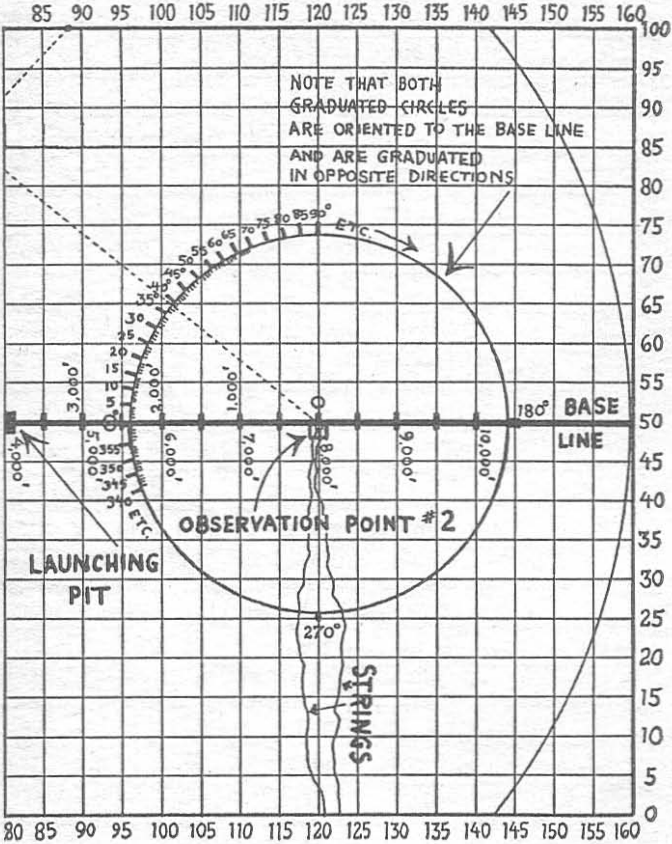


left of the launching pit (coord. 80-50). The location of this point was determined by intersection of the azimuth readings from OP#1 (46°) and OP#2 (38°). The strings tacked to OP#1 and OP#2 are used by the plotter to lay in the azimuths reported to him and then to measure the distance to the point 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.

$$\text{tangent BAC} = \frac{BC}{BA}$$

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:

$$BC = BA \text{ x tangent BAC}$$

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.

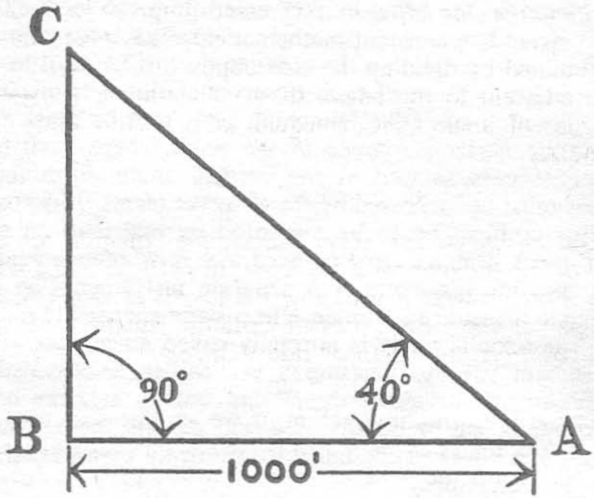
Substituting the values shown in the illustration for angle BAC and side BA in our equation, we can make a simple calculation of the length of side BC:

$$BC = 1000 \text{ ft.} \times \tan 40 \text{ degrees}$$

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.

