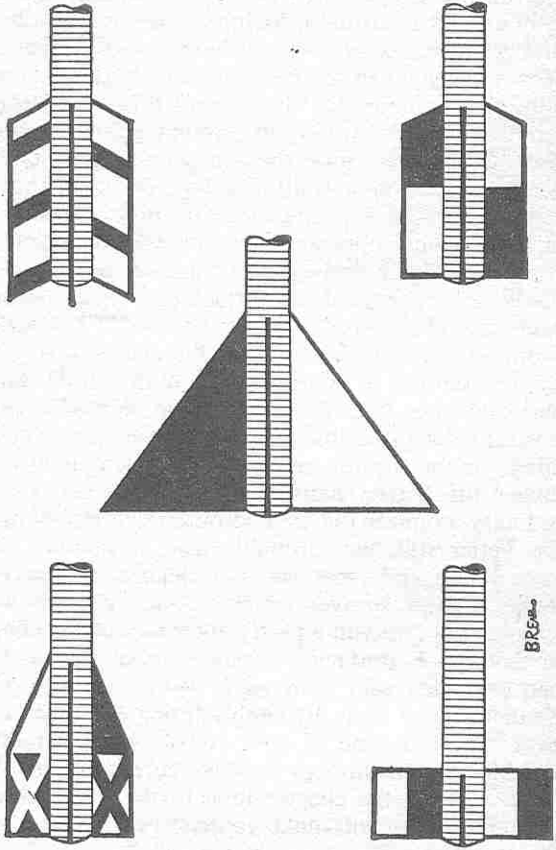
unreliable. Although many good theories have been advanced for the operation of such mechanisms, very few of them seem to function in actual flight-testing. Also, for the light source to be effective as a tracking aid, the rocket carrying it must be launched at night, or in gathering darkness, which is another limitation on its usefulness.

Perhaps the simplest, most reliable, and most widely used method for creating a visible vapor trail which can be followed by trackers after the burnout of the propellant is the ram-jet system described in Illustration *83*. It is easy to build and is virtually foolproof. Its one disadvantage is that it increases air drag, whereas most other methods do not. As you can see from the sketch, the system utilizes the airflow created by the forward thrust of the rocket to force a stream of liquid out through a tiny porthole in the side of the rocket hull, thus creating a spray effect and a dense, visible vapor trail. The type of liquid that you use for this purpose is pretty much up to you, and the choice of a good one represents another area in which you can conduct research and experimentation. Some groups have used titanium tetrachloride, which produces a dense, smoky vapor but is expensive. Others have tried kerosene, which produces a light vapor by itself, but can be vastly improved by the addition of colored dyes. With a little imagination and ingenuity you should have no difficulty developing several substances that will produce a good vapor which clings in the air for an appreciable length of time (the longer the better, naturally). You can test them in an ordinary atomizer that can be purchased in any drug store. Or, better still, you probably have a vacuum cleaner in your house and most vacuum cleaner accessory kits include a paint sprayer which nobody ever uses. Such a sprayer will give you a pretty good idea of the effectiveness of any vapor-producing substance you wish to test. You can even test your own vapor generator with a vacuum cleaner, if you wish, by simply fitting the tube end tightly over the nose cone of your rocket, on a suitable stand, and blowing air through it. Make sure, of course, that you have attached the cleaner tube to the *blower* end of the vacuum, or you will make yourself very unpopular around the house.

The vapor generator shown in Illustration *83* can be made to any dimensions you desire in order to provide a

Illustration No. 82

TYPES of FIN MARKINGS USED TO INCREASE VISIBILITY



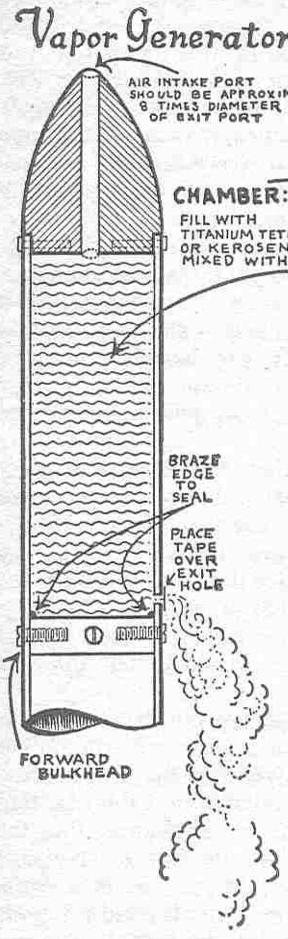
vapor trail throughout the entire flight of your rocket. It is recommended, however, that the hole in the nose cone be about eight times the diameter of the exit port at the bottom of the liquid chamber in order to ensure sufficient air pressure to form a good strong vapor spray. The liquid can be poured into the chamber through the hole in the nose cone, and a piece of tape placed over the exit port to prevent it from leaking out prior to the launching. The downward inertia of the liquid and the sudden increased air pressure at take-off should be sufficient to burst the tape loose from the exit port; but if you want to be certain that the tape comes loose at take-off you can attach one end of it securely to the launching rack.

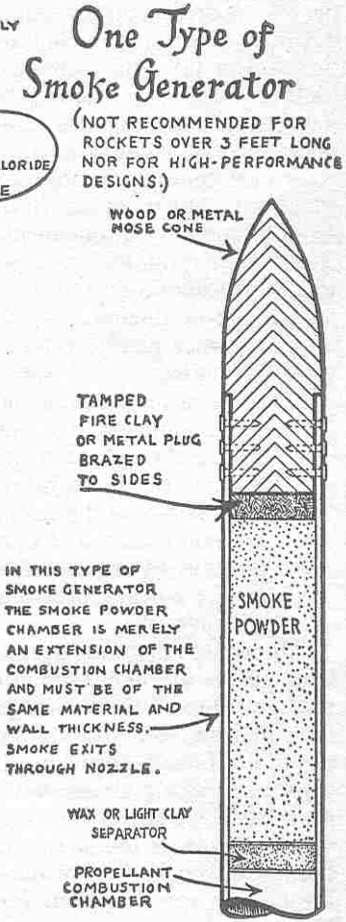
Smoke generators produce the same effect as vapor generators, but by means of burning a powdered chemical, or combination of chemicals, rather than vaporizing a liquid. Generally, they are less reliable than vapor generators, and in addition you have the problem of ignition of the smoke-producing powder to contend with. Ignition of the powder charge is usually accomplished by one of three methods:

a. Ignition on the launching rack by means of an electrical squib or wire filament, using the same power source that is used to ignite the propellant.
b. Ignition during flight by means of an electrical charge from some mechanical device designed to trigger the ignition system at a particular point in the flight.
c. Ignition by means of a fuse which is itself ignited by the burning propellant at approximately the time of burnout.

All of these methods pose design and construction problems which will challenge your ingenuity; but when all is said and done I think that you will find the first method indicated above to be the most reliable and the one that poses the fewest problems. It means, of course, that the smoke-producing charge will be burning at the same time that the propellant is burning, so that you are, in a sense, wasting some of the smoke charge. This is hardly important, however, in view of the fact that the propellant burning time in most amateur rockets is extremely short, and in any rocket the time of powered flight is only a small fraction of the total flight time. The third method (c) has been thought of by virtually everyone who ever undertook

ILLUSTRATION NO. 83





to design an amateur rocket, but by its very nature it is almost certainly doomed to failure. There simply is no way to run a fuse from the combustion chamber of a rocket to any other part of the rocket without also creating a weak point through which pressure will escape. This added exit port will either decrease the performance of the rocket considerably, or blow it apart altogether. Many rocket groups have ignited their smoke compound by simply lighting a fuse with a match while the rocket is still sitting on the launcher. This is considered foolhardy and dangerous in the extreme and should never be done by anyone.

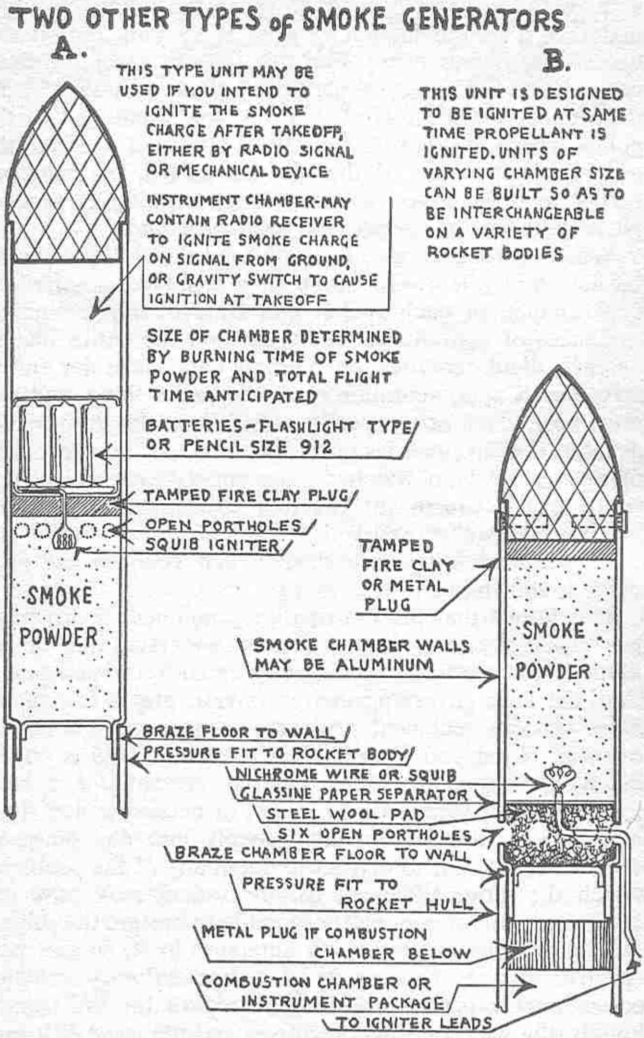
Method *b* above is feasible if you assume that every gadget in your rocket is going to work under flight conditions. Unfortunately, this is seldom the case, even with the most carefully designed and constructed rockets. Most systems for triggering some action in the rocket(e.g., stage separation, parachute release, signal flare, etc.) rely upon some type of gravity switch or timing device. What the inventors of these many gadgets fail to take into consideration is the simple fact that a mechanism which works beautifully while it is standing still at sea level frequently doesn't stand a chance of functioning at all under the impact of several *g*'s acceleration upward, the weightless conditions that occur at the peak of the trajectory, and the reverse gravitational effect on the downward flight. As an example, a piece of bathroom stopper chain suspended inside the hull of a rocket will probably remain suspended in exactly the same position relative to the rocket hull in both upward and downward flight, because it is subjected to the very same forces as is the rocket hull; and on the downward flight it will remain upright, *hanging from its lower end,* simply because it cannot fall any faster than the rocket does. The mercury switch and inertia switch shown in Chapter 6, however, are reliable and have been flight-tested many times.

Illustration *84* shows two designs of smoke generators that have been used successfully in rockets. You have merely to adapt one of these designs to the dimensions and anticipated time of flight of your own rocket. A little experimentation with small quantities of the smoke compound you decide to use will give you a burning time for it. This you can use as the basis for determining how large a smoke compound chamber you will need to provide a smoke trail for the entire period of your rocket's flight. Some smoke-producing compounds which have been used successfully by amateur groups are:

For yellow smoke—red arsenic sulfide (2 parts)
potassium nitrate (2 parts)
sulfur flowers (1 part)
For red smoke —red fusee powder

Aids to Determining Point of Impact: If your group follows the procedures recommended in this chapter for following the flight path of the rocket, marking the azimuths to its point of impact from each observer station, and recording these data on your plotting board, you should have no difficulty in recovering your rockets once firing has been suspended. One thing that will be of definite help to you in this process is to provide a large enough chamber for your smoke compound so that it will continue to burn for a few seconds after impact of the rocket. Another thing that can be helpful, and also a challenge to your group's skill in electronics, is to equip your payload with a small transmitter which will send out a beep that can be located by directional finders at your observation stations. If you have the money to do this, and the personnel in your group who are sufficiently interested, you can make quite a project out of the problem of developing some type of shock-proof housing for this transmitter which will enable it to function after impact. You might also experiment with parachutes or balloons which can be ejected from the rocket after impact and serve as markers of its location. Such things are more fanciful than practical, however, since the damage sustained by the average rocket upon impact, and the depth to which it will sometimes bury itself in the ground, more or less precludes the possibility of any mechanical gadget having a chance to function. There is always room for imagination and inventiveness, nevertheless, and your group may come up with something that is not only practical, but of definite use to other rocket groups. Do not attempt to experiment with high explosive charges for this purpose, however. Not only is it illegal and dangerous to store and handle them; but they represent an additional hazard to any personnel who may be in the impact area and a very decided fire hazard if your rocket lands in a wooded or grassy area.

ILLUSTRATION No. 84



Most groups find it impractical to attempt to recover each rocket as it is fired (assuming that a series of rockets is being launched during the day), because the time that it takes for a recovery team to reach the point of impact and return to the launching area is so long that it unnecessarily delays firing. For this reason, several rockets are usually fired over a period of time, and then firing is suspended while recovery teams are dispatched to the points where the rockets have been observed to strike the ground. Proper use of the plotting board, as discussed earlier in the chapter, will enable your group to recover all rockets whose impact has been observed.

When all rockets have been recovered a critique should be held with the entire group in attendance, so that the performance of each rocket can be properly evaluated, evidences of malfunction analyzed, and the entire history of each flight recorded on a firing data sheet for future reference. Experimentation is a progressive thing, and you must begin each new experiment based on the information developed from previous ones. Don't repeat the experience of one group who watched their most successful rocket zoom to a record height and then exclaimed, "That's the best mixture we've used yet! What was it?"

A complete firing data sheet which you can use as a guide is shown in Illustration *85*.

It is hoped that the information contained in this book has enabled you to gain a clearer understanding of the natural forces you are dealing with in rocket experimentation, the laws governing their behavior, and a few of the more obvious technical problems confronting the rocket scientist. What you have read in these chapters is only a beginning, of course. The material presented has been treated in very elementary fashion, of necessity; and there has been no attempt to delve deeply into any phase of rocket science, nor to discuss in detail any of the problems which the more advanced rocket student may have encountered. An attempt has been made to present the subject of rocket experimentation by amateurs in its proper perspective and in the context of a tremendously valuable educational experience—with due regard for the risks it entails, the validity of its objectives and the hazards it may present to the public at large. If the purpose of this book could be expressed in one sentence, it would be this: It

ILLUSTRATION NO. 85

Rocket No.______
Name or Model No.______

FIRING DATA SHEET

______
(NAME OF GROUP)

Place: ______ Date: ______

Weather Data:
Temperature ______
Wind Direction ______
Wind Velocity ______
Precipitation ______
Visibility (Grd) ______
Ceiling ______
Humidity ______

Rocket Data:
Name ______
Length ______
O. D. ______
No. Fins—Type ______
Weight Empty ______ M/R:
Weight Loaded ______

Propellant Data:
Type ______
Mixture ______
Weight ______
Density ______
Burning Rate ______
Spec. Imp. ______

Nozzle: Type ______
Length ______
Throat Area ______
Exit Area ______
O. D. ______
Material ______

Expected Performance:
Total Thrust ______
Total Burning Time ______
Exhaust Velocity ______

Comb. Chamber:
Cross. Area ______
Length ______
Wall Thickness ______
Material ______

Launching Data:
Launcher Used ______
Launching Angle ______
Direction ______

Instrumentation:
______
______
______

Personnel Participating:
Range Officer ______
Safety Officer ______
Key Man ______
Loaders ______
Observers ______

Special Data:
______
______

Remarks: (Include Anticipated Performance in Terms of Altitude, Range, Time of Flight, Velocity, Etc.)

FIRING DATA

Time of Firing: ______
Misfires: —Reason: —Action Taken:
______ ______ ______
______ ______ ______
______ ______ ______

Successful Firing:
Takeoff Normal? ______ Est. Altitude ______ Flight Behavior ______
Burning Time ______ Est. Velocity ______ Part Failures ______
Total Flight Time ______ Impact (Distance) ______ Remarks: ______

has been written to encourage the serious-minded student who hopes to become a scientist, and to discourage the foolhardy adventurer who thinks that the rocket is a simple instrument from which he can derive entertainment.

