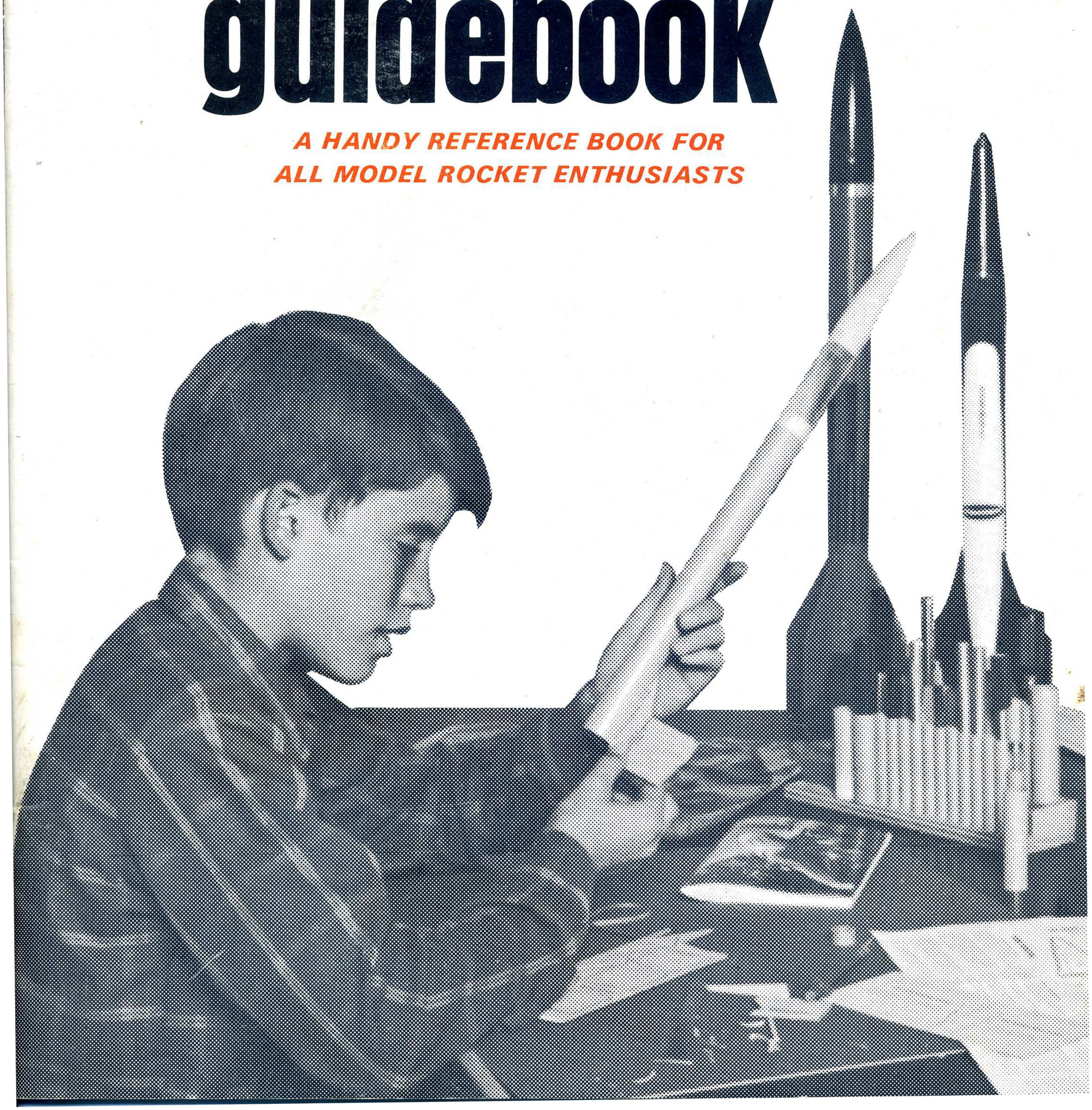
$1.25

Centuri

ROCKETEER'S guidebook

A HANDY REFERENCE BOOK FOR ALL MODEL ROCKET ENTHUSIASTS



MODEL ROCKETRY

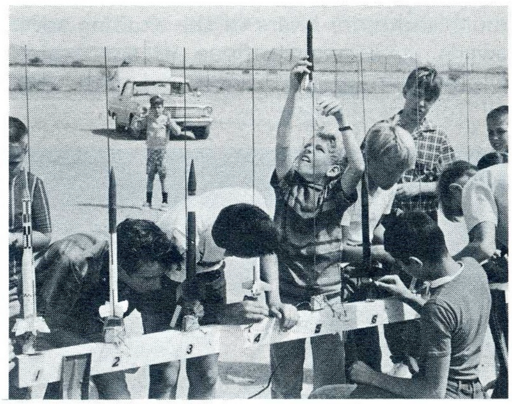
AMERICA'S

FASTEST GROWING

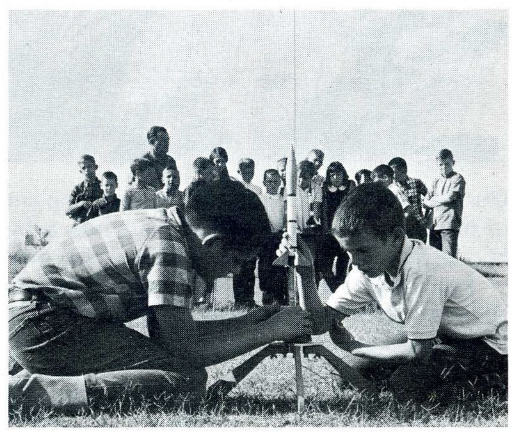
AND

MOST EDUCATIONAL

HOBBY



It was inevitable! It had to come! Just as the development of flying aircraft brought on model aviation, so has today's Space Age rockets and missiles inspired this exciting new Aerospace sport and hobby called MODEL ROCKETRY.



Today, Model Rocketry has become America's most exciting, most educational and fastest-growing hobby. Now you can experience the thrill of pressing the firing button and watch your rocket rise off the launching pad, streak a thousand feet into the sky, eject its colorful parachute and return safely to Earth. The built-in recovery systems and replaceable engine cartridges permit model rockets to be flown again and again.

The real bonus in model rocketry is the opportunity to experiment and learn. You can try different payloads, nose shapes, fin designs, various recovery devices, and new vehicle designs. Guided by this Guidebook plus Centuri's informative Technical Reports, you can become amazingly more successful with each new rocket you build and launch.

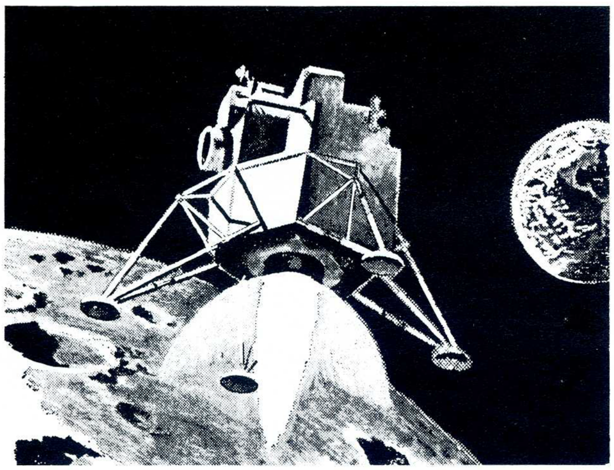
The same scientific principles which apply to the large missiles of research and defense also apply to the smaller model rockets. At the same time you're having fun with model rockets, you'll also be learning principles of physics, math, aerodynamics, electronics, biology, and astronautics. Science subjects become fun and easy-to-understand with model rocketry. Because of this, parents and teachers have praised model rocketry as an extremely motivating and rewarding study aid. Students have found that model rocketry can be a terrific project for award winning Science Fairs.

Get a "head start" in the Space Age with model rocketry and become one of America's young Space Pioneers.

1 WHAT IS MODEL ROCKETRY?

THE SPACE AGE

The realization that we now have the capability to leave the Earth and explore space has developed within us a new awareness of the "Space Age" in which we are living. As each day passes we become more and more aware of the exciting adventure that awaits us as we continue in our exploration and exploitation of the newest and most challenging of all frontiers – Space.



Our new age has stimulated the teaching and learning of many new subjects, and of these new subjects there is one that has stimulated the imagination of millions – Rocketry It seems that nearly everyone at one time or another has had the desire to build and launch rockets.

Because the "Space Age" would not have been possible without rocketry, we have come to recognize the importance of this field. Today, many people are studying rocketry – some are doing it safely, others are not.

A NEW ACTIVITY

The excitement generated by the Space Program stimulated a compelling enthusiasm within our youth to build rockets. But building rockets can be dangerous and in the beginning it was. Most of the experimenters did not know how or where to begin. Some were mixing their own fuel and loading it into metal containers. Because of this, many serious accidents followed and efforts were made by lawmakers to eliminate this type of non-professional rocket activity. However, it was soon apparent that laws outlawing such activity failed❖ to eliminate the accidents. Concerned by this problem, Centuri created safe, educational model rocketry materials for "space minded" young people.