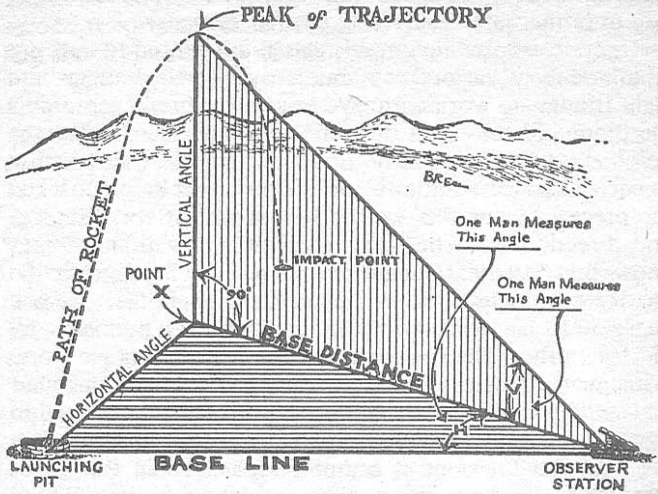
Chart B, Illustration *68,* illustrates this principle for you in perspective in order to show you how the triangle used in solving the problem would appear if you were to visualize it on your launching site. The most important thing to make note of in Chart B is that the base of the triangle (base distance) 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.

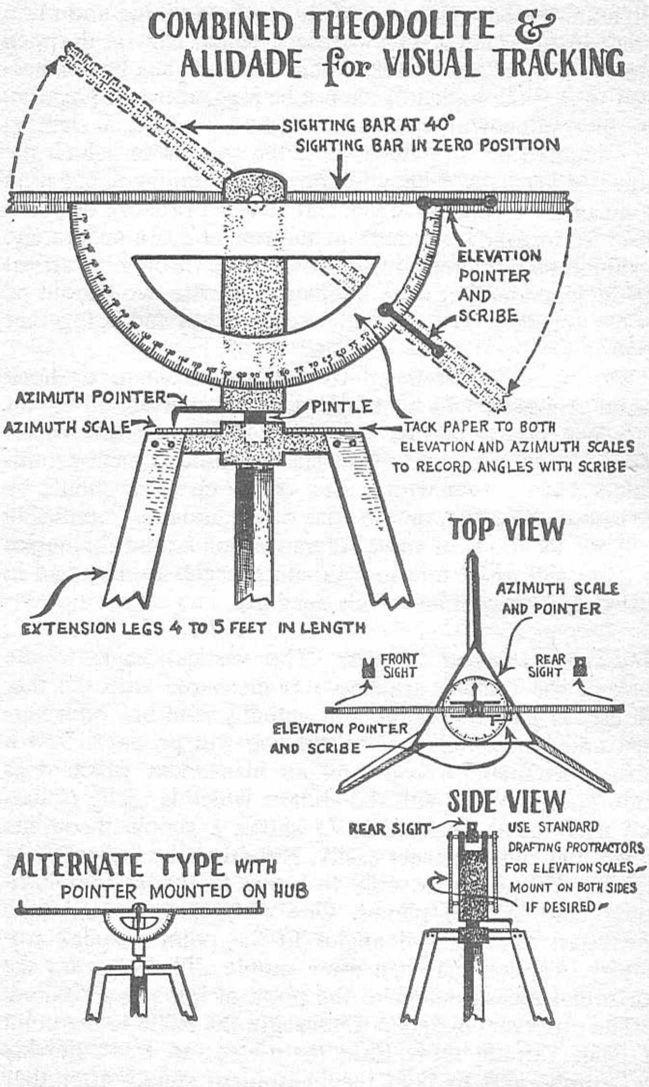
Observer Methods and Techniques

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



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.

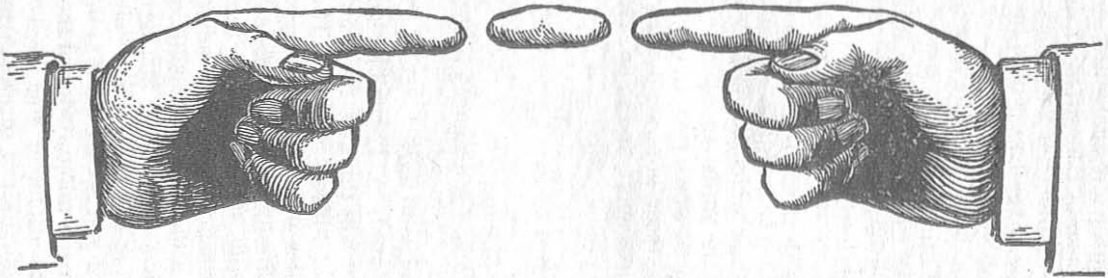
The observers assigned to measure the angle to the point of peak altitude must train themselves to track quickly and surely, and to hold the instrument steady after they have aligned it on the point which represents the apex of the rocket's flight path. This point is not difficult to fix if you have 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



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.