Rocket experimentation by amateurs has been a matter of controversy in this country for the past two years. And it will continue to be a matter of controversy until the responsible officials in the various states decide whether it is feasible to permit such experimentation on a controlled basis for educational purposes, or to ignore the situation altogether. Already there are hopeful signs that the former view is being taken in an increasing number of states, that the scare psychology of alarmists is not panicking officials who are concerned with the public safety, and that a calm appraisal of the arguments for and against amateur rocketry has led many state governments to conclude that the problem of developing technical talent in this country is the more important consideration at this time. The author firmly believes that the accident potential inherent in rocket experimentation has been greatly over-emphasized; due in large measure to the nationwide publicity accorded a few isolated incidents involving injuries—injuries which, incidentally, would have received no publicity at all had they been caused by a bandsaw, an automobile accident, or a fire in the kitchen stove, rather than a rocket. He further believes that accidents can be virtually eliminated by diligent application of the preventive and protective measures developed by the ordnance departments of the military services and the explosives industry during the past century-and-a-half. The proof of this is abundantly evident in the fact that the explosives industry itself has one of the lowest accident rates among all major industries.

The experience of the amateur rocketeer during the past few years has served to illustrate the truth of Alexander Pope's dictum that *a little learning is a dangerous thing*. Since there is no practical means of depriving the nation's budding scientists of the *little learning* they have already gained, it would seem the course of wisdom to supplement it with the companion knowledge they must have to be able to recognize the hazards they are facing and protect themselves from them. To do less would be to contribute to the likelihood of disaster rather than avoid it. It is hoped that this volume provides, in some measure, that extra knowledge which may serve to prolong the lives of the thousands of talented young people from among whom America must draw its scientists of the future.

APPENDIX A—SUMMARY OF STATE LAWS AFFECTING AMATEUR ROCKETRY

State	New Legislation Contemplated	Present Laws Which Apply	Remarks
Alabama	None	Legislation provides that the fire marshal prescribe and enforce regulations concerning manufacture, use, storage, handling, and transportation of explosives and flammable material.	Violation of regulations adopted by the fire marshal shall be considered a misdemeanor and punishable by a fine of no less than $10.00 and no more than $50.00.
Alaska	None	None	None
Arizona	None	Sec. 36-1602 provides that it is unlawful to sell, offer or expose for sale, use, to explode or possess any fireworks.	No laws governing control of experimentation and firing of rockets.
Arkansas	Yes	None	None
California	None	Sec. 12503 covers "Dangerous Fireworks"—sky rockets including all devices which rise in the air during discharge.	Amateur and model rockets are classified by law as "dangerous fireworks."
Connecticut	None	Fireworks statutes apply.	"The issuance of a license by any fire chief or fire marshal for the purpose of constructing or launching a rocket, would be in conflict with the interests of the general public."—Directive of State Fire Marshal.
Delaware	None	Fireworks laws—Sec. 6901, 6902, 6903, 6904, and 6905.	Rockets considered as fireworks.
Florida	None	Sec. 552.091 of Florida Statutes.	Sec. 552.101 of Florida Statutes states that "no person shall be possessed of an explosive unless he is the holder of a license or permit.
Georgia	None	Regulation 31, Georgia Safety Fire Regulations for Explosives.	Requires licensing, but exempts schools and research institutions.
Idaho	None	Department of Aeronautics Regulations	No rockets or missiles may be fired without a permit from the Department of Aeronautics.
Illinois	None	Illinois laws concerning fireworks and explosives. Chap. 38 of Illinois Criminal Code, Sec. 236-239 and 276.	Rockets are considered as fireworks.
Indiana	None	ACI regulation #4 of the Aeronautics Commission of Indiana.	This law is now in full force and effect.
Iowa	None	Sec. 732.17	Miniature rockets come under the definition of fireworks as regulated by the legislature.

State	New Legislation Contemplated	Present Laws Which Apply	Remarks
Kansas	None	Jurisdiction of State Fire Marshal. Article 6—Regulations governing the sale and handling of fireworks in the state of Kansas.	1) Rockets are considered as fireworks. 2) Rockets are prohibited in Kansas unless fired by a science class under the supervision of a science instructor and with the approval of the fire chief.
Kentucky	None	KRS 438.110 Fireworks laws	Rockets are considered as fireworks.
Louisiana	None	Fireworks laws	Rockets are considered as fireworks.
Maine	None	Fireworks laws. Sec. 21 of Chap. 37 R. S. of Maine, 1954	Rockets are considered as fireworks.
Maryland	None	Fire Regulations and Fireworks Laws.	Rockets are considered as fireworks.
Mass.	None	Fire Prevention Regulations Chap. 148, Sec. 9, 10, and 39	Rockets are considered as fireworks.
Michigan	None	No specific legislation.	State Bar Comm. considering question of amateur rocketry but has not as yet recommended any legislation.
Minnesota	None	Rules and regulations of Commissioner of Aeronautics.	Sec. 60 gives specific regulations concerning the firing of rockets.
Mississippi	None	None	None
Missouri	None	None	City of St. Louis ordinances prohibit amateur rocket experiments in the city. Refer to Sec. 111 of St. Louis Building Codes which deal with explosives and fireworks. Schools are exempted
Montana	Yes	None	Legislature contemplates new law on fireworks and explosives during 1959 session.
Nebraska	None	State Fire Marshal Act, Sec. 81-502 and Sec. 81-538, of the General Platitudes empowers the State Fire Marshal to establish regulations as he sees fit.	Violation of these rules will be considered a misdemeanor, punishable by a fine of no less than $5.00 and no more than $100.00.
Nevada	None	Legislation relating to fireworks and explosives applies.	Rockets are considered as fireworks.
New Hamp.	None	Fireworks regulations RSA 160:1	Rockets are considered as fireworks.
New Jersey	Bureau of Engineering and Safety is drafting a bill which permits a person of not less than 15 years of	Fireworks laws—P.L. 1941, c.27 (N.J.S.A. 21:1A-15) and R.S. 21:2-1 (N.J.S.A. 21; 2-1) P.L. 1948, c.210 (N.J.S.A. 21:1A-51)	Bureau of Engineering enforces fireworks laws and classifies amateur rocketry under propellant explosives. Three new bills have been proposed, one of which would create a commission

State	New Legislation Contemplated	Present Laws Which Apply	Remarks
	age to assist in the preparation or use of propellants in amateur rocketry if such work is done under the supervision of a person with a valid permit to use explosives.		to study amateur rocket activity.
N. Mexico	None	1953 New Mexico Statutes Annotated.	None
New York	None	Penal Law Sec. 1894, 1894-a, 1897(2)	1) Rockets are considered as fireworks. 2) No laws in New York City are concerned with the building, testing, and firing of rockets per se, but they are considered to be explosives.
N. Dakota	None	Fire Laws	Rockets are considered as fireworks.
N. Carolina	None	Fireworks Laws	1) "Experimentation with rockets and missiles would violate the fireworks laws of this state."—Opinion of Attorney General. 2) Rockets are considered as fireworks.
Ohio	None	Fire Prevention Laws and laws regulating explosives. Sec. 3743.02, 3743.03	Rockets are considered as fireworks.
Oklahoma	None	None	No available information.
Oregon	None	Fireworks Laws ORS 480.110-480.170	Rockets are considered as fireworks.
Penna.	None	Fireworks Laws—Opinion No. 104 (Dept. of Justice)	Rockets are considered as fireworks.
R. Island	None	None	1) School and local authorities are attempting to regulate amateur rocket activity. 2)[Gen. Assembly created a commission to deal with the distribution and use of dangerous chemicals. It is expected that its study will result in the enactment of a regulatory law.
S. Carolina	None	Act No. 1033 of the Acts of 1948 1958 Supplement to the Code of Laws of South Carolina—Sec. 16-131-131.3 South Carolina House Bill No. 2334 (April 10, 1958)	One of the few states to have enacted a law relating specifically to rockets and missiles which provides for a fine of not more than $100.00 or 30 days in prison for violation.
S. Dakota	None	SDC 13.1607, SDC Supplement 13.1607, SDC 13.1608	Rockets are considered as fireworks.
Tennessee	Possibility	None	No further information.

State	New Legislation Contemplated	Present Laws Which Apply	Remarks
Texas	Possibility	None	No further information.
Utah	None	Title 2 of Utah Code Annotated.	Rockets are considered as fireworks.
Vermont	None	Act No. 93 of 1953	1) Rockets are considered as fireworks. 2) State of Vermont Dept. of Education, Dept. of Public Safety and Aeronautics Dept. have jointly issued a policy statement setting forth conditions under which amateur rocket experiments may be conducted. Vermont is the first state to have done this.
Virginia	None	Fireworks Laws and regulation of explosives. Sec. 15-77.29, Code of Virginia.	Rockets are considered as fireworks.
Washington	None	Washington State Aeronautics Commission Regulation #4.	One of the few states having a regulation which definitely permits launching of amateur rockets upon application.
W. Virginia	None	Fireworks Laws and regulation of explosives.	Rockets are considered as fireworks.
Wisconsin	None	Fireworks Laws Sec. 167.10 of Wisconsin Statutes.	Industrial Commission has various regulations relating to storage and use of explosives.
Wyoming	None	Sec. 29-317 of Wyoming Compiled Statutes, 1945 Sec. 29-430 of Wyoming Statutes, 1945	None

APPENDIX B

FIRST-AID ADVICE FOR ROCKET GROUPS

The following guidance for the First-Aid treatment of common injuries which might result from a rocket explosion, and for injuries which may be sustained from commonly used rocket fuels and oxidizers is printed here for the immediate reference of amateur groups who might find themselves with an accident on their hands. The material is extracted from the Army Manual on First Aid. The complete manual (Department of Army Field Manual 21-11) may be obtained by sending 40 cents together with a request to:

Superintendent of Documents
Government Printing Office
Washington 25, D. C.

As recommended previously in this text, however, the amateur group should make certain that at least one of its members has been adequately trained in First Aid, and if possible, possesses a Red Cross certificate. First Aid, to be effective, must be administered by someone well-trained in the approved techniques, who knows immediately what to do and has the necessary medical equipment close at hand.

THE THREE LIFESAVER STEPS IN FIRST AID

The three lifesaver steps in first aid are: STOP THE BLEEDING! PROTECT THE WOUND! PREVENT OR TREAT SHOCK! You should memorize these three steps and learn the simple methods of carrying them out. Now is the time to learn. Prompt and correct first aid for wounds will not only speed healing, but will often save a life—*and that life may be yours!*

A. *Stop the Bleeding*

(1) a. To stop bleeding, first apply pressure to the wound with a dressing. Uncontrolled bleeding causes shock and finally death. Place the opened dressing against the wound and apply firm pressure. *Use the wounded man's dressing—not your own.* Use an additional dressing, if necessary, to cover the wound. Wrap the tails of the dressing around the wounded part and tie the ends to hold the dressing firmly. If the wound is on the arm or leg and bleeding continues, raise the arm or leg.

b. Have the man lie down with his wounded arm or leg raised. If you think there is a broken bone, do *not* raise the arm or leg. Moving a broken arm or leg is painful and dangerous and will increase shock. When the arm or leg is raised, blood will not flow into it so fast; therefore, bleeding from the wound will be slowed. Of course, some blood will always flow through the arm or leg, so you will still have to use the bandage and pressure.

(2) In the case of a wound or wounds of the arm or leg, *if the bleeding does not slow down* considerably in a few minutes, it is time to try something else—a tourniquet. When pressure and elevation fail to stop bleeding from a limb (arm or leg) or when blood is gushing from a wound, a tourniquet should be applied quickly. However, *never* apply a tourniquet unless blood is gushing from a wound or until all other methods of stopping bleeding have failed. A tourniquet should be tightened only enough to stop arterial bleeding. Veins will continue to bleed until the limb has been drained of blood already present in it, and this is not aided by further tightening of the tourniquet.

a. The tourniquet should always be placed between the wound and the heart, in most cases as low as possible above the wound; however, in case of bleeding below the knee or elbow, it should be placed just above these joints. When possible, protect the skin by putting the tourniquet over the smoothed sleeve or trouser leg.

b. Once a tourniquet has been applied, the wounded man should be seen by a medical officer as soon as possible. The tourniquet should *not* be loosened by anyone *except* a medical officer prepared to stop the bleeding by other means and prepared to replace the blood volume adequately. *Repeated loosening of the tourniquet* by inexperienced personnel is extremely dangerous and can result in considerable blood loss and endanger the life of the patient. Inspect the tourniquet frequently to see if it has slipped or if there is any sign of further bleeding. In extremely cold weather, extremities such as the arms or legs, with tourniquets applied, are subject to cold injury, and therefore should be protected from the cold.

B. *Protect the Wound*

The first-aid dressing protects wounds from the *outside*. It keeps dirt and germs out. It protects wounds from further injury. When applying the first-aid dressing, be careful to keep hands and foreign matter out of the wound.

C. *Prevent or Treat Shock*

(1) Shock is a condition of great weakness of the body. It can result in death. It may go along with any kind of wound; the worse the wound, the more likely it is that shock will develop. Severe bleeding causes shock. A person in shock may tremble and appear nervous; he may be thirsty; he may become very pale, wet with sweat, and may pass out.

(2) Shock may not appear for some time after an injury. *Treat the wounded man for shock before he has a chance to get it.*

(3) To prevent or treat shock, make the patient comfortable. Take off anything he is carrying. Loosen his belt and

clothes. Handle him very gently. Do not move him more than absolutely necessary. If he is lying in an abnormal position, make sure no bones are broken before you straighten him out. If there is no head wound, lower the head and shoulders or if possible raise the legs to increase the flow of blood to the brain. Victims with head wounds are treated as described in paragraph D under Head Wounds. If the ground slants, turn him gently so that the feet are uphill and the head downhill. Keep the man warm by wrapping him with a blanket, coat, or poncho. Place something under him to protect him from the cold ground. If he is unconscious, place him face down with his head turned to one side, to prevent choking in case he should vomit. If he is conscious, replace body fluids of the patient by giving fluids by mouth. Warm stimulants such as coffee, cocoa, or tea are excellent. Do not give fluids to an unconscious person or to a person with a belly wound.

FIRST-AID MEASURES FOR GENERAL INJURIES

A. Chest Wounds

Chest wounds through which air is being sucked in and blown out of the chest cavity are particularly dangerous. The chest wound itself is not as dangerous as the air which goes through it into the chest cavity. This air squeezes the lung, thereby collapsing it and preventing proper breathing.

The life of the victim may depend upon how quickly the wound is made airtight. Have the patient forcibly exhale (breathe out), if possible, and immediately apply a dressing which is large enough to cover the wound and stop the flow of air. Pack the dressing firmly over the wound. Cover the dressing with a large piece of raincoat or other material to help make the wound airtight. Bind this covering securely with belts or strips of torn clothing. Encourage the patient to lie on his injured side so that the lung on his uninjured side can receive more air. If he wishes, let him sit up. This position may ease his breathing.

B. Belly Wounds

(1) *Do's*

a. Cover the wound with the sterile dressing from a first aid packet and fasten securely.

b. Treat the wounded person for shock.

(2) *Do Not's*

a. Don't try to replace any organs, such as intestines, protruding from the belly. If you do, you will cause infection and severe shock. However, if it is necessary to move an exposed intestine onto the belly in order to cover the wound adequately, then do so.

b. Don't give (or take) food or water. Anything taken by mouth will pass out from the intestine and spread germs in the belly. (If evacuation is delayed, the lips may be moistened with a wet handkerchief.)

C. Jaw Wounds

If the victim is wounded in the face or neck, he will need special treatment to prevent his choking on blood. Bleeding from the face and neck is usually severe because of the many blood vessels in these parts. First, stop the bleeding by exerting pressure with a sterile dressing. Then bind the dressing so as to protect the wound. If the jaw is broken, place the absorbent part of the dressing over the wound and tie the tails over the top of the head to lend support. An additional dressing may be used to tie under the chin for added support, but allow enough freedom for free drainage from the mouth. The mouth should not be bandaged shut. To avoid choking on blood a man may sit up with his head held forward and down, or he may lie face down. These positions will allow the blood to drain out of his mouth instead of down his windpipe. Remember to treat for shock but do not use the face-up, head-low shock position.

D. Head Wounds

(1) A head wound may consist of one of the following conditions or of a combination of them: a cut or bruise of the scalp, fracture of the skull and injury to the brain, and/or injury to the blood vessels of the scalp, skull, and brain. Usually, serious skull fractures and brain injuries occur together. It will be easy for you to discover a scalp wound because of the profuse bleeding. A scalp wound may need nothing more than the three lifesaver steps in first aid which are:

STOP THE BLEEDING
PROTECT THE WOUND
PREVENT OR TREAT SHOCK

However, if there is internal injury of the head, it will be more difficult for you to discover.