PROFESSIONALS

The rocket engineers who are involved in our military and civilian Space Programs are highly paid, well trained, experienced professionals who work with a great deal of expensive equipment.

NON-PROFESSIONALS

Because non-professional rocketeers did not have the expensive equipment, the training, nor the experience to build rockets from scratch, there existed a need for a safe, relatively inexpensive form of rocketry.

❖Restrictive laws would only stop the safe, worthwhile educational programs. The unsupervised backyard experimenter would not be stopped and the deaths and injuries would not be reduced. The building materials could not be eliminated because 90% of the components consisted of common household items.

THREE FORMS OF NON-PROFESSIONAL ROCKETRY

The three forms of non-professional rocketry are: 1) Basement Bomber, 2) Amateur, and 3) Model. Model Rocketry and its advantages are understood better and appreciated more when you consider the other forms of non-professional rocketry.

The basement bomber is a unique breed that is easily recognized, but difficult to describe. He is the type that is either ignorant of, or refuses to follow safety precautions. He begins by locating the nearest metal pipe and mixing a concoction that he will call a fuel. He will then attempt to load the "fuel" into his "rocket". If this doesn't finish him, he will next attempt to ignite the rocket with a fuse hoping he has enough time to run for cover. It should be obvious that his chances of being injured or killed are quite high.

The American Institute of Aeronautics and Astronautics, formerly the American Rocket Society, says that this type of experimenter has an accident rate seven times higher than that for people who ride in cars.

Amateur rocketeers usually work under the direction of an experienced person who has been trained in rocketry. Although this can be considered advantageous, the working conditions are not.

Amateurs usually begin by considering various fuels, choosing one, and then studying its composition in greater detail. After they have prepared their fuels, they will load it into their metal containers. When the rocket is complete, it is taken to their isolated launch range which usually consists of a rigidly constructed shelter, or bunker, for their protection and an elaborate launch tower.

Amateur rocketry can be a worthwhile activity, but it does have some obvious disadvantages.

1. You need to find an experienced person who understands rockets and is willing to work with young people. It is difficult to locate this type of person. (Local Chemistry teachers are usually not anywhere near qualified enough to attempt such an activity and they will be the first to admit it).
2. You need expensive equipment (fuels, metals, lathes, loading devices, control devices, launch facilities, etc.).
3. You will be mixing dangerous chemicals, and even professionals can be injured or killed while working under "controlled" conditions with chemical propellants.
4. You will need lots of space.

These disadvantages tend to make amateur rocketry undesirable for most school programs.

Figure 1 - Basement Bomber

Figure 2 - Amateur Rocketry

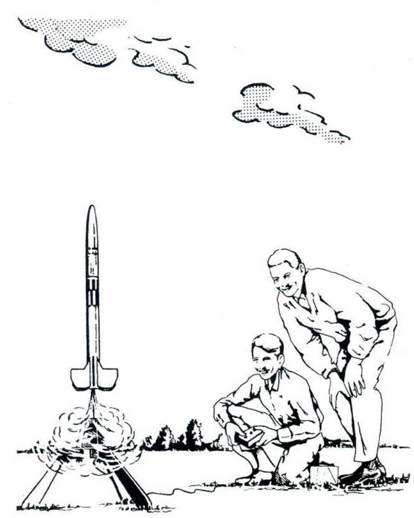


Figure 3 - Model Rocketry

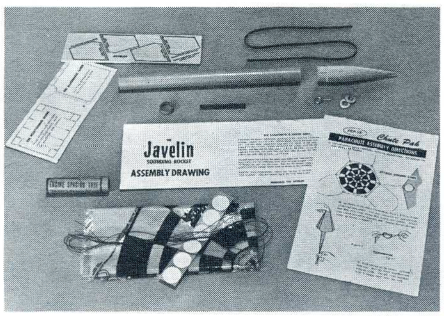
Model rocketeers work with a unique type of rocket that requires a special type of engine. The best way to define or describe Model Rocketry is to refer to the four major guidelines and the Safety Code that are observed by everyone that participates in the activity. These items not only tell us what Model Rocketry is, they also tell us why Model Rocketry is as safe as it is.

MODEL ROCKETRY GUIDELINES

Here are four basic, but very important, concepts to remember.

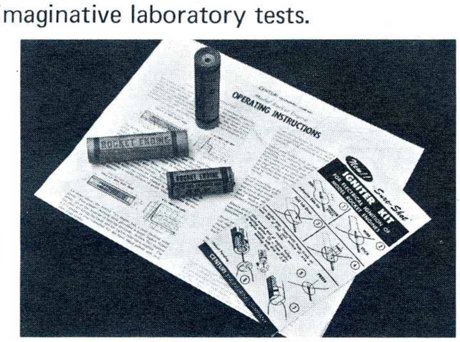
1. The construction components used to build model rockets consist of lightweight materials such as balsa wood, cardboard (laminated paper), and plastic. (Total weight of the rocket is not to exceed 500 grams (1.1 lb. or 17.6 oz.)). No substantial metallic parts are used — this eliminates the chance of a model becoming a dangerous weapon.

   The lightweight materials that are used give maximum strength with minimum weight. Even the professional rocket engineers have to consider these two factors when they design rockets for the Space Program.



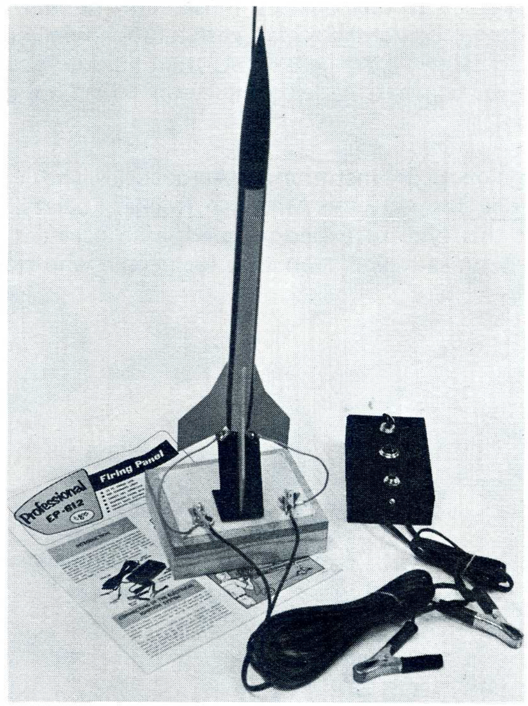
2. The engines used in model rockets are non-metallic self contained, solid propellant engines, (total weight of the propellant is not to exceed 125 grams (4.4 oz.)), that have been commercially prepared by professionals — this eliminates the dangerous mixing of chemicals.

   The reason for purchasing the engines from experienced professionals should be obvious. For no matter what your background, you cannot consistently build engines that are safe and dependable without complicated and expensive equipment. Even in industry, the cost of solid propellants has been high because of the safety requirements necessary to their manufacture. Model rocket engines have been used in a variety of models and in many imaginative laboratory tests.



3. An electrical ignition system must be used to ignite a model rocket engine that is on the launch pad. Under no conditions should any other means of ignition ever be used (never use any kind of fuse). With an electrical system the launch panel and all spectators can be a safe distance away from the launch pad (at least 5 meters (16 feet)) — this prevents anyone from being injured should an engine or model ever malfunction.

   The electrical ignition system that is used is basically the same type of system that is employed by the military and NASA in the launching of some of their solid propellant rockets.



4. A recovery device must be used — this eliminates the hazard of high speed falling objects.

   The recovery devices that can be used vary in design (e.g., parachutes, streamers, the glide concept, the slow tumble concept, the autogyro concept, etc.). The basic idea is to slow down the rocket's return to Earth.

CONCLUSION

These Guidelines tell us why Model Rocketry is the only form of non-professional rocketry in which everyone can safely build, launch, and experiment with rockets.

For a more complete description and a greater understanding of this activity, refer to the Model Rocketry Safety Code on the next page.

Model Rocketeer's SAFETY CODE

1 As a model rocketeer, I will conduct myself and my rocketry activities in a mature manner and with safety foremost at all times. For I realize that the "safety conscious" modelers are responsible for the success of Model Rocketry. I will therefore do my part to uphold the excellent safety record of Model Rocketry.

2 I will not attempt to compound propellants nor mix dangerous chemicals. I will use only factory-made commercial model rocket engines and will never tamper with or attempt to reload them. I will not use model rocket engines for any purpose than recommended by the manufacturer. I will examine each engine before using and will never use any engine showing signs of damage.