ILLUSTRATION NO. 74

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.

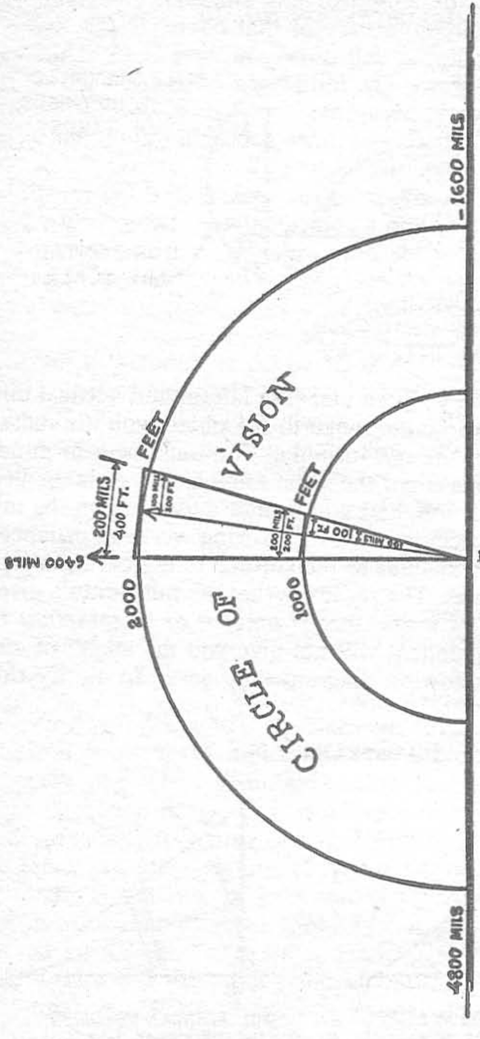
A mil is defined as the angle which subtends a width of 1 yard at a distance of 1000 yards. In other words, 1000 yards away from the point at which two straight lines intersect at an angle of 1 mil, those lines are 1 yard apart. At 2000 yards, they are 2 yards apart, and so on. This relation may be expressed 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

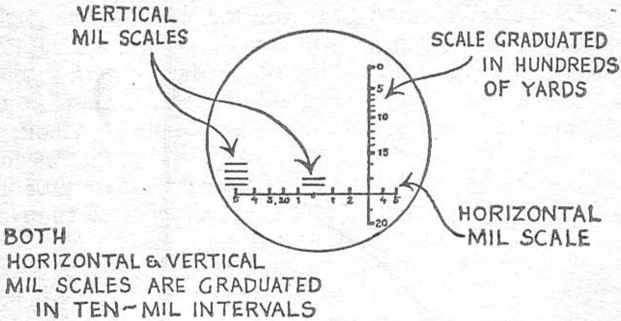


THE MIL SYSTEM OF MEASUREMENT...

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.

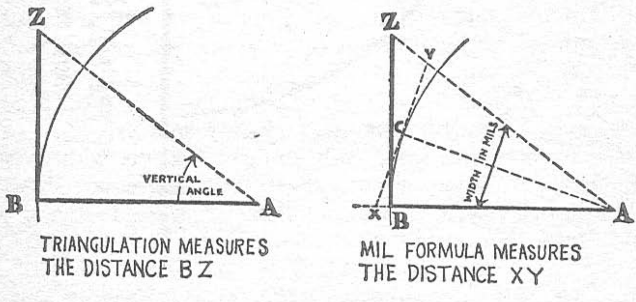
binoculars contains a reticule with a mil scale that looks like this:

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



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.