(2) Check for head wounds if person—

a. Is now or has recently been unconscious.

b. Has blood or other fluid escaping from the nose or ears.

c. Has a slow pulse.

d. Has a headache.
e. Is vomiting.
f. Has had a convulsion.

(3) Do not give morphine to victim with head wounds. Morphine hides signs or symptoms that the doctor should see in order to know what to do for the victim. It also causes breathing to slow down and may even cause it to stop. Do not place the victim's head in a position lower than the rest of his body. A man with a head wound should be promptly evacuated on a litter. If the man is conscious, examination of the mouth should be made for false teeth or other objects which might cause choking. If he is unconscious, move him face down and lying on his abdomen or on his side to prevent his having any difficulty in breathing.

D. Severe Burns

Severe burns are more likely to cause SHOCK than other severe wounds. Follow the procedure for prevention of shock. There is also a great danger of INFECTION. Do NOT pull clothes away from the burned area; instead, cut or tear the clothes and gently lift them off. Do NOT try to remove pieces of cloth that stick to the skin. Carefully cover the burned area with sterile dressings. If no sterile dressing is available, leave the burn uncovered. Never break blisters or touch the burn. It is especially important to treat for shock and to prevent infection. The victim should drink lots of water because severe burns cause a great loss of body fluids. There is also a great loss of body salts. Therefore, if possible, add two salt tablets or ¼ teaspoonful of loose salt to each quart of water. Three or more quarts should be drunk in 24 hours.

E. Fractures

A fracture is a broken bone.

(1) Signs

a. These are the signs of a broken bone—
   i. Tenderness over the injury with pain on movement.
   ii. Inability to move the injured part.
   iii. Unnatural shape (deformity).
   iv. Swelling and discoloration (change in color of the skin).

b. A fracture may or may not have all these signs. If you aren't sure, give the wounded the benefit of the doubt and treat the injury as a fracture.

(2) Kinds—There are two main kinds of fractures:

a. A closed fracture or a break in the bone without a break in the overlying skin.

b. An *open fracture* or broken bone that is exposed to contamination through a break in the skin. Open fractures may be caused by broken bones piercing the skin or by missiles which pierce the flesh and break the bone.

(3) Greatest Care

If you think a person has a broken bone, handle with greatest care. Rough or careless handling causes pain and increases the chances of shock. Furthermore, the broken ends of the bone are razor-sharp and can cut through muscle, blood vessels, nerves, and skin. Remember—don't move a man with a fracture unless it is necessary. If you do, be gentle and keep the fractured part from moving. *If there is a wound with a fracture, apply a dressing as you would for any other wound.* If there is bleeding, it must be stopped. To stop bleeding, see the Three Lifesaver Steps in First Aid at the beginning of this chapter. Do not apply a tourniquet over the site of the fracture.

(4) Splinting for Fractures

a. Most fractures require splinting. Persons with fractures of long bones should be splinted "where they lie" before any movement or transportation is attempted. Proper splinting greatly relieves the pain of a fracture and often prevents or lessens shock. Fixing the fragments of a broken bone by use of splints prevents the jagged edges of the bone from tearing blood vessels and nerves. In a closed fracture (one in which there is no break in the skin), proper application of a splint will prevent the bone from piercing the skin and changing it into an open fracture. If the fracture is open, splinting will prevent further injury to the wound and the introduction of more infection.

b. First aid in the field may require improvising splints from any material that is handy.

(5) Splints for Fractured Bones of Leg, Hip, or Thigh

a. The quickest way to splint the broken bone in a leg is to tie both legs together above and below the break. In this way, the uninjured leg will serve as a splint for the broken bone. You can use a belt, cartridge belt, rifle sling, strips of cloth, or handkerchiefs tied together. Do *not* move a man with a fractured bone of the leg unless it is necessary to get him off a road or away from enemy fire. If you must move him, tie his legs together first, grasp him by the shoulders and pull him in a straight line. Do not roll him or move him sideways.

b. If you have time, you can make a good splint for the lower leg by using two long sticks or poles. Roll the sticks into a folded blanket from both sides. This pads the leg and forms a trough in which the leg rests. Bind the splint firmly at several places. Splints for fractures of the bones of the leg should extend from a point above the knee to a little below the foot. If the broken bone is in the thigh or hip, the inside splint should extend from the crotch to a little below the foot and the outside splint should extend from the armpit to a little below the foot. Always be sure that the ends of the sticks or poles are well-padded.

(6) Splints—for Fractured Bones of the Arm

a. When possible, keep the fractured bone of the arm from moving by supporting the arm with splints. This reduces pain and prevents damage to the tissues. Temporary splints can be made from boards, branches, bayonets, scabbards, etc. Splints should always be padded with some soft material to protect the limb from pressure and rubbing. Bind splints securely at several places above and below the fracture but not so tightly as to stop the flow of blood. It is well to apply two splints, one on either side of the arm. If an injured elbow is bent, do not try to straighten it; if straight, do not bend it.

b. A sling is the quickest way to support a fractured bone of the arm or shoulder, a sprained arm, or an arm with a painful injury. The arm should be bound snugly to the body to prevent movement. You can make a sling by using any material that will support all or a portion of the lower arm and hold it close to the body.

(7) Broken Back

a. It is often impossible to be sure a man has a broken back. Be suspicious of any back injuries, especially if the back has been sharply struck or bent, or the person has fallen. The most important thing to remember is that if the sharp bone fragments are moved, they may cut the spinal cord. This will cause permanent paralysis of the body and legs.

b. For a Broken Back

i Do's

(a) Place a low roll, such as a bath towel or clothing, under the middle of the back to suport it and bend it backwards.

(b) If the man must be moved, lift him onto a litter or board without bending his spine forward. It is best to have at least four men for this job.

(c) If the man is in a face down position, he may be carried face down in a blanket.

(d) Keep the patient's body alignment straight and natural at all times and keep the air passages free.

ii Do Not's

(a) Don't move the patient unless absolutely necessary.
(b) Don't raise his head even for a drink of water.
(c) Don't twist his neck or back.

(d) Don't carry him in a blanket face up.

(8) Broken Neck

A broken neck is extremely dangerous. Bone fragments may cut the spinal cord just as in the case of the broken back. *Keep the patient's head straight and still.* Moving him may cause his death.

a. Keep the head and neck motionless by placing large stones or packs at each side of the head as support. Place a rolled blanket under the neck for support and padding. Raise the shoulders in order to place the roll under the neck. Don't bend the neck forward. Don't twist or raise the head at all.

b. A good way to keep the head in the right position is to immobilize the neck with a high collar. A high collar tends to lengthen the neck and raise the chin so as to arch the neck backward. A simple collar can be made from an artillery shell container. Cut the cardboard cylinder into a collar about five inches high. Split it on one side, pull it apart, and place it around the neck. Fasten the collar with adhesive tape. A similar type of splint can be made by wrapping a folded shirt, jacket, or newspaper around the neck. Use a belt, string, or strip of cloth to hold it in place, but be sure not to choke the patient.

c. If the man must be moved, get help. One person should support the man's head and keep it straight while others lift him. Transport him on a hard stretcher or board.

d. Never turn a man over who has a broken neck!

FIRST AID FOR INJURIES SUSTAINED FROM ROCKET FUELS

I. OXIDIZERS

A. Red and White Fuming Nitric Acid.

(1) Solutions of red and white fuming nitric acid cause severe chemical burns when in contact with skin or eyes. Remove the acid immediately by washing skin and eyes with large amounts of clean water for at least 15 minutes, and follow by application of a weak solution of bicarbonate of soda and water or use the bicarbonate of soda and water solution without washing the skin and eyes. After neutralizing or washing the contaminated skin, treat acid burn as follows:

a. Severe Burns—Prevent Shock and Infection

Severe burns are more likely to cause shock than other severe wounds. Follow the procedure outlined in paragraph #3 below. There is also a great danger of infection. Do not pull clothes away from the burned area; instead, cut or tear clothes and gently lift them off. Do not try to remove pieces of cloth that stick to the skin. Carefully cover the burned area with sterile dressings. If no sterile dressing is available, leave the burn uncovered. Never break blisters or touch the burn. It is especially important to treat for shock and to prevent infection. The victim should drink lots of water because severe burns cause a great loss of body fluids. There is also a great loss of the body salts. Therefore, if possible, add two salt tablets or ¼ teaspoonful of loose salt to each quart of water. Three or more should be drunk in 24 hours.

b. Small Burns.

Small burns are a frequent injury; and such burns, unless properly treated, often become infected. If a first-aid kit containing sterile gauze is available, apply the gauze over the burn as a dressing. Cover the burned area with an additional dry dressing of suitable size. If no sterile dressing is available, leave the burn uncovered.

c. Shock.

To prevent or treat shock, make the patient comfortable. Loosen his belt and clothes. Handle him very gently. Do not move him more than is absolutely necessary. Keep him warm. Try to get his feet slightly higher than his head.

(2) If solution of red and white fuming nitric acid is swallowed, immediately dilute the acid by drinking large amounts of water. Try not to vomit. Get medical treatment immediately.

(3) The fumes of the nitric acids (the nitrogen oxides) are in many ways more dangerous than obvious liquid skin contact because after inhalation their harmful effects may show up long after the exposure has occurred; also, amounts not immediately irritating may cause serious illness later. Leave the area without delay, if possible. The fumes of nitric acid may cause irritation of the eyes, choking burning in the chest, violent cough, spitting of yellow spit, headache, and vomiting. These symptoms may be relieved by getting to fresh uncontaminated air immediately, following which you may continue with your normal duties. However, seek immediate medical attention in the presence of continued difficulty in breathing, nausea and vomiting, or more than the usual shortness of breath on exertion. If medical attention is not available, rest quietly until help arrives.

(4) Solution of hydrogen peroxide in contact with skin and eyes will usually cause irritation but it will be tem-

porary if skin and eyes are quickly cleansed and rinsed with water. Additionally, affected skin may be covered with vaseline or vaseline gauze.

(5) Hydrogen peroxide vapors irritate the mucous membranes of the nose and throat, causing excessive coughing and nasal and throat secretion. Fine droplets (mists) of strong hydrogen peroxide solution may be injurious to the nose, throat, and especially to the eye. The damaging effects on the eye may develop long after the exposure. Get fresh air immediately or put on an approved type protective breathing apparatus.

(6) First-aid treatment for severe skin burns caused by hydrogen peroxide is the same as that for an ordinary thermal burn.

B. Liquid Oxygen.

(1) Liquid oxygen is nontoxic and does not produce irritating fumes. When it comes in contact with the skin, it freezes the tissues, producing an effect very similar to a burn or a scald. Remove from the skin immediately. Rinse the skin with water. If possible use warm water. If contamination is sufficient to cause a burn, first remove the liquid oxygen and then treat as any ordinary thermal burn. Severe skin exposure usually requires medical attention.

(2) Remove contamination from the eyes by immediately washing with large amounts of clean water. Get prompt medical attention.

(3) Remove contaminated clothing immediately.

(4) Remove body contamination by taking a long shower, for at least 15 minutes.

II. PROPELLANT FUELS

A. Aniline.

(1) Aniline is a flammable, colorless, oily liquid which darkens on exposure to light or air. It has a burning taste and a characteristic odor. It is a poisonous liquid and also gives off toxic vapors.

(2) Contact with the skin causes severe irritation. If allowed to remain, it will be absorbed into the blood stream through the skin. The vapor causes irritation of the throat and lungs, leading to sore throat and deep cough. Taken internally, it will cause poisoning. A sense of well-being is often experienced in the early stages of exposure. As the amount of exposure increases, the lips turn blue, and bluish tinges appear on the fingernail beds, the tongue, the mouth, and lining of the eyelids. This is followed by headache and drowsiness, sometimes with nausea and vomiting. Stupor

and unconsciousness may follow. Recognition of the bluish tinge in dark-skinned races can best be accomplished by examination of the tongue and the lining of the mouth and eyelids.

(3) If you are exposed to this chemical, take immediate action. Wash liquid aniline from the skin with large amounts of water or a 5 per cent solution of acetic acid or vinegar. If aniline vapors are present, evacuate the area immediately or remove them by ventilation. If the vapors cannot be removed by ventilation or the area cannot be evacuated, put on your protective mask immediately.

(4) Remove eye contamination by washing with large amounts of clean water. If aniline gets into the ear, flush it with 3 per cent acetic acid solution or vinegar. Remove contaminated clothing immediately and soak them in a diluted acetic acid solution or vinegar. If acetic acid solution or vinegar is not available, use clean water. In all cases of severe exposure, or if aniline is accidentally swallowed, get immediate medical attention.

(5) If any of the symptoms of aniline poisoning occur, such as severe headache, drowsiness, nausea, and vomiting; remove the victim to fresh air, and keep quiet, give a mild stimulant such as black coffee (*never* alcohol), and keep warm. Give artificial respiration to victims who are not breathing.

B. Ethyl Alcohol. Do Not Drink.

(1) Ethyl alcohol is a highly intoxicating liquid which evaporates quickly and is flammable. Like water in appearance, ethyl alcohol cannot be distinguished from other more poisonous alcohols, such as methyl alcohol, by its burning taste and odor. It may contain certain toxic substances which have been added to it to make it unfit for human consumption.

(2) The vapors of this liquid cause severe irritation to the eyes and upper respiratory tract. Wear an approved form of respiratory protective equipment in areas where there is likely to be a high concentration of these vapors.

(3) If ethyl alcohol is spilled into the eyes, wash it out immediately with large amounts of water. If the symptoms persist, get medical attention.

(4) This liquid has little effect on the skin. However, remove contaminated clothing and bathe contaminated skin area because prolonged contact causes irritation of the skin.

C. Furfuryl Alcohol. *Do Not Drink.*

(1) Furfuryl alcohol is a straw-yellow to dark-amber liquid with a brine-like odor and bitter taste. It is poisonous if absorbed from prolonged skin contact or taken internally. Drinking this alcohol is very dangerous.

(2) If furfuryl alcohol is spilled on the skin or in the eyes, it will cause irritation. Remove immediately by washing with large amounts of clean water.

(3) Although it does not vaporize quickly in closed spaces at high temperatures, troublesome collections of vapor may gather or collect which cause irritation to the throat or lungs.

(4) Remove contaminated clothing and rinse affected skin areas with water.

D. Methyl Alcohol. (Wood Alcohol) Do Not Drink.

(1) Methyl alcohol is a highly poisonous chemical. It is colorless like water. It has an odor very much like ethyl alcohol, and the sense of smell should not be relied upon to distinguish between these two alcohols. It evaporates quickly and is flammable.

(2) This chemical may enter your body by your breathing the vapors, by absorption through the skin, or by drinking it; and, in small amounts, it will cause headache, nausea, vomiting, and irritation of the mucous membranes. Larger amounts in the blood cause dizziness, staggering walk, severe cramps, sour stomach, blindness, convulsion, coma, and death. Swallowing a small amount of this chemical may cause death.

(3) When working in closed spaces with this chemical, provide adequate ventilation or use some approved form of respiratory protective equipment.

(4) Wash contaminated skin areas with large amounts of clean water. Remove contaminated clothing.

(5) If this chemical is accidentally swallowed, get medical attention immediately. If medical attention cannot be obtained at once, large amounts of epsom salts with large amounts of water may be taken in order to assist in the elimination of as much as possible of the chemical from the stomach. Get medical attention as soon as possible.

E. Hydrazine

(1) Hydrazine is a colorless, alkaline, fuming liquid which is odorless or may have the odor of ammonia. It is flammable, highly explosive, and corrosive. Hydrazine is poisonous to humans by breathing, by skin contact, and if taken internally. Skin contact results in an intense burning sensation. If you are exposed to moderate

or heavy concentrations of vapors, they will cause immediate violent irritation of the nose and throat, itching, burning, and swelling of the eyes; and prolonged exposure may cause temporary blindness. If you are exposed to mild concentrations of these vapors, signs may not appear until 3 or 4 hours later in the form of the same eye and nose effects as described above.

(2) Remove skin contamination by washing with large amounts of clean water, followed by an application of boric acid paste. Troops exposed to hydrazine should obtain this first-aid item from a medical installation and keep the item constantly and readily available.

(3) In any concentration of vapors, use a closed breathing apparatus. Remove victims overcome by poisonous fumes from the area. Give artificial respiration to those not breathing.