3 I will build model rockets only from lightweight and substantially nonmetallic materials. I will never use metallic rocket engines. My rockets will not weigh more than 16 ounces total at lift-off, nor contain more than 4 ounces of propellant as prescribed by Federal Regulations.

4 I will always equip my model rocket with a recovery device to slow its descent after its upward flight and return it safely to Earth. Just prior to launch, I will carefully inspect the recovery device to make sure that it is properly installed.

5 I will store my model rocket engines in a cool, dry place, away from heaters or other heat producing equipment. I will never smoke near rocket engines nor launch my rockets near highly flammable materials. I will use only flameproof wadding in my rockets.

6 My model rockets will be ignited by remotely operated electrical means only, and with the proper igniters as recommended by the manufacturer. I will never use matches or fuse to ignite my rockets, and I will remain at least 15 feet away from any model rocket being launched.

7 I will always launch my rockets from a guide rod or rail type launcher which will keep the rocket in a vertical flight direction until stabilizing velocity is reached. I will never launch at an angle greater than 30° from the vertical nor into trajectories as weapons against targets on the ground. My models will never contain explosive or pyrotechnic warheads.

8 To prevent accidental eye injury from the launch rod, I will avoid leaning directly over the rod or I will position the launcher so the tip end of the launch rod is above eye level.

9 I will launch my rockets from an open field away from houses, building, airports, power lines, or trees. I will select a launch site clear of dense foliage or dried grass. I will never launch in high winds or conditions of low visibility.

10 I will check the stability of my model rocket before its first flight whenever possible; or, when testing a new design having uncertain stability, I will launch it in an isolated area away from persons not directly involved in the launch. I will always be considerate of other persons and property when engaged in rocketry activities.

THE QUALITY LEADER IN HIGH FLYING MODEL ROCKETS
Centuri

2

WHAT IS A MODEL ROCKET?

A model rocket is a real flying model of a military, research, or space booster type rocket — and quite often of original design. A model rocket is made of lightweight material such as balsa wood, paper, and plastic. Powered by commercially loaded miniature solid rocket engines, and ignited electrically, these lightweight models reach altitudes of 100 to 2000 feet. All model rockets contain the following basic components:

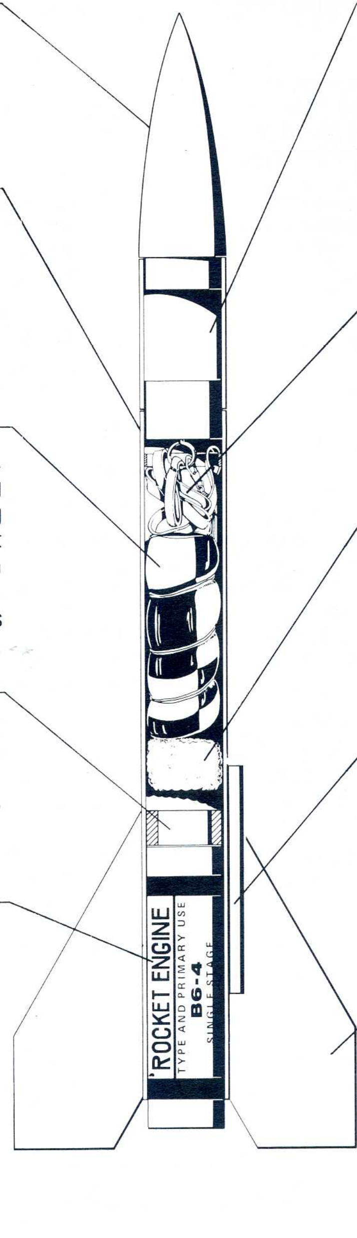
NOSE CONE
At the frontal end, the nose cone serves to guide the airflow smoothly around the rocket. Many different shapes are used and usually made of balsa or plastic.

BODY TUBE
Also called the "airframe", this is the basic component of a model rocket. All other components are either contained inside or attached to the body tube. It is most generally made from a strong thinwall paper tube.

PARACHUTE
Ejected from the rocket at peak altitude, it slows the returning rocket to a safe speed, preventing damage to the rocket when it lands. Plastic, silk, and nylon are common parachute materials. Other types of recovery devices such as streamers are also used.

THRUST RING
Positioned and glued into body tube, the thrust ring prevents the engine from moving forward and also transmits engine "thrust" to the airframe. Usually made from heavy wall paper tubing or balsa.

ROCKET ENGINE
Completely self contained non-metallic power package, the model rocket engine "pushes" the rocket upward when electrically ignited. A "built-in" time delay allows the rocket to coast up to its maximum altitude before an ejection charge pushes the nose cone and parachute out of the body tube.



PAYLOAD SECTION
A compartment within the rocket, usually paper or plastic, used to carry biological specimens (such as insects) or instrumented payloads. On many high altitude or sport flying rockets the payload section is left off and the nose cone is connected directly to the body tube.

SHOCK CORD
Elastic cord connecting nose cone to body tube. Absorbs the "separation shock" when the ejection charge pushes the parachute and nose cone out of the body tube.

WADDING
A flameproof cotton material that protects the parachute from the heat of the ejection charge. It also acts as a piston when pushing out the parachute and is expended with each flight.

LAUNCH LUG
Slender paper or plastic tube fastened to the side of the rocket body to hold the rocket on the launch rod, and guide the rocket along the rod until sufficient air speed is reached for the fins to guide the rocket.

STABILIZER FINS
Usually made from balsa, the fins are attached to the aft end and serve to guide the rocket in a straight flight path after it leaves the launcher.

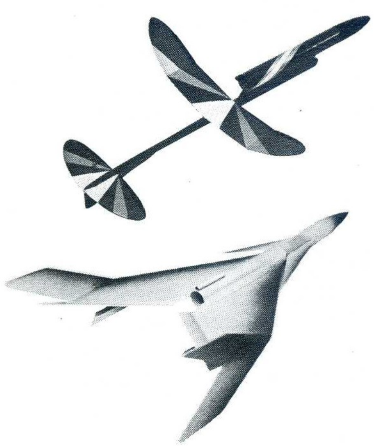
TYPICAL SINGLE STAGE MODEL CUT-AWAY VIEW

MODEL ROCKETS VARY IN SIZE AND SHAPE

So far we have only discussed one model rocket. There are, however, many types with which to experiment. The following schedule of activities outlines a program of study that could serve as a guide for introducing and understanding the many model rocket designs. (Complete instructions are included with all model rocket kits).

SINGLE-STAGE KITS
Basic Principles of Rocketry

Build and launch several single-stage kits which will demonstrate the principles of rocket construction, engine ignition and operation, and various recovery systems.

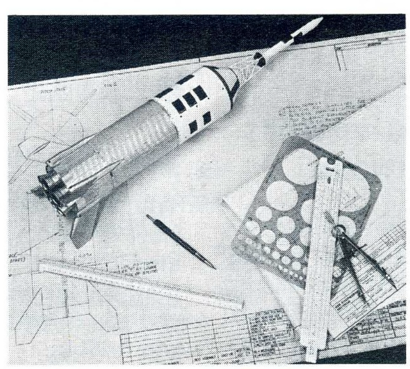


ROCKET GLIDERS
Aerodynamics

Build and launch a boost-glider kit to study aerodynamics and to observe how space vehicles may someday function.

PAYLOAD LAUNCHING
Effects of Acceleration

Launch an egg or a small biological specimen, such as an insect, in a payload carrying model to study effects of acceleration and payload handling.



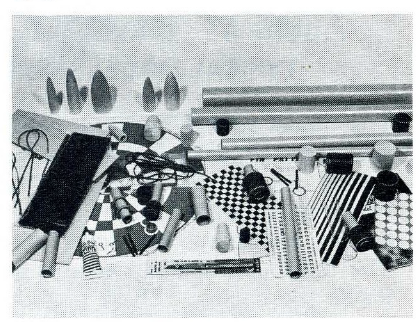
SCALE MODEL ROCKETS
Scale Techniques

Study the material in a scale model kit to learn the basics of sizing and designing a scale model. Then choose a well-known vehicle and send to the manufacturer for construction data and scale your own "bird".

MULTI-STAGE KITS
Stage Coupling & Separation

Construct and launch several multi-stage kits which will demonstrate techniques of stage coupling, booster separation, and upper-stage ignition.

Extremely high altitude flights can be made by staging or coupling engines together. The basic principles of multi-staging are explained and demonstrated in all Centuri multi-stage rocket kits. Before attempting a multi-stage design however, you should become thoroughly familiar with single-stage fundamentals.



CREATIVE DESIGN
Build With Custom Parts

Now, with the understanding and experience you've gained from the steps above, design and build your own creation using the custom parts available in Centuri's Model Rocket Catalog.

3 HOW DOES A MODEL ROCKET WORK?

BASIC OPERATION

The basic operation of a typical model rocket is based upon the design of both the engine and the model and consists of the seven basic steps that are described on this page and diagramed on the next. These steps tell us what is happening with the engine and the model during each phase of a model rocket's flight.