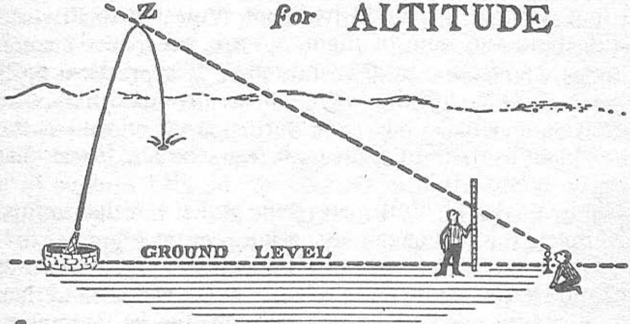
A further refinement of this system, which can actually be developed into a fairly accurate method of tracking, is to station the observer behind a net or a section of Cyclone fence. From this position he can observe the entire flight path of the rocket just as it would appear if plotted on a piece of 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.

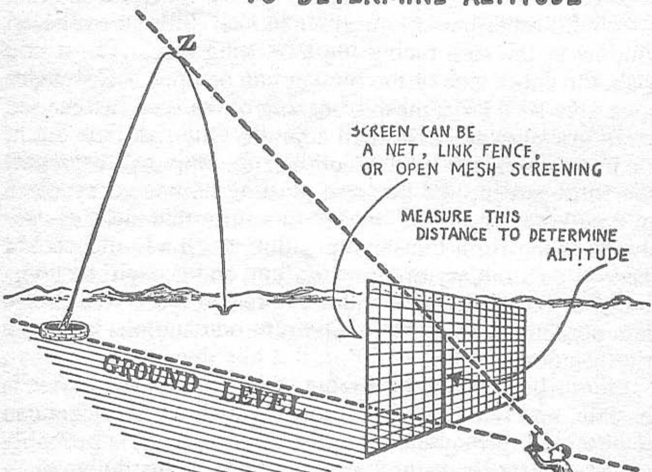
Measuring altitude by timing the flight of your rocket is feasible, and reasonably accurate, providing the rocket can be observed throughout its entire flight path. It is probably just as accurate a method as shooting a triangulation when you consider the many small errors in basic data which can have 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 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 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