(4) Remove eye contamination by washing with large amounts of water or 3 per cent boric acid solution if available.

(5) Remove contaminated clothing and bathe the skin area with clean water or 5 per cent acetic acid solution.

(6) Remove whole body contamination by taking a long shower for at least 15 minutes.

(7) In all cases of exposure to hydrazine, receive medical attention promptly.

F. Hydrocarbon Fuels

(1) Hydrocarbon fuels are flammable compounds (gasoline, jet-propulsion fuels, kerosene, heptane, butane, octane, pentane, etc.). All of these fuels produce essentially the same effects in varying degrees. They give off vapors at normal temperatures which, when mixed with proper air mixtures, are ignitable by spark or flame. The vapors given off are heavier than air and, therefore, tend to collect in storage areas. Hydrocarbons are poisonous, both in inhalation and absorption through the skin. In addition to the poisonous qualities due to hydro-carbon content, aviation gasoline contains tetraethyl lead and jet fuels contain aromatics, both of which are also poisonous by inhalation, skin absorption, or if taken internally.

(2) If you do not immediately remove hydrocarbon fuels which have come in contact with your skin, it will become red and irritated and later will blister. Long exposure of the skin to hydrocarbon fuel can result in death of the tissue with scarring and deformity. Contact with the eyes causes immediate irritation, redness, and large amounts of tears.

(3) Whenever any of these hydrocarbons come in contact with the skin or eyes, wash them out with large amounts of water. Keep areas where concentrations of hydrocarbon vapors are likely to gather well-ventilated or use some form of self-contained breathing apparatus.

(4) When hydrocarbon poisoning is apparent, get medical attention immediately. In the meantime, get the victim into fresh air, keep warm, quiet, and lying down. If he is unconscious or having breathing difficulty, give him a few sniffs of aromatic spirits of ammonia and apply artificial respiration. When consciousness has been regained, give stimulants (coffee or tea).

G. Solid Propellants

(1) Solid doublebase propellants contain nitrocellulose and nitroglycerin. Nitroglycerin causes unpleasant and serious effects upon exposure, such as flushing of the face, moderate to severe headache, rapid pulse, nausea, and vomiting, colicky pains, diarrhea, irregular breathing, and unconsciousness. Not all of these symptoms will appear. Any one or several may appear, but the most common is headache. In cases of severe poisoning, victims may be delirious, may have convulsions, or collapse.

(2) If any of the above signs occur after exposure to these chemicals, keep the victim lying down with the legs raised and the head lowered, provide plenty of fresh air, give stimulants (coffee or hot tea), and alternate hot and cold applications to the chest. If the victim is having breathing difficulty, apply artificial respiration. Get immediate medical attention.

(3) If exposed to either of these chemicals, do not drink even the smallest amount of alcohol. Alcohol makes the signs more severe and dangerous.

(4) After handling these materials, wash the hands thoroughly before eating, smoking, or drinking, to prevent taking the chemical into the stomach.

APPENDIX C—USEFUL TABLES

TABLE OF ALTITUDES

Distances In Feet From Observation Point To Point "X" (Base Distance)

ELEVATIONS IN DEGREES AS SIGHTED FROM OBSERVATION POINTS	1000	1250	1500	1750	2000	2250	2500	2750
20°	*364	455	546	637	728	819	910	1,001
25°	466	582	699	815	932	1,048	1,165	1,281
30°	577	722	866	1,010	1,154	1,299	1,443	1,587
35°	700	875	1,050	1,225	1,400	1,575	1,750	1,925
40°	839	1,049	1,259	1,469	1,678	1,888	2,098	2,308
45°	1,000	1,250	1,500	1,750	2,000	2,250	2,500	2,750
50°	1,191	1,488	1,785	2,083	2,381	2,678	2,975	3,273
55°	1,428	1,786	2,144	2,502	2,860	3,218	3,575	3,933
60°	1,732	2,165	2,598	3,031	3,464	3,897	4,330	4,763
65°	2,145	2,681	3,217	3,753	4,290	4,826	5,362	5,898
70°	2,750	3,437	4,125	4,812	5,500	6,187	6,875	7,562
75°	3,732	4,664	5,596	6,529	7,461	8,393	9,326	10,258
80°	5,670	7,087	8,505	9,922	11,340	12,757	14,175	15,593
85°	11,430	14,287	17,145	20,002	22,860	25,717	28,575	31,432

*All altitudes shown are approximate, since decimals have been rounded off, but in no case is the error more than ten feet.

EXPLANATION: The table shows altitudes in feet for elevation readings from 20° to 85° and for various distances from the observation point to the point on the ground over which the rocket reaches its greatest height. For base distances or elevation readings not shown in the table, you can determine the altitude by interpolation. For instance, if your base distance is 1,600 feet and the angle of elevation is 30°, you can find the proper altitude as follows: The table shows 866 feet in altitude for 1,500 feet base distance, and 1,010 feet for 1,750 feet base distance. The difference between 1,500 and 1,600 is two-fifths of the difference between 1,500 and 1,750 $\left(\frac{100}{250}\right)$. Therefore the proper altitude will be two-fifths of the difference between 866 and 1,010, added to 866 — or approximately 924 feet. This method will work for variations in base distance because altitude increases directly as distance increases (e.g., at 20° elevation the altitude at a distance

TABLE OF ALTITUDES

Distances In Feet From Observation Point To Point "X" (Base Distance)

3000	3250	3500	3750	4000	4250	4500	4750	5000
1,092	1,183	1,274	1,365	1,456	1,547	1,638	1,729	1,820
1,398	1,515	1,632	1,748	1,865	1,981	2,098	2,214	2,330
1,731	1,876	2,020	2,164	2,308	2,452	2,597	2,741	2,885
2,100	2,275	2,450	2,625	2,800	2,975	3,150	3,325	3,500
2,517	2,727	2,937	3,147	3,356	3,566	3,776	3,986	4,195
3,000	3,250	3,500	3,750	4,000	4,250	4,500	4,750	5,000
3,571	3,868	4,165	4,462	4,760	5,057	5,354	5,651	5,950
4,291	4,648	5,006	5,363	5,721	6,078	6,436	6,793	7,150
5,196	5,629	6,062	6,495	6,928	7,361	7,794	8,227	8,660
6,435	6,971	7,507	8,043	8,580	9,116	9,652	10,188	10,725
8,250	8,937	9,625	10,312	11,000	11,687	12,375	13,062	13,750
11,190	12,123	13,055	13,987	14,920	15,852	16,784	17,717	18,650
17,010	18,427	19,845	21,262	22,680	24,097	25,515	26,932	28,350
34,290	37,147	40,005	42,862	45,720	48,577	51,435	54,292	57,150

of 5,000 feet is exactly 5 times the altitude at a distance of 1,000 feet). The method of interpolation for variations in elevation, however, is considerably more complicated.

The following may be helpful in approximating altitudes or in checking your calculations:

At 14°	altitude is ¼ the base distance
At 26½°	altitude is ½ the base distance
At 45°	altitude is equal to the base distance
At 63½°	altitude is 2 times the base distance
At 71½°	altitude is 3 times the base distance
At 76°	altitude is 4 times the base distance
At 78°40′	altitude is 5 times the base distance
At 80½°	altitude is 6 times the base distance
At 84°20′	altitude is 10 times the base distance
At 87°10′	altitude is 20 times the base distance

Quantity-Distance Table Extracted from Department of Army Technical Manual 9-1903

TABLE XI. CLASSES 9 AND 10 QUANTITY-DISTANCE

Weight of explosives in pounds	Unbarricaded distance in feet			
	INHABITED BUILDING DISTANCE	PUBLIC RAILWAY DISTANCE	PUBLIC HIGHWAY DISTANCE	MAGAZINE DISTANCE
10	145	90	45	60
10 — 25	145	90	45	60
25 — 50	145	90	45	60
50 — 100	240	140	70	80
100 — 200	360	220	110	100
200 — 300	520	310	150	120
300 — 400	640	380	190	130
400 — 500	720	430	220	140
500 — 600	800	480	240	150
600 — 700	860	520	260	160
700 — 800	920	550	280	165
800 — 900	980	590	300	170
900 — 1,000	1,020	610	310	190
1,000 — 1,500	1,060	640	320	210

AUTHOR'S NOTE: This table shows the distances which should separate various types of structures from stored explosives. Use the first column, labeled 'Inhabited building distance' as a guide for the placement of your firing bunker. No personnel should be closer to the rocket than this distance, which will vary with the weight of the propellant in your chamber. For propellant weights of less than ten pounds, use the minimum distance of 145 feet. Actually, these distances can be reduced if proper protective barricades are provided; but since the distances are not great it is wiser and safer to follow them as they are shown in the table.

Thickness of Materials Required to Protect Against Penetration of Fragments from Projectiles and Bombs Exploding at a Distance of 50 feet

MATERIAL Thickness measured in *Inches*	High explosive shell and rockets			General-purpose bomb			
	75-mm	105-mm	155-mm	100-pound	250-pound	500-pound	1,000-pound
Solid walls:							
Brick masonry	4 in.	6	8	8	10	13	17
Concrete (plain)	4	5	6	8	11	15	18
Concrete (reinforced)	3	4	5	7	9	12	15
Timber	8	10	14	15	18	24	30
Walls of loose material packed between boards:							
Brick rubble	9	10	12	18	24	28	30
Gravel, small stones	9	10	12	18	24	28	30
Earth	15	18	24	24	30	....	....
Sandbags filled with—							
Brick rubble	10	10	20	20	20	30	40
Gravel, small stones	10	10	20	20	20	30	40
Sand	10	10	20	30	30	40	40
Earth	20	20	30	30	40	40	50
Thickness measured in *Feet*							
Parapets of — (1)							
Sand (dry)	1 ft.	1½	2	2	3	3	4
Earth (dry)	2	3	4	3	4	5	....

(1) Figures given to nearest half foot.

NOTE: Condensed tables extracted from department of Army field manual 5-15, Field Fortifications.

Functions of Numbers, 1 to 49

No.	Square	Cube	Square root	Cube root	Logarithm	No. = diameter	
						Circumference	Area
1	1	1	1.0000	1.0000	0.00000	3.142	0.7854
2	4	8	1.4142	1.2599	0.30103	6.283	3.1416
3	9	27	1.7321	1.4422	0.47712	9.425	7.0686
4	16	64	2.0000	1.5874	0.60206	12.566	12.5664
5	25	125	2.2361	1.7100	0.69897	15.708	19.6350
6	36	216	2.4495	1.8171	0.77815	18.850	28.2743
7	49	343	2.6458	1.9129	0.84510	21.991	38.4845
8	64	512	2.8284	2.0000	0.90309	25.133	50.2655
9	81	729	3.0000	2.0801	0.95424	28.274	63.6173
10	100	1000	3.1623	2.1544	1.00000	31.416	78.5398
11	121	1331	3.3166	2.2240	1.04139	34.558	95.0332
12	144	1728	3.4641	2.2894	1.07918	37.699	113.097
13	169	2197	3.6056	2.3512	1.11394	40.841	132.732
14	196	2744	3.7417	2.4101	1.14613	43.982	153.938
15	225	3375	3.8730	2.4662	1.17609	47.124	176.715
16	256	4096	4.0000	2.5198	1.20412	50.265	201.062
17	289	4913	4.1231	2.5713	1.23045	53.407	226.980
18	324	5832	4.2426	2.6207	1.25527	56.545	254.469
19	361	6859	4.3589	2.6684	1.27875	59.690	283.529
20	400	8000	4.4721	2.7144	1.30103	62.832	314.159
21	441	9261	4.5826	2.7589	1.32222	65.973	346.361
22	484	10648	4.6904	2.8020	1.34242	69.115	380.133
23	529	12167	4.7958	2.8439	1.36173	72.257	415.476
24	576	13824	4.8990	2.8845	1.38021	75.398	452.389
25	625	15625	5.0000	2.9240	1.39794	78.540	490.874
26	676	17576	5.0390	2.9625	1.41497	81.681	530.929
27	729	19683	5.1962	3.0000	1.43136	84.823	572.555
28	784	21952	5.2915	3.0366	44716	87.965	615.752
29	841	24389	5.3852	3.0723	1.46240	91.106	660.520
30	900	27000	5.4772	3.1072	1.47712	94.248	706.858
31	961	29791	5.5678	3.1414	1.49136	97.389	754.768
32	1024	32768	5.6569	3.1748	1.50515	100.53	804.248
33	1089	35937	5.7446	3.2075	1.51851	103.67	855.299
34	1156	39304	5.8310	3.2396	1.53148	106.81	907.920
35	1225	42875	5.9161	3.2711	1.54407	109.96	962.113
36	1296	46656	6.0000	3.3019	1.55630	113.10	1017.88
37	1369	50653	6.0828	3.3322	1.56820	116.24	1075.21
38	1444	54872	6.1644	3.3620	1.57978	119.38	1134.11
39	1521	59319	6.2450	3.3912	1.59106	122.52	1194.59
40	1600	64000	6.3246	3.4200	1.60206	125.66	1256.64
41	1681	68921	6.4031	3.4482	1.61278	128.81	1320.25
42	1764	74088	6.4807	3.4760	1.62325	131.95	1385.44
43	1849	79507	6.5574	3.5034	1.63347	135.09	1452.20
44	1936	85184	6.6332	3.5303	64345	138.23	1520.53
45	2025	91125	6.7082	3.5569	1.65321	141.37	1590.43
46	2116	97336	6.7823	3.5830	1.66276	144.51	1661.90
47	2209	103823	6.8557	3.6088	1.67210	147.65	1734.94
48	2304	110592	6.9282	3.6342	1.68124	150.80	1809.56
49	2401	117649	7.0000	3.6593	1.69020	153.94	1885.74

Functions of Numbers, 50 to 99

No.	Square	Cube	Square root	Cube root	Logarithm	No. = diameter	
						Circumference	Area
50	2500	125000	7.0711	3.6840	1.69897	157.08	1963.50
51	2601	132651	7.1414	3.7084	1.70757	160.22	2042.82
52	2704	140608	7.2111	3.7325	1.71600	163.36	2123.72
53	2809	148877	7.2801	3.7563	1.72428	166.50	2206.18
54	2916	157464	7.3485	3.7798	1.73239	169.65	2290.22
55	3025	166375	7.4162	3.8030	1.74036	172.79	2375.83
56	3136	175616	7.4833	3.8259	1.74819	175.93	2463.01
57	3249	185193	7.5498	3.8485	1.75587	179.07	2551.76
58	3364	195112	7.6158	3.8709	1.76343	182.21	2642.08
59	3481	205379	7.6811	3.8930	1.77085	185.35	2733.97
60	3600	216000	7.7460	3.9149	1.77815	188.50	2827.43
61	3721	226981	7.8102	3.9365	1.78533	191.64	2922.47
62	3844	238328	7.8740	3.9579	1.79239	194.78	3019.07
63	3969	250047	7.9373	3.9791	1.79934	197.92	3117.25
64	4096	262144	8.0000	4.0000	1.80618	201.06	3216.99
65	4225	274625	8.0623	4.0207	1.81291	204.20	3318.31
66	4356	287496	8.1240	4.0412	1.81954	207.35	3421.19
67	4489	300763	8.1854	4.0615	1.82607	210.49	3525.65
68	4624	314432	8.2462	4.0817	1.83251	213.63	3631.68
69	4761	328509	8.3066	4.1016	1.83885	216.77	3739.28
70	4900	343000	8.3666	4.1213	1.84510	219.91	3848.45
71	5041	357911	8.4261	4.1408	1.85126	223.05	3959.19
72	5184	373248	8.4853	4.1602	1.85733	226.19	4071.50
73	5329	389017	8.5440	4.1793	1.86332	229.34	4185.39
74	5476	405224	8.6023	4.1983	1.86923	232.48	4300.84
75	5625	421875	8.6603	4.2172	1.87506	235.62	4417.86
76	5776	438976	8.7178	4.2358	1.88081	238.76	4536.46
77	5929	456533	8.7750	4.2543	1.88649	241.90	4656.63
78	6084	474552	8.8318	4.2727	1.89209	245.04	4778.36
79	6241	493039	8.8882	4.2908	1.89763	248.19	4901.67
80	6400	512000	8.9443	4.3089	1.90309	251.33	5026.55
81	6561	531441	9.0000	4.3267	1.90849	254.47	5153.00
82	6724	551368	9.0554	4.3445	1.91381	257.61	5281.02
83	6889	571787	9.1104	4.3621	1.91908	260.75	5410.61
84	7056	592704	9.1652	4.3795	1.92428	263.89	5541.77
85	7225	614125	9.2195	4.3968	1.92942	267.04	5674.50
86	7396	636056	9.2736	4.4140	1.93450	270.18	5808.80
87	7569	658503	9.3274	4.4310	1.93952	273.32	5944.68
88	7744	681472	9.3808	4.4480	1.94448	276.46	6082.12
89	7921	704969	9.4340	4.4647	1.94939	279.60	6221.14
90	8100	729000	9.4868	4.4814	1.95424	282.74	6361.73
91	8281	753571	9.5394	4.4979	1.95904	285.88	6503.88
92	8464	778688	9.5917	4.5144	1.96379	289.03	6647.61
93	8649	804357	9.6437	4.5307	1.96848	292.17	6792.91
94	8836	830584	9.6954	4.5468	1.97313	295.31	6939.78
95	9025	857375	9.7468	4.5629	1.97772	298.45	7088.22
96	9216	884736	9.7980	4.5789	1.98227	301.59	7238.23
97	9409	912673	9.8489	4.5947	1.98677	304.73	7389.81
98	9604	941192	9.8995	4.6104	1.99123	307.88	7542.96
99	9801	970299	9.9499	4.6261	1.99564	311.02	7697.69