After we explain the basic operation, we will discuss in greater detail the design and performance of both the engine and the model so that you will understand not only what is happening, but why it is happening.

As you study the following material, refer to the diagrams in Figures 5 and 6 and relate the numbers on this page to the flight phases on the next.

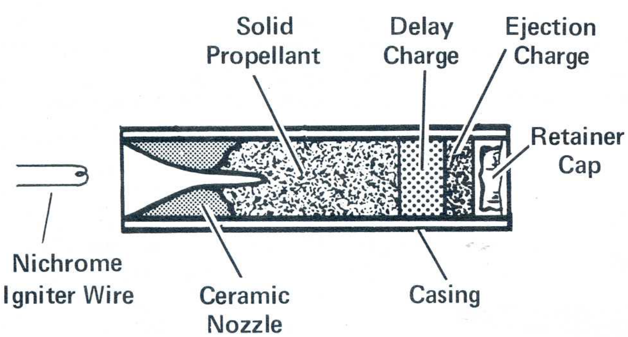


FIGURE 5 CROSS-SECTIONAL VIEW OF TYPICAL MODEL ROCKET ENGINE

The model rocket engine is prepared for ignition by first inserting an igniter wire so that it passes by the nozzle and comes in contact with the propellant. When an electrical current passes through the wire, it will be heated red hot and (1) ignite the propellant. The burning propellant creates tremendous pressures inside the engine. These pressures cause the rocket to move upward and (2) lift-off the pad.

After all the propellant has been expended, we have what is called (3) burn-out. This term implies that the propulsive power of the engine has ended. The model, however, will continue (4) coasting upwards on its flight path, using the momentum that it built up during the thrusting phase.

After burn-out, the engine still has a job to perform. The heat created and remaining from the burning propellant will ignite the delay charge next. The delay charge has a twofold purpose. First, it allows the model to coast to its highest point (5) apogee before the recovery device is deployed. Second, it provides a smoke trail so that you can follow the path of your model. This trail of smoke appears very much like the exhaust from the propellant, except that it is thinner in appearance. Because the delay charge provides a negligible amount of power, it is important to realize that your engine will appear to be providing power longer than it really is. If, however, you carefully watch the flight of a model rocket, you will be able to recognize when the powered phase of the flight ends (burn-out) and the coast phase begins.

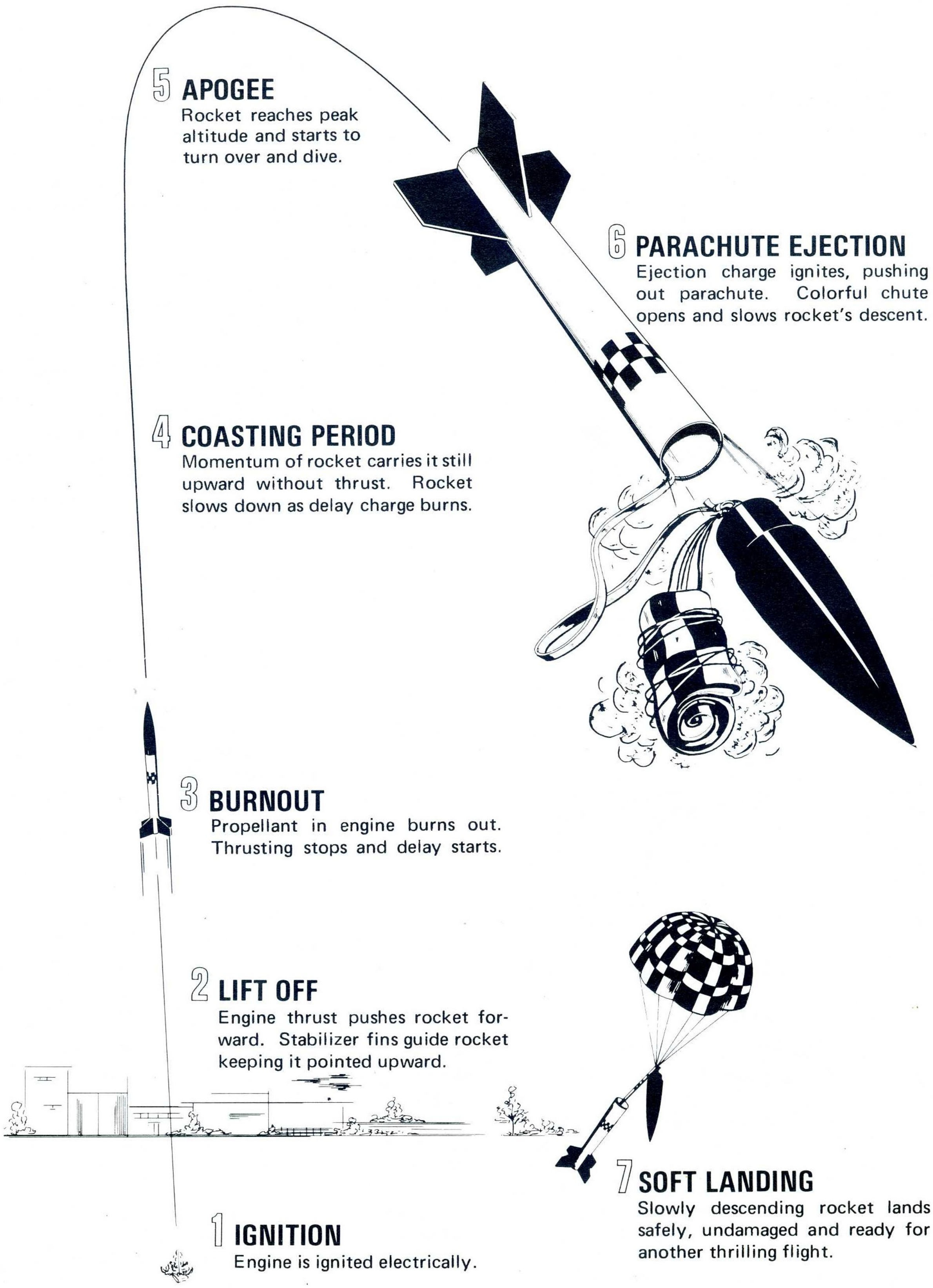
After the delay charge has been expended, the ejection charge will ignite immediately and cause a tremendous expansion of gases. This expansion will create a high pressure inside the engine that will push both toward the front and the rear of the rocket. This expansion could do two things: It could force the engine toward or out the rear of the model. This is desirable in some models and will happen if the engine is not in tight; or it will force everything that is in front of the engine out the front of the model. This force will blow off the nose cone and (6) deploy the recovery device. This is desirable in models with parachutes and streamers and will happen if the engine is in tight. With the recovery device deployed, the model will return slowly to Earth, make a (7) soft landing and be recovered.

VARYING THE PERFORMANCE

You should by now be aware that there are two basic ways in which you can vary the performance of a model rocket. You can choose different engines from the "Engine Selection Chart" in the catalog and/or you can construct models with different sizes, shapes, and finishes.

STUDYING THE PERFORMANCE

So far we have studied how a model is designed, how an engine is designed, and how the model and engine work together to make the model rocket perform as it does. For a more complete understanding of why a model rocket operates as it does, we will now discuss in greater detail the design and performance of both the engine and the model.

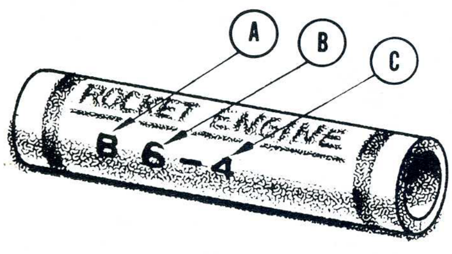


HOW DOES A MODEL ROCKET WORK?

ENGINE DESIGN AND PERFORMANCE

All model rocket engines are stamped with a code which, when understood, provides the rocketeer with useful information concerning the performance of the engines.

THE CODE ❖



1. The first symbol represents the "Total Impulse" range into which the engine belongs. The total Impulse of a rocket engine represents its total power.

CODED TOTAL IMPULSE CHART		
TYPE	TOTAL IMPULSE (NEWTON-SECONDS)	TOTAL IMPULSE (LB–SECONDS)
¼A	0.00 to 0.625	0.00 to 0.14
½A	0.626 to 1.25	0.15 to 0.28
A	1.26 to 2.50	0.29 to 0.56
B	2.51 to 5.00	0.57 to 1.12
C	5.01 to 10.00	1.13 to 2.24

FIGURE 8

❖ Model rocket engines are coded in an International System – The Metric System. They were at one time coded in the English System. (The changeover was made in 1968). Because the code can be easily transferred into the English System, a rocketeer can work with whichever system he prefers. The ISO (International Standards Organization) adopted the SI (Systeme Internationale) in 1960. It is today the standard system around the world for technical work. All nations, except Canada and the United States, already are metric or going metric. With Congress about to order a three-year study concerning the adoption of the Metric System in the U.S., industry and education are beginning to prepare for the inevitable.