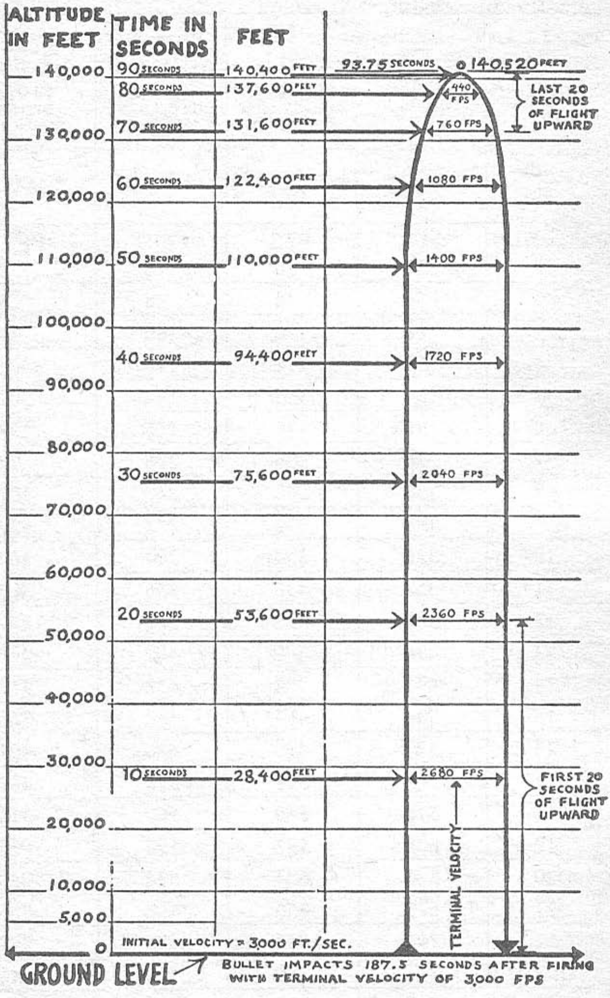


ILLUSTRATION No. 80

TABLE OF VELOCITIES AND DISTANCES ACHIEVED BY FREE-FALLING BODIES 1 TO 25 SECONDS

$\underline{t}$ — TIME — AT END OF	$\underline{V}$ TERMINAL VELOCITY IS	$\underline{v}$ AVERAGE VELOCITY DURING LAST SECOND WAS	$\underline{s}$ DISTANCE TRAVELED DURING LAST SECOND WAS	$\underline{S}$ CUMULATIVE OR TOTAL DISTANCE TRAVELED IS
$t = \frac{V}{g}$	$V = gt$	$v = gt - \frac{g}{2}$	$s = 1v$	$S = \frac{1}{2} g t^2$
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.

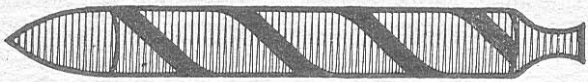
Distinctive markings on the hull of your rocket which provide good contrast can be very helpful in making the rocket stand out against the background of the sky. In general you should avoid the use of neutral colors, particularly grays and light blues, which will tend to blend with sky and clouds. Some 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.

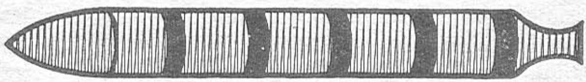
Lights, Smoke and Vapor Trails: Many amateur groups have experimented with various types of light-flashing devices and smoke or vapor generators to increase the chances of good observation of the rocket throughout its trajectory. Generally speaking, light-flashing devices are more difficult to design and fabricate and are sometimes

Illustration No. 81

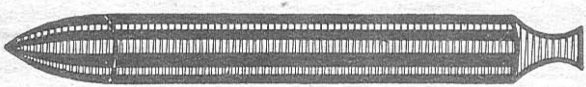
TYPES of ROCKET MARKINGS
USED TO INCREASE VISIBILITY



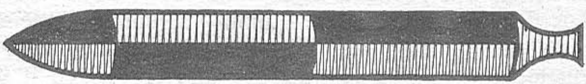
BARBER POLE



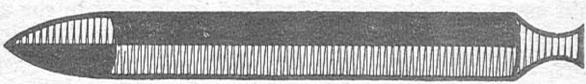
HORIZONTAL STRIPES



VERTICAL STRIPES



HALF HARLEQUIN



HARLEQUIN

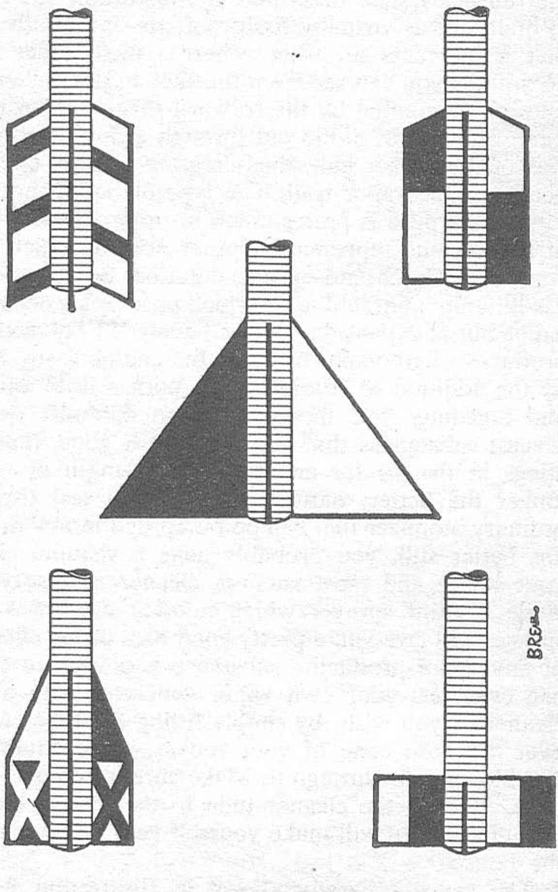
unreliable. Although many good theories have been advanced for the operation of such mechanisms, very few of them seem to function in actual flight-testing. Also, for the light source to be effective as a tracking aid, the rocket carrying it must be launched at night, or in gathering darkness, which 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