NATURAL TRIGONOMETRIC FUNCTIONS

Degrees	Sines							Cosines
	0′	10′	20′	30′	40′	50′	60′	
0	0.00000	0.00291	0.00582	0.00873	0.01164	0.01454	0.01745	89
1	0.01745	0.02036	0.02327	0.02618	0.02908	0.03199	0.03490	88
2	0.03490	0.03781	0.04071	0.04362	0.04653	0.04943	0.05234	87
3	0.05234	0.05524	0.05814	0.06105	0.06395	0.06685	0.06976	86
4	0.06976	0.07266	0.07556	0.07846	0.08136	0.08426	0.08716	85
5	0.08716	0.09005	0.09295	0.09585	0.09874	0.10164	0.10453	84
6	0.10453	0.10742	0.11031	0.11320	0.11609	0.11898	0.12187	83
7	0.12187	0.12476	0.12764	0.13053	0.13341	0.13629	0.13917	82
8	0.13917	0.14205	0.14493	0.14781	0.15069	0.15356	0.15643	81
9	0.15643	0.15931	0.16218	0.16505	0.16792	0.17078	0.17365	80
10	0.17365	0.17651	0.17937	0.18224	0.18509	0.18795	0.19081	79
11	0.19081	0.19366	0.19652	0.19937	0.20222	0.20507	0.20791	78
12	0.20791	0.21076	0.21360	0.21644	0.21928	0.22212	0.22495	77
13	0.22495	0.22778	0.23062	0.23345	0.23627	0.23910	0.24192	76
14	0.24192	0.24474	0.24756	0.25038	0.25320	0.25601	0.25882	75
15	0.25882	0.26163	0.26443	0.26724	0.27004	0.27284	0.27564	74
16	0.27564	0.27843	0.28123	0.28402	0.28680	0.28959	0.29237	73
17	0.29237	0.29515	0.29793	0.30071	0.30348	0.30625	0.30902	72
18	0.30902	0.31178	0.31454	0.31730	0.32006	0.32282	0.32557	71
19	0.32557	0.32832	0.33106	0.33381	0.33655	0.33929	0.34202	70
20	0.34202	0.34475	0.34748	0.35021	0.35293	0.35565	0.35837	69
21	0.35837	0.36108	0.36379	0.36650	0.36921	0.37191	0.37461	68
22	0.37461	0.37730	0.37999	0.38268	0.38537	0.38805	0.39073	67
23	0.39073	0.39341	0.39608	0.39875	0.40142	0.40408	0.40674	66
24	0.40674	0.40939	0.41204	0.41469	0.41734	0.41998	0.42262	65
25	0.42262	0.42525	0.42788	0.43051	0.43313	0.43575	0.43837	64
26	0.43837	0.44098	0.44359	0.44620	0.44880	0.45140	0.45399	63
27	0.45399	0.45658	0.45917	0.46175	0.46433	0.46690	0.46947	62
28	0.46947	0.47204	0.47460	0.47716	0.47971	0.48226	0.48481	61
29	0.48481	0.48735	0.48989	0.49242	0.49495	0.49748	0.50000	60
30	0.50000	0.50252	0.50503	0.50754	0.51004	0.51254	0.51504	59
31	0.51504	0.51753	0.52002	0.52250	0.52498	0.52745	0.52992	58
32	0.52992	0.53238	0.53484	0.53730	0.53975	0.54220	0.54464	57
33	0.54464	0.54708	0.54951	0.55194	0.55436	0.55678	0.55919	56
34	0.55919	0.56160	0.56401	0.56641	0.56880	0.57119	0.57358	55
35	0.57358	0.57596	0.57833	0.58070	0.58307	0.58543	0.58779	54
36	0.58779	0.59014	0.59248	0.59482	0.59716	0.59949	0.60182	53
37	0.60182	0.60414	0.60645	0.60876	0.61107	0.61337	0.61566	52
38	0.61566	0.61795	0.62024	0.62251	0.62479	0.62706	0.62932	51
39	0.62932	0.63158	0.63383	0.63608	0.63832	0.64056	0.64279	50
40	0.64279	0.64501	0.64723	0.64945	0.65166	0.65386	0.65606	49
41	0.65606	0.65825	0.66044	0.66262	0.66480	0.66697	0.66913	48
42	0.66913	0.67129	0.67344	0.67559	0.67773	0.67987	0.68200	47
43	0.68200	0.68412	0.68624	0.68835	0.69046	0.69256	0.69466	46
44	0.69466	0.69675	0.69883	0.70091	0.70298	0.70505	0.70711	45
Sines	60′	50′	40′	30′	20′	10′	0′	Degrees
	Cosines							

NATURAL TRIGONOMETRIC FUNCTIONS

Degrees	Cosines							Sines
	0′	10′	20′	30′	40′	50′	60′	
0	1 00000	1 00000	0 99998	0 99996	0 99993	0 99989	0.99985	89
1	0 99985	0 99979	0 99973	0 99966	0 99958	0.99949	0.99939	88
2	0 99939	0 99929	0 99917	0.99905	0 99892	0 99878	0 99863	87
3	0 99863	0 99847	0 99831	0 99813	0 99795	0 99776	0.99756	86
4	0 99756	0 99736	0 99714	0 99692	0 99668	0 99644	0 99619	85
5	0 99619	0 99594	0 99567	0 99540	0 99511	0 99482	0 99452	84
6	0.99452	0 99421	0 99390	0 99357	0 99324	0 99290	0.99255	83
7	0 99255	0 99219	0 99182	0 99144	0 99106	0 99067	0.99027	82
8	0.99027	0 98986	0.98944	0 98902	0 98858	0 98814	0 98769	81
9	0 98769	0 98723	0 98676	0 98629	0 98580	0 98531	0 98481	80
10	0 98481	0 98430	0 98378	0 98325	0 98272	0 98218	0 98163	79
11	0 98163	0 98107	0 98050	0 97992	0 97934	0 97875	0 97815	78
12	0 97815	0 97754	0 97692	0 97630	0 97566	0.97502	0 97437	77
13	0 97437	0 97371	0 97304	0 97237	0 97169	0 97100	0 97030	76
14	0 97030	0 96959	0.96887	0 96815	0 96742	0 96667	0 96593	75
15	0 96593	0 96517	0.96440	0 96363	0 96285	0.96206	0 96126	74
16	0 96126	0.96046	0 95964	0 95882	0 95799	0 95715	0 95630	73
17	0 95630	0 95545	0.95459	0 95372	0 95284	0 95195	0 95106	72
18	0 95106	0 95015	0 94924	0 94832	0 94740	0 94646	0 94552	71
19	0 94552	0 94457	0 94361	0 94264	0 94167	0 94068	0 93969	70
20	0 93969	0 93869	0 93769	0 93667	0 93565	0 93462	0 93358	69
21	0 93358	0 93253	0 93148	0.93042	0 92935	0 92827	0 92718	68
22	0 92718	0 92609	0 92499	0 92388	0 92276	0 92164	0 92050	67
23	0 92050	0 91936	0.91822	0 91706	0 91590	0 91472	0 91355	66
24	0 91355	0 91236	0 91116	0 90996	0 90875	0 90753	0 90631	65
25	0.90631	0 90507	0 90383	0 90259	0 90133	0 90007	0 89879	64
26	0.89879	0 89752	0 89623	0 89493	0 89363	0 89232	0 89101	63
27	0 89101	0 88968	0 88835	0 88701	0 88566	0 88431	0 88295	62
28	0 88295	0 88158	0 88020	0.87882	0 87743	0 87603	0 87462	61
29	0.87462	0.87321	0 87178	0 87036	0 86892	0 86748	0 86603	60
30	0 86603	0 86457	0 86310	0 86163	0 86015	0 85866	0 85717	59
31	0.85717	0 85567	0 85416	0 85264	0 85112	0 84959	0 84805	58
32	0 84805	0 84650	0 84495	0 84339	0 84182	0 84025	0 83867	57
33	0 83867	0 83708	0 83549	0.83389	0 83228	0 83066	0 82904	56
34	0 82904	0.82741	0 82577	0 82413	0 82248	0 82082	0 81915	55
35	0 81915	0 81748	0 81580	0 81412	0 81242	0 81072	0 80902	54
36	0 80902	0 80730	0 80558	0 80386	0 80212	0 80038	0 79864	53
37	0 79864	0 79688	0 79512	0 79335	0 79158	0 78980	0 78801	52
38	0 78801	0 78622	0 78442	0 78261	0 78079	0 77987	0 77715	51
39	0 77715	0 77531	0 77347	0 77162	0 76977	0 76791	0 76604	50
40	0.76604	0 76417	0 76229	0 76041	0 75851	0 75661	0 75471	49
41	0 75471	0 75280	0 75088	0 74896	0 74703	0 74509	0 74314	48
42	0.74314	0 74120	0 73924	0 73728	0 73531	0 73333	0 73135	47
43	0 73135	0 72937	0 72737	0.72537	0 72337	0.72136	0 71934	46
44	0 71934	0 71732	0 71529	0 71325	0.71121	0 70916	0 70711	45
Cosines	60′	50′	40′	30′	20′	10′	0′	Degrees
	Sines							

NATURAL TRIGONOMETRIC FUNCTIONS

Degrees	Tangents							Cotangents
	0′	10′	20′	30′	40′	50′	60′	
0	0.00000	0.00291	0.00582	0.00873	0.01164	0.01455	0.01746	89
1	0.01746	0.02036	0.02328	0.02619	0.02910	0.03201	0.03492	88
2	0.03492	0.03783	0.04075	0.04366	0.04658	0.04949	0.05241	87
3	0.05241	0.05533	0.05824	0.06116	0.06408	0.06700	0.06993	86
4	0.06993	0.07285	0.07578	0.07870	0.08163	0.08456	0.08749	85
5	0.08749	0.09042	0.09335	0.09629	0.09923	0.10216	0.10510	84
6	0.10510	0.10805	0.11099	0.11394	0.11688	0.11983	0.12278	83
7	0.12278	0.12574	0.12869	0.13165	0.13461	0.13758	0.14054	82
8	0.14054	0.14351	0.14648	0.14945	0.15243	0.15540	0.15838	81
9	0.15838	0.16137	0.16435	0.16734	0.17033	0.17333	0.17633	80
10	0.17633	0.17933	0.18233	0.18534	0.18835	0.19136	0.19438	79
11	0.19438	0.19740	0.20042	0.20345	0.20648	0.20952	0.21256	78
12	0.21256	0.21560	0.21864	0.22169	0.22475	0.22781	0.23087	77
13	0.23087	0.23393	0.23700	0.24008	0.24316	0.24624	0.24933	76
14	0.24933	0.25242	0.25552	0.25862	0.26172	0.26483	0.26795	75
15	0.26795	0.27107	0.27419	0.27732	0.28046	0.28360	0.28675	74
16	0.28675	0.28990	0.29305	0.29621	0.29938	0.30255	0.30573	73
17	0.30573	0.30891	0.31210	0.31530	0.31850	0.32171	0.32492	72
18	0.32492	0.32814	0.33136	0.33460	0.33783	0.34108	0.34433	71
19	0.34433	0.34758	0.35085	0.35412	0.35740	0.36068	0.36397	70
20	0.36397	0.36727	0.37057	0.37388	0.37720	0.38053	0.38386	69
21	0.38386	0.38721	0.39055	0.39391	0.39727	0.40065	0.40403	68
22	0.40403	0.40741	0.41081	0.41421	0.41763	0.42105	0.42447	67
23	0.42447	0.42791	0.43136	0.43481	0.43828	0.44175	0.44523	66
24	0.44523	0.44872	0.45222	0.45573	0.45924	0.46277	0.46631	65
25	0.46631	0.46985	0.47341	0.47698	0.48055	0.48414	0.48773	64
26	0.48773	0.49134	0.49495	0.49858	0.50222	0.50587	0.50953	63
27	0.50953	0.51320	0.51688	0.52057	0.52427	0.52798	0.53171	62
28	0.53171	0.53545	0.53920	0.54296	0.54674	0.55051	0.55431	61
29	0.55431	0.55812	0.56194	0.56577	0.56962	0.57348	0.57735	60
30	0.57735	0.58124	0.58513	0.58905	0.59297	0.59691	0.60086	59
31	0.60086	0.60483	0.60881	0.61280	0.61681	0.62083	0.62487	58
32	0.62487	0.62892	0.63299	0.63707	0.64117	0.64528	0.64941	57
33	0.64941	0.65355	0.65771	0.66189	0.66608	0.67028	0.67451	56
34	0.67451	0.67875	0.68301	0.68728	0.69157	0.69588	0.70021	55
35	0.70021	0.70455	0.70891	0.71329	0.71769	0.72211	0.72654	54
36	0.72654	0.73100	0.73547	0.73996	0.74447	0.74900	0.75355	53
37	0.75355	0.75812	0.76272	0.76733	0.77196	0.77661	0.78129	52
38	0.78129	0.78598	0.79070	0.79544	0.80020	0.80498	0.80978	51
39	0.80978	0.81461	0.81946	0.82434	0.82923	0.83415	0.83910	50
40	0.83910	0.84407	0.84906	0.85408	0.85912	0.86419	0.86929	49
41	0.86929	0.87441	0.87955	0.88473	0.88992	0.89515	0.90040	48
42	0.90040	0.90569	0.91099	0.91633	0.92170	0.92709	0.93252	47
43	0.93252	0.93797	0.94345	0.94896	0.95451	0.96008	0.96569	46
44	0.96569	0.97133	0.97700	0.98270	0.98843	0.99420	1.00000	45
Tangents	60′	50′	40′	30′	20′	10′	0′	Degrees
	Cotangents							