From the "Coded Total Impulse Chart", you can determine the total Impulse range for a particular code in either the Metric or the English System. Although the total Impulse of a particular engine could be made by a manufacturer to lie anywhere within a given range, all of the Centuri engines are made so that they have the maximum total Impulse for each range.

For example, the total Impulse of all Centuri ¼A engines is .625 newton-seconds or (.14 pound-seconds), all ½A engines is 1.25 newton-seconds or (.28 pound-seconds), etc.

The units newton-seconds or pound-seconds represent the measurement of a force applied for a period of time. The relationship between the total Impulse (I_t) which is the total power of the engine, the average thrust (f) which is the average force being produced by the engine, and the thrust duration (t) which is the length of time the force is acting can be expressed mathematically by the following formula:

$$I_T = f \times t$$

2. The second symbol represents the engine's "average thrust" rounded off to the nearest newton. (A newton is the metric unit of force). If you wish to change from newtons to pounds, simply divide by 4½. (The figure 4½ is only an approximation, but then so is the coded average thrust). When computing the average thrust from a formula, you might wish to use the more accurate figure of 4.448).

3. The third symbol represents the time for the burning of the delay charge rounded off to the nearest second. A zero "0" delay time means that the engine is a booster.

On some model rocket engines an "S" may appear as a fourth symbol. This means that the engine has a shorter length than the standard engine. (Standard engines are 70 millimeters (2.75 inches) in length, shorter engines are 45mm (1.75 inches)). All engines have an outside diameter of 18mm (.69 inches). The short engines are desirable for some small lightweight models.

For more information on a particular engine, refer to the "Rocket Engine Data Chart" in catalog.

It may appear, at first, that you cannot affect the performance of your rocket because the engines come already prepared. This, however, is not the case.

You might keep in mind that because of the expense that would be involved in building a new engine for every new rocket, professional rocket engineers have to, on some projects, choose engines from those that are already in existence.

With 30 different engines from which to select, the model rocketeer can vary the performance of his rocket in many ways. He can, if he wishes, use experimental methods to discover the best combination of model and engine. With the propulsion information from the section on "Rocketry Fundamentals" and Technical Information Report #100 he can also compute ahead of time, the best engine(s) to use for a particular purpose. Equipped with either experimental or computational methods, the rocketeer will find Model Rocketry as challenging as the rocket engineer finds his work in the Space Program.

We have already discussed the design of the standard model rocket engine (Figure 5) and explained how it affects the performance of the model rocket. For the sake of convenience, we will refer to this type of engine as a "sustainer" to differentiate it from the "booster" engine (Figure 9-A)

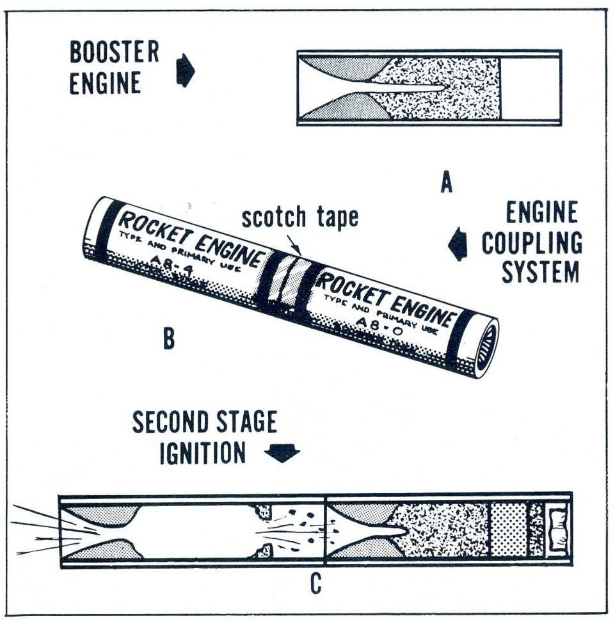


FIGURE 9 STAGING

Although a sustainer engine, in rocketry, is usually thought of as the upper-stage engine in a multistage rocket because it sustains or continues the thrust of the lower stage(s) it can, in Model Rocketry, also apply to a single-stage rocket because the delay charge helps to "sustain" the rocket's flight until it reaches "apogee" (i.e., the delay charge "sustains" the rocket's flight in that it does not stop its upward momentum).

When a booster engine finishes its thrusting, the forward propellant wall burns through and ejects hot particles out the front of the engine. If another engine is attached to a booster, the hot particles will pass through its nozzle and ignite the propellant.

When the forward wall burns through, a high-pressure force is built up in the area between the engines. This pressure could cause the engines to separate before the hot particles have a chance to ignite the top engine. This problem can be easily solved by taping (e.g., cellophane tape) the engines together (Figure 9-B). This is a very reliable method of coupling and it will hold the engines together until the upper engine ignites. The thrust force produced by the upper stage will then cause stage separation. Always double check your coupling system to see if you have the engines joined together in the correct order. For reliability and safety, your model rockets should not have more than three stages.

MULTISTAGE ROCKET

In a multistage rocket (pictured above) sometimes referred to as a multistep rocket , the bottom or lowest stage is called the first stage. The other stages are named accordingly.

If you are working with a multistage rocket, remember to always place a sustainer engine in the uppermost stage.

MODEL DESIGN AND PERFORMANCE

As the model passes through the air, the air acts on the model's external components and attempts to resist its forward motion. This resistance is the force* we call drag. Rocketeers must consider this force when designing high performance models.

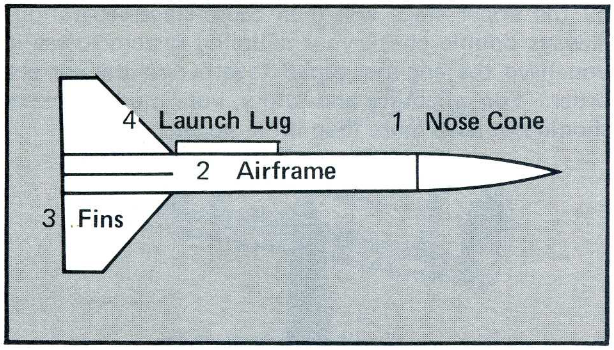


FIGURE 10 EXTERNAL COMPONENTS

1. The Nose Cone. The efficiency of various nose cone designs have been measured in special high performance wind tunnel tests. A variety of shapes are shown in Figure 11. Because model rockets travel at subsonic speeds, the sharp pointing nose is not the best design. The slightly rounded (parabolic) nose cone actually has less drag.

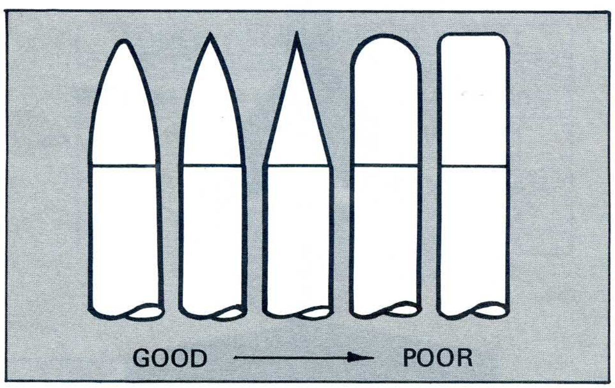


FIGURE 11 NOSE CONES

2. The Airframe. The airframe (or body) of the rocket is usually cylindrical in shape and cannot be altered significantly. The cross-sectional area, the base, and the smoothness of the surface are the most important factors to consider in designing rockets that will have the least amount of drag.

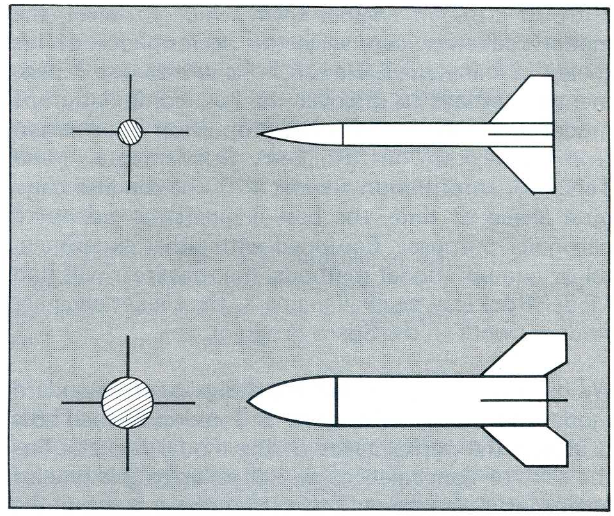


FIGURE 12 THE CROSS-SECTIONAL AREA

The air passing around the base of a rocket creates a low-pressure area behind the base. Because of this the rocket, especially during its coasting period, tends to be forced back into this area. This, of course, reduces the performance of the rocket. To eliminate this source of drag, to a certain degree, you can round out or slope the base, as shown in Figure 13. This design is referred to as a "boat-tail".