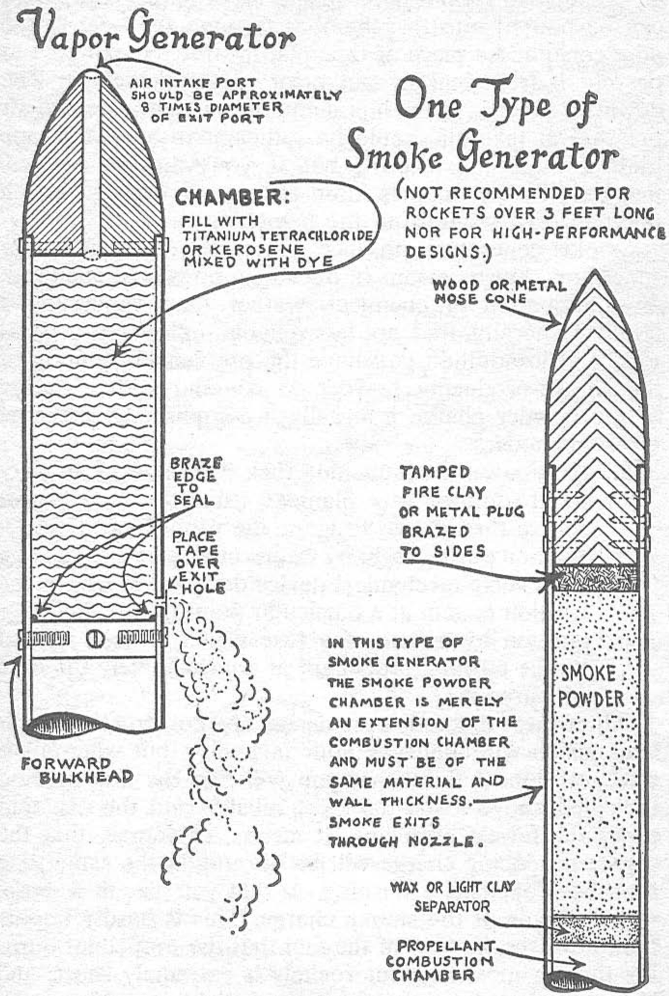
vapor trail throughout the entire flight of your rocket. It is recommended, however, that the hole in the nose cone be about eight times the diameter of the exit port at the bottom of the liquid chamber in order to ensure sufficient air pressure to form a good strong vapor spray. The liquid can be poured 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.

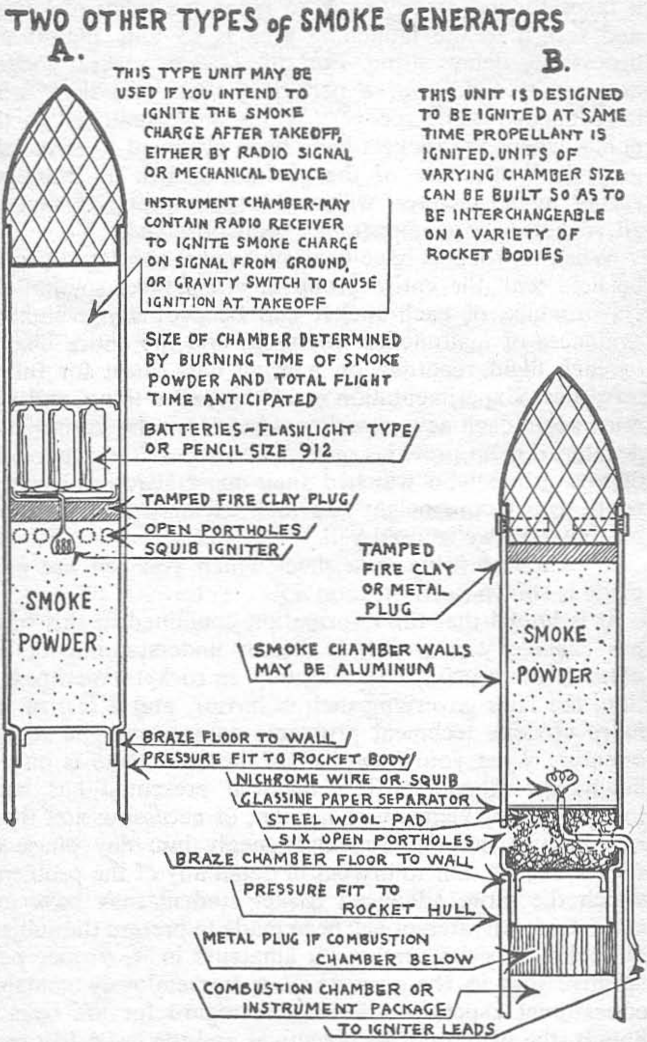
Method *b* above is feasible if you assume that every gadget in your rocket is going to work under flight conditions. Unfortunately, this is seldom the case, even with the most carefully designed and constructed rockets. Most systems for triggering some action in the rocket(e.g., stage separation, parachute 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 ________