NATURAL TRIGONOMETRIC FUNCTIONS

Degrees	Cotangents							Tangents
	0′	10′	20′	30′	40′	50′	60′	
0	∞	343.77371	171.88540	114.58865	85.93979	68.75009	57.28996	89
1	57.28996	49.10388	42.96408	38.18846	34.36777	31.24158	28.63625	88
2	28.63625	26.43160	24.54176	22.90377	21.47040	20.20555	19.08114	87
3	19.08114	18.07498	17.16934	16.34986	15.60478	14.92442	14.30067	86
4	14.30067	13.72674	13.19688	12.70621	12.25051	11.82617	11.43005	85
5	11.43005	11.05943	10.71191	10.38540	10.07803	9.78817	9.51436	84
6	9.51436	9.25530	9.00983	8.77689	8.55555	8.34496	8.14435	83
7	8.14435	7.95302	7.77035	7.59575	7.42871	7.26873	7.11537	82
8	7.11537	6.96823	6.82694	6.69116	6.56055	6.43484	6.31375	81
9	6.31375	6.19703	6.08444	5.97576	5.87080	5.76937	5.67128	80
10	5.67128	5.57638	5.48451	5.39552	5.30928	5.22566	5.14455	79
11	5.14455	5.06584	4.98940	4.91516	4.84300	4.77286	4.70463	78
12	4.70463	4.63825	4.57363	4.51071	4.44942	4.38969	4.33148	77
13	4.33148	4.27471	4.21933	4.16530	4.11256	4.06107	4.01078	76
14	4.01078	3.96165	3.91364	3.86671	3.82083	3.77595	3.73205	75
15	3.73205	3.68909	3.64705	3.60588	3.56557	3.52609	3.48741	74
16	3.48741	3.44951	3.41236	3.37594	3.34023	3.30521	3.27085	73
17	3.27085	3.23714	3.20406	3.17159	3.13972	3.10842	3.07768	72
18	3.07768	3.04749	3.01783	2.98869	2.96004	2.93189	2.90421	71
19	2.90421	2.87700	2.85023	2.82391	2.79802	2.77254	2.74748	70
20	2.74748	2.72281	2.69853	2.67462	2.65109	2.62791	2.60509	69
21	2.60509	2.58261	2.56046	2.53865	2.51715	2.49597	2.47509	68
22	2.47509	2.45451	2.43422	2.41421	2.39449	2.37504	2.35585	67
23	2.35585	2.33693	2.31826	2.29984	2.28167	2.26374	2.24604	66
24	2.24604	2.22857	2.21132	2.19430	2.17749	2.16090	2.14451	65
25	2.14451	2.12832	2.11233	2.09654	2.08094	2.06553	2.05030	64
26	2.05030	2.03526	2.02039	2.00569	1.99116	1.97680	1.96261	63
27	1.96261	1.94858	1.93470	1.92098	1.90741	1.89400	1.88073	62
28	1.88073	1.86760	1.85462	1.84177	1.82907	1.81649	1.80405	61
29	1.80405	1.79174	1.77955	1.76749	1.75556	1.74375	1.73205	60
30	1.73205	1.72047	1.70901	1.69766	1.68643	1.67530	1.66428	59
31	1.66428	1.65337	1.64256	1.63185	1.62125	1.61074	1.60033	58
32	1.60033	1.59002	1.57981	1.56969	1.55966	1.54972	1.53987	57
33	1.53987	1.53010	1.52043	1.51084	1.50133	1.49190	1.48256	56
34	1.48256	1.47330	1.46411	1.45501	1.44598	1.43703	1.42815	55
35	1.42815	1.41934	1.41061	1.40195	1.39336	1.38484	1.37638	54
36	1.37638	1.36800	1.35968	1.35142	1.34323	1.33511	1.32704	53
37	1.32704	1.31904	1.31110	1.30323	1.29541	1.28764	1.27994	52
38	1.27994	1.27230	1.26471	1.25717	1.24969	1.24227	1.23490	51
39	1.23490	1.22758	1.22031	1.21310	1.20593	1.19882	1.19175	50
40	1.19175	1.18474	1.17777	1.17085	1.16398	1.15715	1.15037	49
41	1.15037	1.14363	1.13694	1.13029	1.12369	1.11713	1.11061	48
42	1.11061	1.10414	1.09770	1.09131	1.08496	1.07864	1.07237	47
43	1.07237	1.06613	1.05994	1.05378	1.04766	1.04158	1.03553	46
44	1.03553	1.02952	1.02355	1.01761	1.01170	1.00583	1.00000	45
Cotangents	60′	50′	40′	30′	20′	10′	0′	Degrees
	Tangents							

LOGARITHMS 100 to 1000

	0	1	2	3	4	5	6	7	8	9
10	.00000	.00432	.00860	01284	01703	02119	02531	02938	03342	03743
11	.04139	.04532	04922	05308	05690	06070	06446	.06819	07188	.07555
12	.07918	.08279	.08636	08991	.09342	09691	.10037	.10380	10721	11059
13	.11394	.11727	.12057	.12385	.12710	.13033	.13354	.13672	13988	14301
14	.14613	.14922	.15229	.15534	.15836	16137	.16435	.16732	17026	17319
15	.17609	.17898	.18184	.18469	.18752	19033	.19312	19590	19866	.20140
16	.20412	.20683	20952	.21219	21484	21748	.22011	22272	22531	22789
17	.23045	.23300	23553	.23805	.24055	.24304	.24551	24797	25042	.25285
18	.25527	25768	.26007	.26245	.26482	26717	.26951	.27184	.27416	27646
19	.27875	.28103	.28330	.28556	.28780	.29003	.29226	.29447	.29667	.29885
20	.30103	.30320	.30535	.30750	30963	31175	.31387	.31597	.31806	32015
21	.32222	32428	.32634	.32838	.33041	.33244	.33445	.33646	33846	34044
22	.34242	.34439	.34635	.34830	35025	.35218	.35411	.35603	35793	35984
23	.36173	.36361	36549	.36736	.36922	.37107	.37291	.37475	.37658	37840
24	.38021	.38202	.38382	.38561	.38739	.38917	.39094	.39270	.39445	39620
25	.39794	.39967	.40140	.40312	40483	40654	.40824	.40993	41162	41330
26	.41497	41664	.41830	.41996	.42160	.42325	.42488	42651	42813	42975
27	.43136	.43297	.43457	43616	43775	43933	.44091	.44248	.44404	44560
28	.44716	44871	.45025	.45179	.45332	.45484	45637	.45788	.45939	46090
29	.46240	.46389	.46538	.46687	.46835	.46982	.47129	.47276	47422	47567
30	.47712	47857	.48001	.48144	.48287	.48430	48572	.48714	.48855	48996
31	.49136	49276	.49415	49554	.49693	.49831	49969	50106	.50243	50379
32	.50515	50651	50786	.50920	51055	51188	.51322	51455	51587	51720
33	.51851	.51983	52114	52244	52375	52504	52634	52763	.52892	53020
34	.53148	53275	53403	53529	53656	53782	.53908	54033	.54158	54283
35	.54407	54531	54654	.54777	54900	55023	55145	55267	55388	55509
36	55630	55751	55871	55991	56110	56229	56348	56467	56585	56703
37	.56820	56937	57054	57171	57287	57403	57519	.57634	57749	57864
38	.57978	58092	58206	58320	58433	58546	58659	58771	58883	58995
39	59106	.59218	59329	59439	59550	59660	59770	.59879	59988	60097
40	60206	60314	.60423	60531	60638	60746	60853	60959	61066	61172
41	.61278	.61384	61490	61595	61700	61805	61909	62014	.62118	62221
42	62325	62428	62531	62634	62737	62839	62941	63043	63144	63246
43	63347	63448	63548	63649	63749	63849	63949	64048	64147	64246
44	.64345	.64444	.64542	64640	64738	64836	64933	65031	65128	65225
45	65321	65418	65514	65610	65706	65801	65896	65992	66087	66181
46	66276	66370	66464	66558	66652	66745	66839	66932	67025	67117
47	67210	67302	67394	67486	67578	67669	67761	67852	67943	68034
48	68124	68215	68305	68395	68485	68574	68664	68753	68842	68931
49	.69020	69108	69197	69285	69373	69461	69548	69636	69723	69810
50	69897	69984	70070	70157	.70243	70329	70415	70501	70586	70672
51	70757	70842	70927	71012	71096	71181	71265	71349	71433	71517
52	71600	71684	71767	71850	71933	72016	72099	72181	72263	72346
53	72428	72509	72591	.72673	72754	72835	72916	72997	73078	73159
54	.73239	.73320	.73400	73480	73560	73640	.73719	73799	73878	73957

	0	1	2	3	4	5	6	7	8	9
55	.74036	.74115	.74194	.74273	.74351	.74429	.74507	.74586	.74663	.74741
56	.74819	.74896	.74974	.75051	.75128	.75205	.75282	.75358	.75435	.75511
57	.75587	.75664	.75740	.75815	.75891	.75967	.76042	.76118	.76193	.76268
58	.76343	.76418	.76492	.76567	.76641	.76716	.76790	.76864	.76938	.77012
59	.77085	.77159	.77232	.77305	.77379	.77452	.77525	.77597	.77670	.77743
60	.77815	.77887	.77960	.78032	.78104	.78176	.78247	.78319	.78390	.78462
61	.78533	.78604	.78675	.78746	.78817	.78888	.78958	.79029	.79099	.79169
62	.79239	.79309	.79379	.79449	.79518	.79588	.79657	.79727	.79796	.79865
63	.79934	.80003	.80072	.80140	.80209	.80277	.80346	.80414	.80482	.80550
64	.80618	.80686	.80754	.80821	.80889	.80956	.81023	.81090	.81158	.81224
65	.81291	.81358	.81425	.81491	.81558	.81624	.81690	.81757	.81823	.81889
66	.81954	.82020	.82086	.82151	.82217	.82282	.82347	.82413	.82478	.82543
67	.82607	.82672	.82737	.82802	.82866	.82930	.82995	.83059	.83123	.83187
68	.83251	.83315	.83378	.83442	.83506	.83569	.83632	.83696	.83759	.83822
69	.83885	.83948	.84011	.84073	.84136	.84198	.84261	.84323	.84386	.84448
70	.84510	.84572	.84634	.84696	.84757	.84819	.84880	.84942	.85003	.85065
71	.85126	.85187	.85248	.85309	.85370	.85431	.85491	.85552	.85612	.85673
72	.85733	.85794	.85854	.85914	.85974	.86034	.86094	.86153	.86213	.86273
73	.86332	.86392	.86451	.86510	.86570	.86629	.86688	.86747	.86806	.86864
74	.86923	.86982	.87040	.87099	.87157	.87216	.87274	.87332	.87390	.87448
75	.87506	.87564	.87622	.87679	.87737	.87795	.87852	.87910	.87967	.88024
76	.88081	.88138	.88195	.88252	.88309	.88366	.88423	.88480	.88536	.88593
77	.88649	.88705	.88762	.88818	.88874	.88930	.88986	.89042	.89098	.89154
78	.89209	.89265	.89321	.89376	.89432	.89487	.89542	.89597	.89653	.89708
79	.89763	.89818	.89873	.89927	.89982	.90037	.90091	.90146	.90200	.90255
80	.90309	.90363	.90417	.90472	.90526	.90580	.90634	.90687	.90741	.90795
81	.90849	.90902	.90956	.91009	.91062	.91116	.91169	.91222	.91275	.91328
82	.91381	.91434	.91487	.91540	.91593	.91645	.91698	.91751	.91803	.91855
83	.91908	.91960	.92012	.92065	.92117	.92169	.92221	.92273	.92324	.92376
84	.92428	.92480	.92531	.92583	.92634	.92686	.92737	.92788	.92840	.92891
85	.92942	.92993	.93044	.93095	.93146	.93197	.93247	.93298	.93349	.93399
86	.93450	.93500	.93551	.93601	.93651	.93702	.93752	.93802	.93852	.93902
87	.93952	.94002	.94052	.94101	.94151	.94201	.94250	.94300	.94349	.94399
88	.94448	.94498	.94547	94596	.94645	.94694	.94743	.94792	.94841	.94890
89	.94939	94988	.95036	.95085	.95134	.95182	.95231	.95279	.95328	.95376
90	.95424	.95472	.95521	.95569	.95617	.95665	.95713	.95761	.95809	.95856
91	.95904	.95952	.95999	.96047	.96095	.96142	.96190	.96237	.96284	.96332
92	.96379	.96426	.96473	.96520	.96567	.96614	.96661	.96708	.96755	.96802
93	.96848	.96895	.96942	.96988	.97035	.97081	.97128	.97174	.97220	.97267
94	97313	.97359	.97405	.97451	.97497	.97543	.97589	.97635	.97681	.97727
95	.97772	.97818	.97864	.97909	.97955	.98000	.98046	.98091	.98137	.98182
96	.98227	.98272	.98318	.98363	.98408	.98453	.98498	.98543	.98588	.98632
97	.98677	.98722	.98767	.98811	.98856	.98900	.98945	.98989	.99034	.99078
98	.99123	.99167	.99211	.99255	.99300	.99344	.99388	.99432	.99476	.99520
99	.99564	.99607	.99651	.99695	.99739	.99782	.99826	.99870	.99913	.99957

DECIMAL OF AN INCH AND OF A FOOT

Fractions of inch or foot		Inch equivalents to foot fractions	Fractions of inch or foot		Inch equivalents to foot fractions	Fractions of inch or foot		Inch equivalents to foot fractions	Fractions of inch or foot		Inch equivalents to foot fractions
	.0052	1/16		.2552	3 1/16		.5052	6 1/16		.7552	9 1/16
	.0104	1/8		.2604	3 1/8		.5104	6 1/8		.7604	9 1/8
1/64	.015625	3/16	17/64	.265625	3 3/16	33/64	.515625	6 3/16	49/64	.765625	9 3/16
	.0208	1/4		.2708	3 1/4		.5208	6 1/4		.7708	9 1/4
	.0260	5/16		.2760	3 5/16		.5260	6 5/16		.7760	9 5/16
1/32	.03125	3/8	9/32	.28125	3 3/8	17/32	.53125	6 3/8	25/32	.78125	9 3/8
	.0365	7/16		.2865	3 7/16		.5365	6 7/16		.7865	9 7/16
	.0417	1/2		.2917	3 1/2		.5417	6 1/2		.7919	9 1/2
3/64	.046875	9/16	19/64	.296875	3 9/16	35/64	.546875	6 9/16	51/64	.796875	9 9/16
	.0521	5/8		.3021	3 5/8		.5521	6 5/8		.8021	9 5/8
	.0573	11/16		.3073	3 11/16		.5573	6 11/16		.8073	9 11/16
1/16	.0625	3/4	5/16	.3125	3 3/4	9/16	.5625	6 3/4	13/16	.8125	9 3/4
	.0677	13/16		.3177	3 13/16		.5677	6 13/16		.8177	9 13/16
	.0729	7/8		.3229	3 7/8		.5729	6 7/8		.8229	9 7/8
5/64	.078125	15/16	21/64	.328125	3 15/16	37/64	.578125	6 15/16	53/64	.828125	9 15/16
	.0833	1		.3333	4		.5833	7		.8333	10
	.0885	1 1/16		.3385	4 1/16		.5885	7 1/16		.8385	10 1/16
3/32	.09375	1 1/8	11/32	.34375	4 1/8	19/32	.59375	7 1/8	27/32	.84375	10 1/8
	.0990	1 3/16		.3490	4 3/16		.5990	7 3/16		.8490	10 3/16
	.1042	1 1/4		.3542	4 1/4		.6042	7 1/4		.8542	10 1/4
7/64	.109375	1 5/16	23/64	.359375	4 5/16	39/64	.609375	7 5/16	55/64	.859375	10 5/16
	.1146	1 3/8		.3646	4 3/8		.6146	7 3/8		.8646	10 3/8
	.1198	1 7/16		.3698	4 7/16		.6198	7 7/16		.8698	10 7/16
1/8	.1250	1 1/2	3/8	.3750	4 1/2	5/8	.6250	7 1/2	7/8	.8750	10 1/2
	.1302	1 9/16		.3802	4 9/16		.6302	7 9/16		.8802	10 9/16
	.1354	1 5/8		.3854	4 5/8		.6354	7 5/8		.8854	10 5/8
9/64	.140625	1 11/16	25/64	.390625	4 11/16	41/64	.640625	7 11/16	57/64	.890625	10 11/16
	.1458	1 3/4		.3958	4 3/4		.6458	7 3/4		.8958	10 3/4
	.1510	1 13/16		.4010	4 13/16		.6510	7 13/16		.9010	10 13/16
5/32	.15625	1 7/8	13/32	.40625	4 7/8	21/32	.65625	7 7/8	29/32	.90625	10 7/8
	.1615	1 15/16		.4115	4 15/16		.6615	7 15/16		.9115	10 15/16
	.1667	2		.4167	5		.6667	8		.9167	11
11/64	.171875	2 1/16	27/64	.421875	5 1/16	43/64	.671875	8 1/16	59/64	.921875	11 1/16
	.1771	2 1/8		.4271	5 1/8		.6771	8 1/8		.9271	11 1/8
	.1823	2 3/16		.4323	5 3/16		.6823	8 3/16		.9323	11 3/16
3/16	.1875	2 1/4	7/16	.4375	5 1/4	11/16	.6875	8 1/4	15/16	.9375	11 1/4
	.1927	2 5/16		.4427	5 5/16		.6927	8 5/16		.9427	11 5/16
	.1979	2 3/8		.4479	5 3/8		.6979	8 3/8		.9479	11 3/8
13/64	.203125	2 7/16	29/64	.453125	5 7/16	45/64	.703125	8 7/16	61/64	.953125	11 7/16
	.2083	2 1/2		.4583	5 1/2		.7083	8 1/2		.9583	11 1/2
	.2135	2 9/16		.4635	5 9/16		.7135	8 9/16		.9635	11 9/16
7/32	.21875	2 5/8	15/32	.46875	5 5/8	23/32	.71875	8 5/8	31/32	.96875	11 5/8
	.2240	2 11/16		.4740	5 11/16		.7240	8 11/16		.9740	11 11/16
	.2292	2 3/4		.4792	5 3/4		.9292	8 3/4		.9792	11 3/4
15/64	.234375	2 13/16	31/64	.484375	5 13/16	47/64	.734375	8 13/16	63/64	.984375	11 13/16
	.2396	2 7/8		.4896	5 7/8		.7396	8 7/8		.9896	11 7/8
	.2448	2 15/16		.4948	5 15/16		.7448	8 15/16		.9948	11 15/16
1/4	.2500	3	1/2	.5000	6	3/4	.7500	9	1	1.0000	12