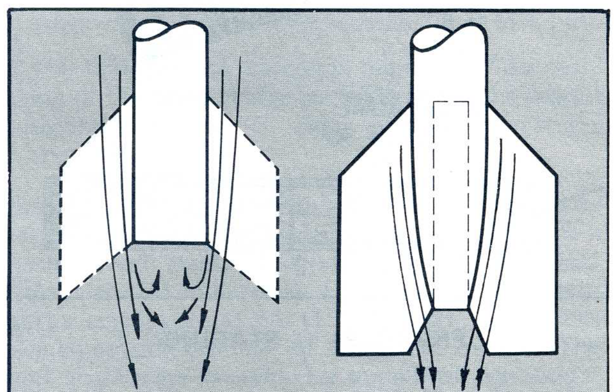


FIGURE 13 THE BASE

The smoothness (i.e., the finish) of a model rocket is very important in reducing drag. You might feel at first that finishing materials, such as fillercoat and paint, will add excessive weight and cut down on the performance of your model. The fact is, however, that if you carefully (and with patience) employ the proper finishing techniques (to the nose cone, airframe, and fins), the improved drag characteristics that will result will improve the performance of your model significantly. You might experimentally compare the performance of two rockets that are identical in every respect except for their finishes.

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* There are four forces that can act on a vehicle in the atmosphere (thrust, drag, lift, and gravity). The effects of these forces need to be considered when determining the performance of your model rocket.

3. The Fins. Fins, and any other attachment to the rocket, will also increase drag. Figure 14 shows some of the fin shapes that can be used on a model rocket. Others can be designed by modifying or combining the shapes shown. Although the fins create some drag, they are needed to make the rocket stable and fly correctly.

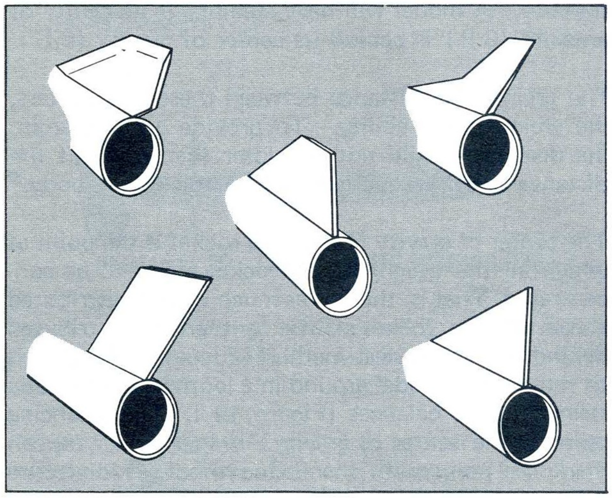


FIGURE 14 THE FINS

Fins, like nose cones, should not have sharp leading edges. This again is due to the subsonic speeds of the model rockets. The nose cone shapes apply equally well to the leading edges of the fins. The fins, however, will actually perform better if the trailing edges are sharp or pointed (refer to Figure 15).

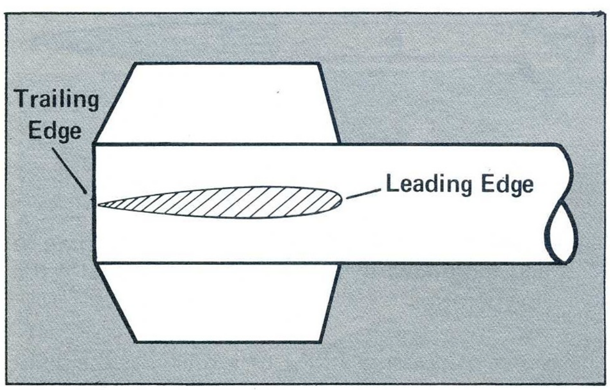


FIGURE 15 CROSS-SECTIONAL VIEW OF FIN

The direction of the grain is also an important factor to consider when attaching the fins to the body. Designing the fins so that the grain runs parallel to the airframe is an undesirable situation because the air pressure forces can easily shear off segments of the fins (Figure 16). Properly designed fins should have the grain "running" parallel to the leading edge. (This method gives the fins their greatest strength).

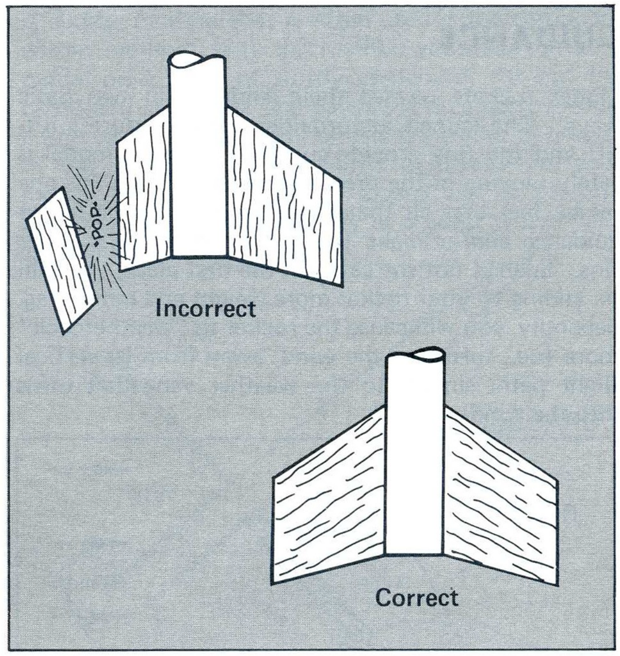


FIGURE 16 THE GRAIN

4. The Launch Lug. Although the launch lug contributes to the drag forces on a model rocket, we must remember that some type of system is needed for initial guidance.

Some rocketeers have eliminated the launch lug by designing alternate launching systems. One of these systems allows the rocket to slide between four guide rails as is shown in Figure 17.

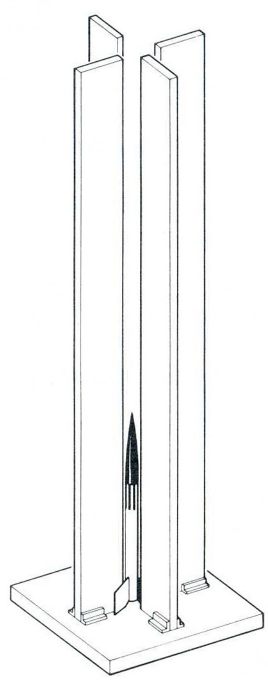


FIGURE 17 GUIDE RAIL LAUNCHER

GUIDANCE

Model rockets receive their guidance in two basic ways. The launch lug provides guidance during lift-off and the fins provide guidance once the model is safely moving in the proper direction. From this one might feel that all that is needed to provide better guidance and/or make the rocket go higher is larger fins. Such is not the case. In the first place, you will be adding to your rocket more weight and more drag. Secondly, you will cause the rocket to "weathercock" more (i.e., turn into the wind, away from its vertical flight path, similar to the weather vane that turns into the wind).

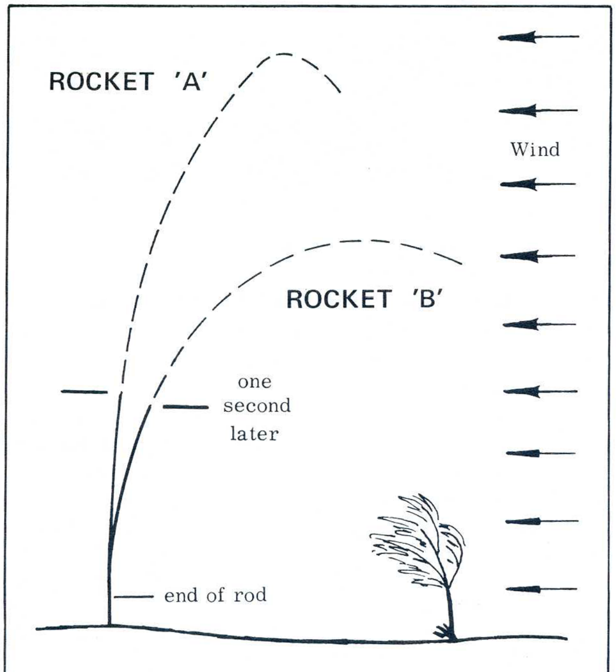


FIGURE 18 WEATHERCOCKING

Rocket "A" is reacting as if little or no wind is blowing against it. Rocket "B" is "weathercocking" because the wind is "pushing" against the greater area at the rear of the rocket.

THE PRINCIPLE OF WEATHERCOCKING

All objects that are free to rotate will rotate about their center of gravity. If there is a greater area (e.g., the fins) on one side of the center of gravity, the moving air will "push" against this area more causing the object (e.g., a rocket) to rotate and point into the wind. The greater the wind or the larger the area, the more the rocket will "weathercock".