Propellant Data:

Type ________
Mixture ________
Weight ________
Density ________
Burning Rate ________
Spec. Imp. ________

Expected Performance:

Total Thrust ________
Total Burning Time________
Exhaust Velocity ________

Launching Data:

Launcher Used ________
Launching Angle ________
Direction ________

Personnel Participating:

Range Officer ________
Safety Officer ________
Key Man ________
Loaders ________
Observers ________

Rocket Data:

Name ____________
Length ____________
O. D. ____________
No. Fins—Type ________
Weight Empty ______ M/R:
Weight Loaded______

Nozzle: Type ________
Length ________
Throat Area ________
Exit Area ________
O. D. ________
Material ________

Comb. Chamber:

Cross. Area ________
Length ________
Wall Thickness________
Material ________

Instrumentation:

____
____
____

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	
						Circum-ference	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	56 549	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 0990	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	1 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	1 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
	60′	50′	40′	30′	20′	10′	0′	
Sines	Cosines							Degrees

Natural Trigonometric Functions

Degrees	Cosines 0′	10′	20′	30′	40′	50′	60′	Sines
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′ Sines	Degrees

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 0′	10′	20′	30′	40′	50′	60′	Tangents
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′ Tangents	Degrees

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	571[illegible]1	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	6253[illegible]	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	7050[illegible]	70586	70672
51	70757	70842	70927	71012	71096	71[illegible]8[illegible]	71265	71349	71433	71517
52	71600	71684	71767	71850	71933	72016	72099	7218[illegible]	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/in²
P_c	Chamber pressure, absolute	lb/in²
P_e	Nozzle exit pressure, absolute	lb/in²
P_o	Ambient absolute pressure (pressure in surrounding environment)	lb/in²
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	in²
T	Absolute temperature	°R
T_c	Combustion temperature	°R
t	Time	sec
t_b (t_c)	Time at burnout (time at cut-off) or Burning Time	sec
t_w	Wall thickness	in
V	Volume	in³
V_c	Combustion chamber volume	in³

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	—
δ_O	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)

$$S = \frac{\dot{W}}{r_b D}$$

(where: D = density
$\dot{W}$ = *weight* of propellant burned per second.
r_b = burning rate in *inches* of propellant.)

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)

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

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)

$$h_c = g\, (I_{SP})^2 \left(\frac{n-1}{\psi\, n} \right) \left[1 - \frac{ln\, n}{n-1} - ½ \right] \frac{n-1}{\psi\, n}$$

Height from Cutoff to Peak Altitude:

$$h_p - h_c = \frac{g_e^2}{2\bar{g}} \left(I_{SP} \right)^2 \left(ln\, n - \frac{n-1}{\psi\, n} \right)^2$$

where: g_e = 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)

$$t = \frac{2v_c}{g} \sin \phi$$

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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