APPENDIX D—ROCKET SYMBOLS

Symbol	Stands for	Unit Expressed in
A	Area	in^2
A_c	Chamber crossectional area	in^2
A_e	Nozzle exit area	in^2
A_t	Nozzle throat area	in^2
A_w	Chamber inner wall surface area	in^2
a	Sonic velocity	ft/sec
C_f	Thrust coefficient	—
CG	Center of Gravity	—
C_p	Specific heat at constant pressure	BTU
C_v	Specific heat at constant volume	BTU
c	Effective exhaust velocity	ft/sec
c^*	Characteristic exhaust velocity	ft/sec
D	Diameter (also density)	in
D_c	Chamber diameter	in
D_e	Nozzle exit diameter	in
D_t	Nozzle throat diameter	in
F	Thrust	lbs
g	Acceleration of gravity	ft/sec^2
h	Height or altitude	ft
h_b (h_c)	Height at burnout (or cutoff)	ft
h_p	Height at peak altitude	ft
I_{sp}	Specific Impulse	sec
I_t	Total impulse	lb-sec
k	Ratio of specific heats $\frac{C_p}{C_v}$	—
l	Length	in
l_c	Combustion chamber length	in
L^*	Characteristic length	in

Symbol	Stands for	Unit Expressed in
M	Mach number (ratio to speed of sound)	—
M_c	Mach number (speed) of gases at end of chamber	—
M_e	Mach number (speed) of gases at nozzle exit	—
M_t	Mach number (speed) of gases at nozzle throat	—
M_w	Molecular weight	lb/mol
$\mathring{M}$	Mass flow $(\frac{W}{g})$	lb-sec/ft
n	Loaded weight/cutoff weight (mass ratio)	—
n	*or* polytropic exponent	
P_a	Atmospheric pressure	lb/in^2
P_c	Chamber pressure, absolute	lb/in^2
P_e	Nozzle exit pressure, absolute	lb/in^2
P_o	Ambient absolute pressure (pressure in surrounding environment)	lb/in^2
R	Universal gas constant	ft-lbs/mol-°R
R'	Particular gas constant $\frac{R}{M_w}$	—
°R	Degrees Rankine (°F+460°)	°R
r	Mixture ratio, $\mathring{W}_o/\mathring{W}_f$	—
r_b	Burning rate or	(in/sec (lb/sec
S	Burning surface	in^2
T	Absolute temperature	°R
T_c	Combustion temperature	°R
t	Time	sec
t_b (t_c)	Time at burnout (time at cutoff) or Burning Time	sec
t_w	Wall thickness	in
V	Volume	in^3
V_c	Combustion chamber volume	in^3

Symbol	Stands for	Unit Expressed in
v	Velocity	ft/sec
v_b (v_c)	Burnout velocity (cutoff velocity)	ft/sec
v_e	Exhaust velocity	ft/sec
v_o	Initial velocity	ft/sec
W	Weight	lb
W_f	Weight of fuel	lb
W_i	Initial weight	lb
W_o	Weight of oxidizer	lb
W_p	Total propellant weight	lb
$\mathring{W}$	*Fluid* flow rate or *propellant* consumption rate	lb/sec
$\mathring{W}_f$	Fuel flow rate	lb/sec
$\mathring{W}_o$	Oxidizer flow rate	lb/sec
X	Range	ft
l_n	Logarithm	—
(Greek)		
δ (delta)	Specific gravity	—
δ_F	Specific gravity of fuel	—
δo	Specific gravity of oxidizer	—
ϵ (epsilon)	Area ratio, (A_e/A_t)	—
θ (theta)	Path of flight angle of divergence from vertical	degrees
θ_c	Path of flight angle of divergence from vertical at time of cutoff	degrees
ϕ (phi)	Launching angle (divergence from horizontal)	degrees
ψ (psi)	Initial thrust to weight ratio (F/Wi)	—

APPENDIX E—ROCKET FORMULAS

PROPELLANT PERFORMANCE:

Specific Impulse: (I_{sp})

$$I_{SP} = \sqrt{\frac{2}{k-1}\,\frac{RT_c}{M_w g}\left[1 - \left(\frac{P_e}{P_c}\right)^{\frac{k-1}{k}}\right]}$$

Total Impulse: (I_t)

$$I_t = W_p I_{sp} = F \times T$$

Propellant Bulk Specific Gravity: (δ)

$$\delta = \frac{1 + r}{\frac{1}{\delta_f} + \frac{r}{\delta_o}} \qquad (r = \text{ozidizer-fuel ratio})$$

Burning Surface: (S)

$$S = \frac{\dot{W}}{r_b D} \qquad \left\{\begin{array}{l} \text{where: } D = \text{density} \\ \qquad\quad \dot{W} = \textit{weight} \text{ of propellant} \\ \qquad\qquad\quad \text{burned per second.} \\ \qquad\quad r_b = \text{burning rate in} \\ \qquad\qquad\quad \textit{inches} \text{ of propellant.} \end{array}\right\}$$

THRUST CHAMBER CALCULATIONS:

Thrust: (F)

$$F = \frac{\dot{W} v_e}{g} + A_e\,(P_e - P_o)$$

Coefficient of Thrust: (C_F)

$$C_F = \sqrt{\frac{2k^2}{k-1}\left(\frac{2}{k+1}\right)^{\frac{k+1}{k-1}}\left[1 - \left(\frac{P_e}{P_c}\right)^{\frac{k-1}{k}}\right]} + \frac{P_e - P_a}{P_c}\left(\frac{A_e}{A_t}\right)$$

(NOTE: The term P_o is substituted for P_a if calculation is for performance outside of earth's atmosphere.)

Exhaust Velocity: (v_e)

$$v_e = \sqrt{\frac{2gk}{k-1} RT_c\left[1 - \left(\frac{P_e}{P_c}\right)^{\frac{k-1}{k}}\right]}$$

Effective Exhaust Velocity: (c)

$$c = \frac{F\,g}{\dot{W}} = I_{SP}\,g = v_e + \frac{P_e - P_a}{\dot{W}} A_e\,g$$

Characteristic Exhaust Velocity: (c^*)

$$c^* = \frac{P_c A_t g}{\dot{W}} = \frac{I_{sp} g}{C_F} = \frac{\sqrt{gkR \frac{T_c}{M_w}}}{k \left(\frac{2}{k+1}\right)^{\frac{k+1}{2(k-1)}}}$$

Area of Chamber: (A_c)

$$A_c = \frac{A_t}{0.3}\left[\frac{1 + \frac{k-1}{2}(.09)}{1 + \frac{k-1}{2}}\right]^{\frac{k+1}{2(k-1)}}$$

Volume of Chamber: (V_c)

$$V_c = \frac{\pi D_c^2 l_c}{4} \qquad \text{or} \qquad V_c = L^* A_t$$

Diameter of Chamber: (D_c)

$$D_c = \sqrt{\frac{4A_c}{\pi}}$$

Characteristic Length: (L^*)

$$L^* = \frac{V_c}{A_t}$$

NOZZLE DIMENSIONS:

Area of Throat: (A_t)

$$A_t = \frac{F}{C_{f_o} P_c}$$

Diameter of Throat: (D_t)

$$D_t = \sqrt{\frac{4A_t}{\pi}}$$

Area of Exit: (A_e)

$$\frac{A_e}{A_t} = \frac{M_t}{M_e}\left[\frac{1 + \frac{k-1}{2} M_e^2}{1 + \frac{k-1}{2} M_t^2}\right]^{\frac{k+1}{2(k-1)}}$$

Diameter of Exit: (D_e)

$$D_e = \sqrt{\frac{4A_e}{\pi}}$$

LENGTHS OF CONVERGENT AND DIVERGENT SECTIONS FOR NOZZLES HAVING A CONVERGENT ANGLE OF 30° AND A DIVERGENT ANGLE OF 15°:

Length of Convergent Section: (L_{CON})

$$L_{CON} = \frac{\left(\frac{D_c - D_t}{\tan 30^\circ}\right)}{2}$$

Length of Divergent Section: (L_{DIV})

$$L_{DIV} = \frac{\left(\frac{D_e - D_t}{\tan 15^\circ}\right)}{2}$$

GENERAL FORMULAS

Horsepower Equivalent to Thrust: (HP)

$$HP = \frac{v\,(MPH)}{375}F$$

Velocity of Sound: (a)

In atmosphere:

$$a = 49.1\ \sqrt{T\ (\text{in } ^\circ R)}$$

In any gas:

$$a = \sqrt{kgRT}$$

Mach Number: (M)

$$M = \frac{v}{a} = \frac{v}{\sqrt{kgR'T}}$$

Wall Thickness: (t_w)

$$t_w = \frac{P_c \times \text{RADIUS}}{\text{allowable stress}}$$

BALLISTIC FORMULAS:

Mass Ratio: (n)

$$n = \frac{\text{loaded vehicle weight}}{\text{cutoff vehicle weight}} \quad \text{or} \quad \frac{\text{weight loaded}}{\text{weight empty}}$$

Velocity at Cutoff: (v_c) *Or Burnout:* (v_b)

$$v_c = g\, I_{SP} \left(\ln n - \frac{n-1}{\psi} \right)$$

Altitude at Cutoff: (h_c) *Or Burnout:* (h_b)

$$h_c = g\, (I_{SP})^2 \left(\frac{n-1}{\psi\, n} \right) \left[1 - \frac{\ln n}{n-1} - \tfrac{1}{2} \right] \frac{n-1}{\psi\, n}$$

Height from Cutoff to Peak Altitude:

$$h_p - h_c = \frac{g_o^2}{2\bar{g}} \left(I_{SP} \right)^2 \left(\ln n - \frac{n-1}{\psi\, n} \right)^2$$

where: g_o = gravity at earth's surface.

$\bar{g}$ = average gravity from cutoff to peak.

Peak Altitude: (h_p)

$$h_p = h_c + h_{p-c}$$

Time of Powered Flight: (t_b)

$$t_b = \frac{n-1}{\psi\, n} I_{SP}$$

Total Flight Time: (t)

$$t = \frac{2 v_c}{g} \sin \phi$$

Maximum Altitude: (h)

$$h = \frac{v_c^2}{2g} \sin^2 \phi$$

Range: (x)

$$x = \frac{v_c^2}{g} \sin 2\phi$$

APPENDIX F

GLOSSARY OF MISSILE TERMINOLOGY

ABORT. (1) In an operational action, an instance of a rocket, missile or vehicle failing to function effectively or to achieve the objective plotted for it. (2) A rocket missile, or vehicle that so fails.

ACCELERATION. The rate of increase in velocity. For example, increasing velocity from 20 to 50 feet per second in 1 second is an acceleration of 30 feet per second per second.

ACCELEROMETER. An instrument that measures one or more components of the acceleration of a vehicle.

AERODYNAMICS. That field of dynamics which treats of the motion of air and other gaseous fluids and of the forces acting on solids in motion relative to such fluids.

AFTERBURNING. The process of fuel injection and combustion in the exhaust jet of a turbo-jet engine (after the turbine).

AILERON. A hinged or movable surface on an airframe, the primary function of which is to induce a rolling moment on the airframe. On an airplane it is part of the trailing edge of a wing.

AIR-BREATHING JET. A propulsion device which operates by taking in air and then ejecting it as a high-speed jet.

AIRFOIL. Any object whose geometric shape is such that when properly positioned in an airstream will produce a useful reaction.

AIRFRAME. The bodily structure of a rocket missile or rocket vehicle that supports the different systems and subsystems integral to the missile or vehicle.

ALTIMETER. An instrument that measures elevation above a given datum plane.

ANALOGUE COMPUTER. A computing machine that works on the principle of measuring, as distinguished from counting, in which the measurements obtained, as voltages, resistances, etc., are translated into desired data.

ANGLE OF ATTACK. The angle between a reference line fixed with respect to an airframe and the apparent relative flow line of the air.

ANTENNA. A device—i.e., conductor, horn, dipole—for transmitting or receiving radio waves, exclusive of the means of connecting its main portion with the transmitting or receiving apparatus.

ANTIMISSILE MISSILE. An explosive missile launched to intercept and destroy another missile in flight.

APOGEE. The point in an elliptical orbit which is farthest from the center of the earth.

ARMING. As applied to fuses, the changing from a safe condition to a state of readiness. Generally a fuse is caused to arm by acceleration, rotation, clock mechanism, or air travel, or by combinations of these.

ASTRONAUT. One concerned with flying through space, or one who navigates through space.

ASTRONAUTICS. (1) The art, skill, or activity of operating space vehicles. (2) In a broader sense, the art or science of designing, building, and operating space vehicles.

ATMOSPHERE. The body of air which surrounds the earth, defined at its outer limits by the actual presence of air particles.

ATTITUDE. The position of an aircraft as determined by the inclination of its axes to some frame of reference.

AUTOMATIC PILOT. An automatic control mechanism for keeping an aircraft in level flight and on a set course or for executing desired maneuvers. Sometimes called gyropilot, mechanical pilot, robot pilot, or auto pilot.

BALLISTIC MISSILE. A vehicle whose flight path from termination of thrust to impact has essentially zero lift. It is subject to gravitation and drag, and may or may not perform maneuvers to modify or correct the flight path.

BALLISTIC RANGE. The range on surface of the reference sphere from the cutoff point to the point of reentry through the reference sphere.

BEACON, RADAR. Generally, a nondirectional radiating device, containing an automatic radar receiver and transmitter, that receives pulses ("interrogation") from a radar, and returns a similar pulse or set of pulses ("response"). The beacon response may be on the same frequency as the radar, or may be on a different frequency.

BIPROPELLANT. A liquid rocket propellant that consists of a liquid fuel and a liquid oxidizer each separated from the other until introduced into the combustion chamber; also either the fuel or the oxidizer before being brought together.

BIRD. A figurative name for a missile, earth satellite, or other inanimate object that flies.

BLOCK HOUSE. A reinforced concrete structure, often built underground or half underground, and sometimes dome-shaped, to provide protection against blast, heat, or explosion during missile launchings or related activities.

BOOSTER. An auxiliary propulsion system which travels with the missile and which may or may not separate from the missile when its impulse has been delivered.

BURNOUT. The time at which combustion in a rocket engine ceases.

BURNOUT VELOCITY. The velocity of a rocket at the end of propellant oxidation. (*See* cut-off velocity)

CANARD. A type of airframe having the stablizing and control surfaces forward of the main supporting surfaces.

CELESTIAL MECHANICS. That branch of mechanics concerned with mathematical development of postulates treating of the motions of celestial bodies.

CENTER OF GRAVITY. The point at which all the mass of a body may be regarded as being concentrated, so far as motion of translation is concerned.

CHANNEL. In radio communications, the band of frequencies within which a radio transmitter or receiver must maintain its modulated carrier signal.

CLUSTER. Two or more solid rocket motors bound together so as to function as one propulsive unit.

CLUTTER, RADAR. The visual evidence on the radar indicator screen of the sea-return or ground-return which tends to obscure the target indication.

COMPUTER. A mechanism which performs mathematical operations.

CONTROL, BANG-BANG. A control system used in guidance wherein the corrective control applied to the missile is always applied to the full extent of the servo motion.

CONTROL, PROPORTIONAL. Control in which the action to correct an error is made proportional to that error.

COUNT-DOWN. In the final make-ready for the launching of a rocket missile or vehicle, the action of checking each system or subsystem one after the other, using a count, e.g., T minus 60 minutes, in inverse numerical order so that the count narrows down at the end to 4-3-2-1-zero, minus 1, minus 2, etc., during which time the button is pressed, i.e., the propellant is ignited.