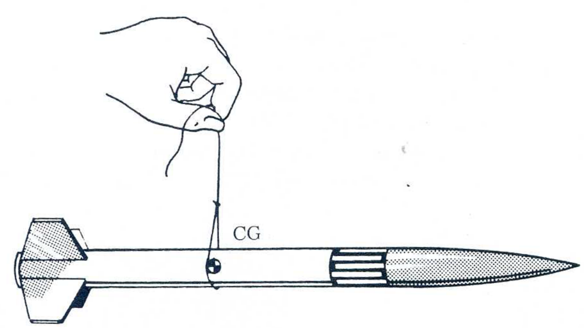
The proper relationship between a rocket's weight and its area is realized when one studies the principle of aerodynamic stability.

STABILITY

Because model rockets spend all of their time in the atmosphere, they are designed so that they will be stabilized by the air while in flight. It is important to remember that everyone, before launching a model rocket, should check their model to see if it has stability. A model will have stability if its center of pressure (C.P.) is behind its center of gravity (C.G.).

The greater the distance between these two centers, the greater the stability. To provide a safe margin, the distance should not be closer than one-half the distance equal to the largest diameter of the body.❖

The center of gravity (C.G.) of a rocket is the point at which all the weight of the rocket seems to be concentrated. That is, there is as much weight distributed ahead of the rocket's C.G. as there is distributed behind it. The easiest method of locating the C.G. is to move your model around in a loop on the end of a string until it balances (Figure 19). The balancing point is the center of gravity. If you wish, you can mark the point with the C.G. symbol ⊕ for future reference.



Balanced rocket

FIGURE 19 CENTER OF GRAVITY

If you wish to change a rocket's C.G., all you have to do is add more area to the model on one side of the balancing point.

The center of pressure (C.P.) of a rocket is the point at which all the air pressure forces on the rocket seem to be concentrated. That is, there is as much air pressure force distributed ahead of the center of pressure (C.P.) as there is distributed behind it. Just as the C.G. was the balancing point for all of the gravitational forces acting on a model, the C.P. can be thought of as the balancing point for the air pressure forces acting on a rocket.

❖ This rule applies to the CG-CP methods described in this booklet.

Look at the model diagram in Figure 20. Assume that there is a wind blowing onto the paper (e.g., imagine you are blowing on the diagram). Would it be possible to balance the model sideways against the wind? Yes! Simply locate the point that has equal areas on both sides. (You could do this experimentally by moving the model between two pins until it balances sideways). This point is referred to as a center of pressure (C.P.).

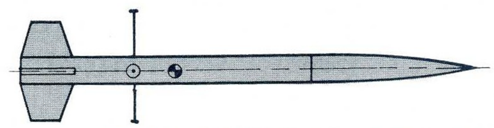


FIGURE 20 CENTER OF PRESSURE

If you wish to change a rocket's C.P., all you have to do is add more area to the model on one side of the balancing point.

You can determine a center of pressure (C.P.) for a model by laying it on some graph paper (Figure 21) and tracing around the model with a pen or pencil that is held perpendicular to the paper. When you have finished the trace, lift the model off the paper and locate the point that has an equal amount of area on both sides (e.g., pick a point that looks about right – then count the spaces in front of and in back of that point. If the number of spaces are uneven, you can take one half the difference and add it to the smallest area. This is a way of locating a point that can be called a center of pressure

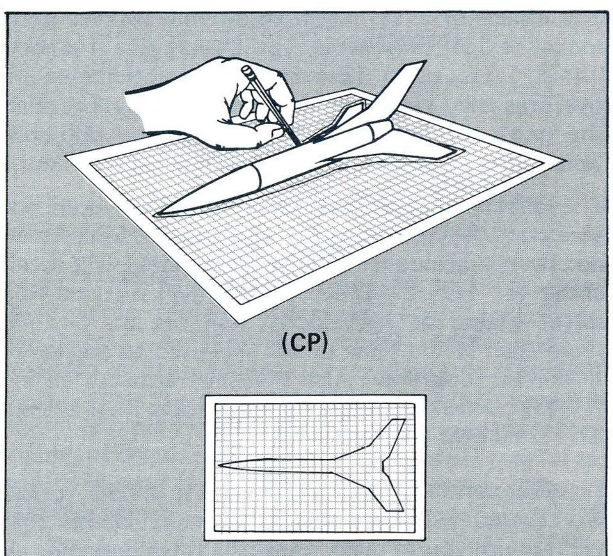


FIGURE 21
FINDING A CENTER OF PRESSURE

A similar method that is often used is the cardboard cutout method. With this method you trace out your model on a piece of sturdy cardboard, cut out the cardboard silhouette and balance it on a narrow edge. Although this balancing point is the center of gravity of the cardboard, it is a center of pressure of your model. (Because the cardboard has a uniform thickness, it will balance only at a point where there are equal areas on both sides).

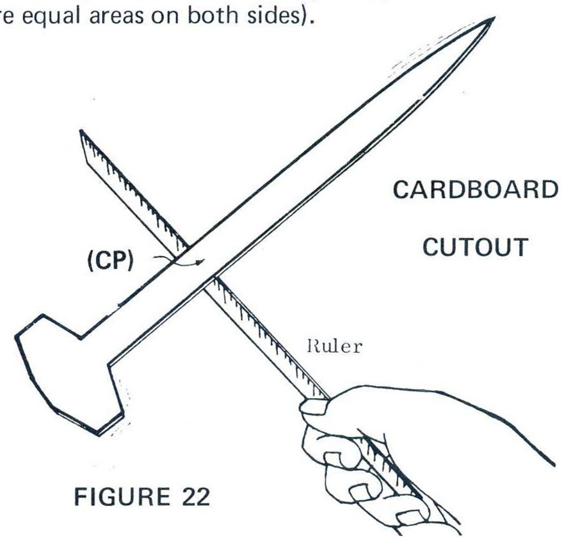


FIGURE 22

Knowing how to find the center of gravity and the center of pressure, and understanding the rule concerning these centers will enable you to check your models to see if they are stable or not.

A MISCONCEPTION

A common misconception among many beginning rocketeers is that forward-mounted fins on a model rocket will tend to increase the stability of a model. This may be so for certain military missiles like the Hercules, Falcon, and Talos, but these rockets contain very sophisticated electronic guidance systems which automatically control the fin surfaces and vehicle stability.

On model rockets, additional fin area near the nose could move the CP of a model ahead of the CG causing instability. It is therefore suggested that aerodynamic fin surfaces not be mounted near the nose of a model rocket.

However, if there is adequate fin surface at the base of the rocket, very small fins (for scaling or decorative purposes) can be added near the front of the rocket.

FIGURE 23 FORWARD FINS

THE SWING TEST

The best and easiest way to check to see whether a rocket is stable or not is to tie a string around it at its C.G. and then swing the fully prepared rocket (parachute, engine, etc.) around you. (With this method you need to know the C.G., but not the C.P. of the model). Start the rocket pointing in the direction of motion. If the rocket remains pointing in the direction you are swinging, it is stable. If it will not stay pointing in the direction of motion, then it probably does not have adequate stability. You might experiment by starting the rocket off at different angles remembering that after it is moving it should always turn and point into the direction of motion.

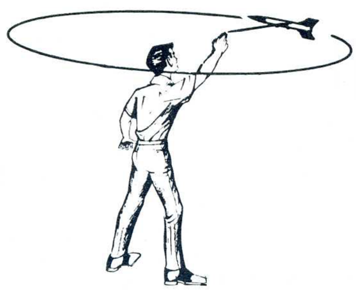


FIGURE 24 SWING TEST

To increase the stability of a rocket you should either move the C.G. forward or the C.P. backwards or both. You can move the C.G. forward by adding weight to the nose or the C.P. backwards by adding area to the base.

You might have your students mark their rockets with C.G. and C.P. symbols. Then prior to launch they can demonstrate their rocket's stability to you by first showing you their CG-CP relationship and then Swing Test their rocket.

After you understand how to make a model rocket stable, you must also understand that it will not become stabilized until after it is moving and the air has a chance to react on it. This is the reason for the launch lug. You should also understand that if you increase the stability you will also increase the amount the rocket will weathercock. Trade-offs are necessary.

For a complete discussion of rocket stability and the CG-CP relationship, refer to: TIR-30 "Stability of a Model Rocket in Flight", and TIR-33 "Calculating the Center of Pressure of a Model Rocket".

TRADE-OFFS

As you continue to study about rockets and rocketry you will learn about the many conditions that can affect performance and you will become aware of the factors you need to consider when building and launching model rockets.

The one consideration that soon becomes apparent is that with numerous factors affecting performance, you will have to make some "trade-offs".