CUT-OFF VELOCITY. The velocity at the point of thrust termination.

DECLINATION. In astronomy and celestial navigation, the angular distance of a celestial body from the celestial equator measured through 90 degrees and named north or south as the body is north or south of the celestial equator measured on an hour circle.

DESTRUCTOR. An explosive or other device for intentionally destroying a missile, an aircraft, or a compound thereof.

DIFFUSER. A duct of varying cross section designed to convert a high-speed gas flow into low-speed flow at an increased pressure.

DIGITAL COMPUTER. A computer that works on the principle of counting, as distinguished from measuring.

DOPPLER EFFECT. The apparent change in frequency of a sound or radio wave reaching an observer or a radio receiver, caused by a change in distance or range between the source and the observer or the receiver during the interval of reception.

DRAG. The component of the total air forces on a body, in excess of the forces owing to static pressure of the atmosphere, and parallel to the relative gas stream but opposing the direction of motion. It is composed of skin-friction, profile-, induced-, interference-, parasite-, and base-drag components.

DUCTED PROPULSION. Generally refers to any propulsion system which passes the surrounding atmosphere through a channel or duct while accelerating the mass of air by a mechanical or thermal process.

ESCAPE VELOCITY. A property of a spatial body expressed in terms of the speed in an outward direction that a molecule, rocket, or other body must move in order for it to escape the gravitational attraction of the spatial body.

EXHAUST VELOCITY. The velocity of gases that exhaust through the nozzle of a rocket engine or motor relative to the nozzle.

EXIT AREA. The cross-sectional area of the rocket engine nozzle where the exhaust gases are released into the atmosphere.

FIN. A fixed or adjustable airfoil attached to the body of a rocket for the purpose of flight control or stability.

GANTRY. Short for gantry crane or gantry scaffold.

GANTRY CRANE. A large crane mounted on a platform that runs back and forth on parallel tracks.

GANTRY SCAFFOLD. A massive scaffolding structure mounted on a bridge or platform supported by a pair of towers or trestles that run back and forth on parallel tracks, used to service a large rocket as the rocket rests on its launching pad.

GATE. (1) In radar or control terminology, an arrangement to receive signals only in a small, selected fraction of the principal time interval. (2) Range of air-fuel ratios in which combustion can be initiated. (3) In computer terminology, a device used to control passage of information through a circuit.

GIMBALED MOTOR. A rocket motor mounted on a gimbal, i.e., on a contrivance having two mutually perpendicular and intersecting axes of rotation, so as to obtain pitching and yawing correction moments.

GRAIN. The body of a solid propellant used in a rocket, fashioned to a particular size and shape so as to burn smoothly without severe surges or detonations.

GRAVITATIONAL CONSTANT (g). The acceleration due to gravity (32.2 feet per second per second)

GUIDANCE. The entire process of determining the path of a missile and maintaining the missile on that path.

GUIDANCE, BEAM RIDER. A guidance system in which equipment aboard the missile causes it to seek out and follow a path specified by a beam.

GUIDANCE, CELESTIAL NAVIGATION. Navigation by means of observations of celestial bodies. A system wherein a missile, suitably instrumented and containing all necessary guidance equipment, may follow a predetermined course in space with reference primarily to the relative positions of the missile and certain preselected celestial bodies.

GUIDANCE, COMMAND. A guidance system wherein intelligence transmitted to the missile from an outside source causes the missile to traverse a directed path in space.

GUIDANCE, FIN STABILIZATION. The simplest method of guiding a rocket or missile in flight where aerodynamic surface fins are mounted on the body of the rocket or missile (usually at the aft end) for stabilizing its flight path and to prevent it from tumbling.

GUIDANCE, HOMING. A system in which a missile steers toward a target by means of radiation which the missile receives from the target, either by reflection (radar or visible light) or by emission from the target (infra-red or acoustic energy).

GUIDANCE, HOMING, PASSIVE. A system of homing guidance wherein the receiver in the missile utilizes natural radiations from the target.

GUIDANCE, HOMING, SEMIACTIVE. A system of homing guidance wherein the receiver in the missile utilizes natural radiations from the target.

GUIDANCE, INERTIAL. A form of guidance in which all guidance components are located aboard the missile. These components include devices to measure forces acting on the missile and generating from this measurement the necessary commands to maintain the missile on a desired path.

GUIDANCE, INFRA-RED. A guidance method operating on the detection of heat (radiation) waves from a target. Sensitive instruments in the nose of the rocket or missile pick up the heat waves (such as engine exhausts) and through a connected control system guide it to the target.

GUIDANCE, MIDCOURSE. The guidance applied to a missile between the termination of the launching phase and the start of the terminal phase of guidance.

GUIDED MISSILE. An unmanned vehicle moving above the earth's surface, whose trajectory or flight path is capable of being altered by a mechanism within the vehicle.

GUIDANCE, PRESET. A technique of missile control wherein a predetermined path is set into the control mechanism of the vehicle and cannot be adjusted after launching.

GUIDANCE, RADAR BEAM. Radio signals from a radar transmitter on the ground or in an aircraft or missile traveling similar to beams of light. The radar beam is reflected from any object (clouds, land, sea, etc.) the same as light is reflected from a mirror. The missile follows this reflected beam to reach its destination.

GUIDANCE, RADAR CONTROL. Radio transmitters located in the missile send out signals to the target that are reflected back to the missile. Timing of the signals to the target and back to the missile makes it possible to determine the distance, altitude, and direction of motion of the target. Control systems in the missile, operating with radar, use this information in guiding the missile to the target.

GUIDANCE, RADIO NAVIGATION. A form of guidance in which the path of the missile is determined by a time measure of radio signals.

GUIDANCE, TERMINAL. The guidance applied to a missile between the termination of the midcourse guidance and impact with or detonation in close proximity of the target.

GUIDANCE, TERRESTRIAL REFERENCE. A technique of missile control wherein the predetermined path set into the control system of a missile can be followed by a device in the missile which reacts to some property of the earth, such as magnetic or gravitational effects.

GYROSCOPE. A wheel or disc, mounted to spin rapidly about an axis and also free to rotate about one or both of two axes perpendicular to each other and to the axis of spin. A gyroscope exhibits the property of rigidity in space.

HARDWARE. Finished pieces of equipment or component parts that constitute or go to make up an operating machine or device such as a missile or vehicle.

IGNITER. A device used to initiate propellant burning in a rocket engine combustion chamber.

INTERCONTINENTAL BALLISTIC MISSILE (ICBM). A ballistic missile which has a range of approximately 5000 nautical miles.

INTERCONTINENTAL RANGE BALLISTIC MISSILE (IRBM). A ballistic missile which has a range of approximately 1500 nautical miles.

ION ENGINE. A projected species of reaction engine whose thrust is to be obtained from a stream of ionized atomic particles supplied by atomic fission, atomic fusion, or solar energy.

IONOSPHERE. That portion of the earth's atmosphere beginning about 30 miles above the earth's surface, which consists of layers of highly ionized air capable of bending or reflecting certain radio waves back to the earth.

IONOSPHERE. An outer stratum of the atmosphere consisting of layers of ionized air particles.

JAMMING. Intentional transmission of r-f energy, in such a way as to interfere with reception of signals by another station.

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

JET. An exhaust stream or rapid flow of fluid from a small opening or nozzle.

JET PROPULSION. The force, motion or thrust resulting from the ejecting of matter from within the propelled body.

LAUNCHER. A device which supports and positions a rocket to permit movement in a desired direction during takeoff.

LIFT. The aerodynamic force on a body measured perpendicular to the direction of motion. Lift is used to turn, stabilize, or support a rocket depending on the location, shape and angle of a surface with respect to the rocket body.

LIQUID PROPELLANT. (1) A rocket propellant that consists either of a mixture of two or more liquids (a fuel, oxidizer, and sometimes an additive) or of a liquid chemical compound that provides its own fuel and oxidizer. (2) Also any one of the liquid ingredients that are to go into the mixture, i.e., the fuel, the oxidizer, or the additive, separately.

MACH NUMBER. The ratio of the velocity of a body to that of sound in the medium being considered. At sea level in air at the Standard U. S. Atmosphere, a body moving at a Mach number of one (M-1) would have a velocity of approximately 1116.2 feet per second, the speed of sound in air under those conditions.

MASS (m). A measure of the quantity of matter in an object.

$$m=\frac{\text{weight}}{\text{gravitational constant}}=\frac{\text{w (lbs.)}}{\text{g (ft./sec.}^2\text{)}}$$

The unit of mass is sometimes called a "slug."

MASS FLOW RATE (m). Propellant consumption rate in slugs per second.

MASS RATIO (LAMBDA). Total weight of rocket divided by weight without propellant.

MESOSPHERE. (1) In the nomenclature of Chapman, a stratum of atmosphere sometimes called the chemosphere. (2) In the nomenclature of Wares, a stratum that extends approximately from 250 to 600 miles, lying between the ionosphere and the exosphere.

MISSILE. A self-propelled unmanned vehicle which travels above the earth's surface.

MOLECULAR WEIGHT (Mw). The atomic weight times the number of atoms per molecule, expressed in pounds. For example, the molecular weight of water (H_2O) = (1x2) + (16x1) = 18 lbs.

MOMENTUM (M). A quantity of motion measured by the product of the mass of an object times its velocity. $M=mV$

MONOPROPELLANT. A rocket propellant, especially a liquid propellant, in which the fuel and oxidizer make up a single substance before injection into the combustion chamber.

MULTISTAGE ROCKET. A rocket having two or more thrust-producing units, each used for a different stage of the rocket's flight.

NOSE CONE. A cone-shaped shield that fits over, or is, the nose of a rocket vehicle or rocket motor, built to withstand high temperatures generated by friction with air particles.

NOZZLE. A duct of changing cross section in which the fluid velocity is increased. Nozzles are usually converging-diverging, but may be uniformly diverging or converging.

ORBIT. The path described by a body in its revolution about another body.

ORBITAL VELOCITY. The average velocity at which an earth satellite or other orbiting body orbits.

OXIDIZER. A substance that combines with another to produce heat and, in the case of a rocket, a gas. OXIDIZER. Any substance which reacts with another substance to support burning.

OZONOSPHERE. A stratum in the upper stratosphere at an altitude of approximately 40 miles having a relatively high concentration of ozone and important for its absorption of ultraviolet radiation from the sun.

PAYLOAD. The equipment carried by the rocket which performs no function in relation to the flight.

PERIGEE. The point in an orbit which is closest to the center of the earth.

PERIHELION. That point on a planet's or comet's orbit nearest the sun.

PHOTOTHEODOLITE. A device for measuring and recording the horizontal and vertical angles to a missile while photographing its flight.

PITCH. An angular displacement about an axis parallel to the lateral axis of an airframe.

PRESSURE (P). The result of the impact of molecules on their surroundings, measured as a force per unit area such as pounds per square inch absolute (psia) or pounds per square inch gage (psig).

PROPELLANT. Material consisting of fuel and oxidizer, either separate or together in a mixture or compound which if suitably ignited changes into a larger volume of hot gases, capable of propelling a rocket or other projectile.

PULSE. A single disturbance of definite amplitude and time length, propagated as a wave or electric current.

RAMJET. A compressorless jet-propulsion device which depends for its operation on the air compression accomplished by the forward motion of the unit.

REACTION ENGINE. An engine or motor that derives thrust by expelling a stream of moving particles to the rear.

RECONNAISSANCE SATELLITE. An earth satellite designed to obtain strategic information, as through photography, television, etc.

RE-ENTRY. The event occurring when a ballistic missile or other object comes back into the sensible atmosphere after being rocketed to altitudes above the sensible atmosphere; the action involved in this event. Attributed as in re-entry problem.

ROCKET. A thrust-producing system or a complete missile which derives its thrust from ejection of hot gases generated from material carried in the system, not requiring intake of air or water.

ROCKETS: BOOSTER ROCKETS, AUXILIARY ROCKETS. Rocket engines that are mounted on airplanes or on missiles to give initial boost during takeoff. Booster rockets usually are jettisoned or dropped after the plane or the missile becomes airborne.

ROCKETS: OPERATIONAL ROCKETS OR MISSILES. Usually refers to missiles that are in service and/or production by the Army, Navy, or Air Force.

ROCKETS: RESEARCH OR SOUNDING ROCKETS. Rocket-powered missiles that carry instruments to high altitudes for measuring atmospheric data, such as cosmic radiation, ultra-violet intensity, temperatures, etc.

ROCKET SLED. A vehicle traveling along a set of rails, and powered by rocket motors. Rocket sleds are used to study high stress or high accelerations on humans and also on components, such as electronic gear, designed for missile guidance systems, etc.

ROCKETS: STAGE ROCKETS, STEP ROCKETS. Rocket vehicles consisting of two or more stages, i.e., one smaller rocket mounted on top of another bigger one. Individual stages are dropped after propellants have been burned. Technique is used to obtain maximum speed in a short time.

ROLL. An angular displacement about an axis parallel to the longitudinal axis of an airframe.

SATELLITE. (1) An attendant body that revolves about another body. (2) A man-made object designed, or expected, to be launched as a satellite.

SEEKER, TARGET. A receiving device on a missile that receives signals emitted from or reflected off the target that is used in guiding on the target.

SIGNAL. Any wave or variation thereof with time serving to convey the desired intelligence in communication.

SOLID PROPELLANT. A rocket propellant consisting of a single solid substance, usually a powder made into a grain of a particular size and shape.

SONIC. Velocity that is equal to the local speed of sound.

SOUNDING ROCKET. A research rocket used to obtain data on the upper atmosphere.

SPECIFIC-IMPULSE, FUEL. Thrust developed by burning one pound of fuel in one second, or the ratio of thrust to the fuel mass flow.

SPEED OF SOUND. The velocity at which sound waves are transmitted through a medium. Speed of sound in the air varies as the square root of the absolute temperature. (*See* MACH NUMBER)

SQUIB. A small pyrotechnic device which may be used to fire the igniter in a rocket or for some similar purpose. Not to be confused with a detonator which explodes.

STATIC FIRING. The firing of a rocket motor or rocket engine in a hold-down position to measure thrust and accomplish other tests.

STRATOSPHERE. (1) A stratum of the atmosphere lying immediately above the troposphere and, as treated by some meteorologists, immediately below the chemosphere. (2) Also applied to a thicker stratum extending through the chemosphere.

SUBSONIC. A velocity less than the local speed of sound, or than a Mach number of one.

SUPERSONIC. A velocity that is greater than the local speed of sound.

SUSTAINER. A propulsion system which travels with and does not separate from a missile usually distinguished from an auxiliary motor, or booster.

TELEMETERING SYSTEM. The complete measuring, transmitting, and receiving apparatus for remotely indicating, recording, and/or integrating information.

TERRESTRIAL SPACE. Space comparatively near the earth in which the attraction of the earth is predominant.

THEODOLITE. An optical instrument for measuring horizontal and vertical angles with precision.

THRUST. The resultant force in the direction of motion, owing to the components of the pressure forces in excess of ambient atmospheric pressure, acting on all inner surfaces of the vehicle parallel to the direction of motion. Thrust less drag equals accelerating force.

TRANSONIC. The intermediate speed in which the flow patterns change from the subsonic flow to supersonic, i.e., from Mach numbers of about .8 to 1.2, or vice versa.

TROPOSPHERE. The lower layer of the earth's atmosphere, extending to about 60,000 feet at the equator and 30,000 feet at the poles.

THROAT. In rocket and jet engines, the most restricted part of an exhaust nozzle.

THROAT AREA. The cross-sectional area of the nozzle at its smallest inner diameter.

TRAJECTORY. The path that a rocket or missile travels from point of launch to point of impact, usually refers to ballistic missiles. Also the route of the course.

TURBO-JET. A jet motor whose air is supplied by a turbine-driven compressor; the turbine being activated by exhaust gases from the motor.

VERNIER ENGINE. A rocket engine of small thrust used to obtain a fine adjustment in the velocity and trajectory of a ballistic missile just after the thrust of the final-stage main engines has been cut off.

WARHEAD. That part of a missile that constitutes the explosive, chemical, or other charge intended to damage the enemy.

WEIGHTLESSNESS. A property or attribute of being without weight.

YAW. An angular displacement about an axis parallel to the "normal" axis of an aircraft.

ZEROGRAVITY. A condition existent when centripetal gravitational attraction of the earth or other spatial body is nullified by inertial (centrifugal) forces.

APPENDIX G—BIBLIOGRAPHY

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