This term implies that you will have to make some compromises when designing model rockets. The reason for this is that if you increase the effectiveness of one of the design factors too much, you may be decreasing the effectiveness of some of the others.

For instance, if you decrease the weight of a model in an attempt to make it go higher, it might not be strong enough to withstand the forces of lift-off. On the other hand, if you choose construction materials with the idea of making a rocket that has excessive strength it might also have a great deal of excessive weight. When you consider the "best" relationship between strength and lightness (i.e., light enough – yet strong enough), you will be making a trade-off.

For a greater comprehension of this concept we have described below three more of the many trade-off situations that can affect your rocket performance.

The effect of Stability: If your rocket does not have enough stability, it will not have enough guidance. If it has too much stability, it will weathercock excessively. Solution: Find the optimum CG-CP relationship. (TIR-33 will help you out).

The effects of Drag: If, in an attempt to keep your rocket as light as possible, you do not give it a good "finish" (i.e., using balsa filler and paint) the excessive drag may cut down the performance more than the extra weight. Solution: Find the optimum weight-drag relationship. (TIR-100 will help you out).

The effects of Acceleration: If a rocket does not accelerate fast enough, the air pressure forces may not have a chance to stabilize the model. If it accelerates too fast, the drag forces, which increase as a direct square of its velocity, will cut the altitude more than if the same power was used to accelerate it slower. Solution: Use the most efficient engine for the particular design. (The Rocket Engine Data Chart will help you out).

As you continue to study how the model rocket works, you will learn about the many factors that will require you to make trade-offs when designing an optimum performing rocket. These trade-offs help to make Model Rocketry a meaningful, educational activity, as well as a challenging science.

4 FROM LAUNCH TO RECOVERY

LAUNCH SYSTEM

During an actual launching, the individual in control of the launch panel should never stand closer than 5 meters (16 feet) from the rocket, while all other assistants and spectators should stand back at least 25 feet. Actually, a better view of the launch is possible when standing back 50 to 100 feet.

Your rocket should be launched from some type of launcher which will keep the rocket in a vertical flight direction until sufficient stabilizing velocity is reached. Never launch a rocket without a launcher.

Launch your rocket from an unpopulated area, away from houses, airports, or airlanes, highways, and trees. Select a cleared launching site — away from dried grass or other dense foliage. Model rockets generally require a launch and recovery area equal to the expected altitude to be reached by the rocket. In other words, a rocket expected to reach 1000 feet altitude should be launched from the center of an open field measuring about 1000 feet by 1000 feet.

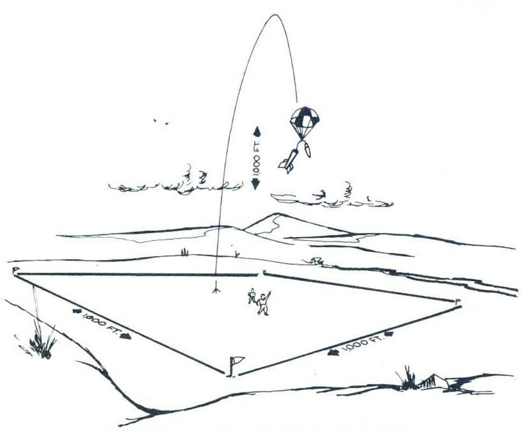


FIGURE 30 LAUNCH SITE

Avoid launching in windy or overcast weather, as recovery under these conditions will be difficult, if not impossible. A lightweight model rocket which is launched in strong winds will weathercock and travel directly into the wind. Remember that a slight wind on the ground usually indicates much faster winds at higher altitudes. Such a wind will cause your chute to drift and land your rocket a considerable distance from the launcher.

Always give a short countdown before launching. This is to alert spectators and draw everyone's attention to the rocket about to be launched.

ENGINE IGNITION

Model rocket engines should be ignited by electrical means only. Never attempt to ignite an engine with a match or fuse and do not stand near a rocket engine while it is firing.

Heat Element Method

The most popular method of engine ignition is the Heat Element Method. Basically, this method uses a nichrome loop which is fastened into the rocket nozzle throat and contacts the propellant. When electrical current from a 6-12 volt battery passes through the loop, it causes the wire to glow red hot and ignites the propellant. With this method, the nichrome loop is expended each time.

The loop is formed and attached to the engine in the following manner: Cut a 2" length of #32 nichrome wire (the type supplied with the engines) and form a double loop in the center by wrapping the wire around a pencil point or ball point pen. A straightened-out paper clip also works very well for loop forming.

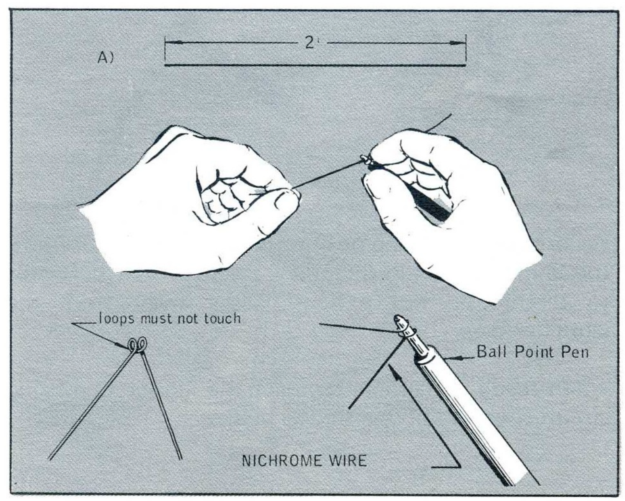


FIGURE 31 PREPARING THE IGNITER

Insert the igniter wire, loop-end first, into the nozzle throat, as far as possible, leaving the wire legs extending out of the nozzle. To hold the loop in place, form a small wad of tissue or kleenex, about the size of a "BB", and press into the nozzle between the leg wires.

With the end of the straightened-out paper clip or a pencil point, push the wad firmly against the loop.

Important!! The wire loop must be pressed firmly against the propellant by the wad.

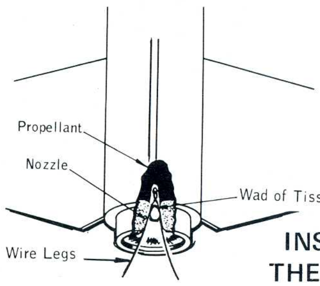
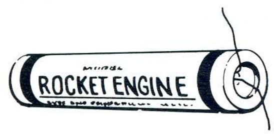


FIGURE 32 INSTALLING THE IGNITER

PLEASE NOTE!! It is normally easier to install the igniter before mounting the engine in the rocket.



Model rockets can be launched from a rod-type launcher, such as those shown in Centuri's catalog. The launcher consists of a straight steel rod 1/8" dia. x 36" long mounted firmly in a base support made of wood or metal.

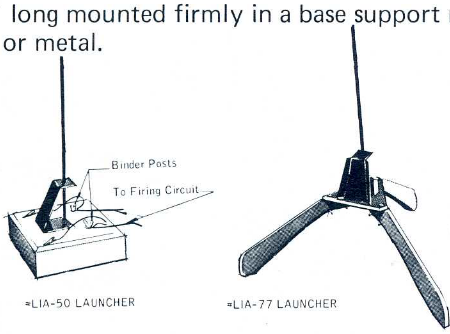


FIGURE 33 LAUNCHERS

To prevent scorching or burning of the stabilized fins, the launcher should include a steel exhaust deflector to direct the hot exhaust gases away from the launcher base.

When ready to launch, connect the igniter to a firing circuit such as the one shown below:

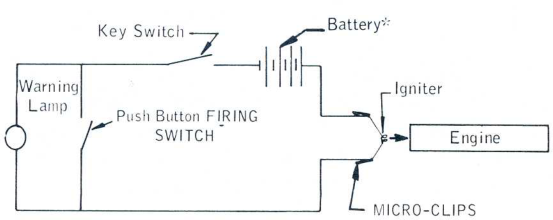
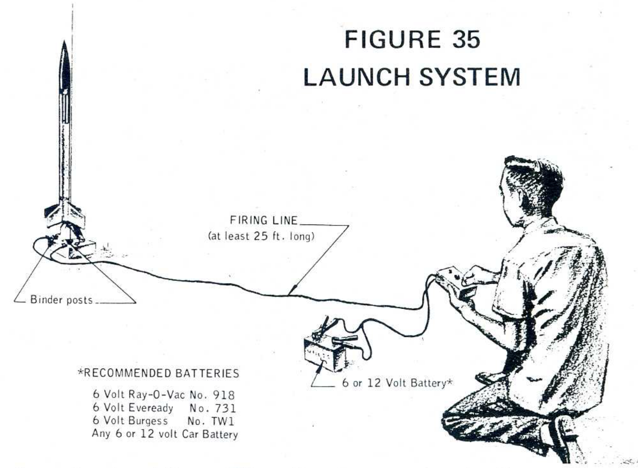


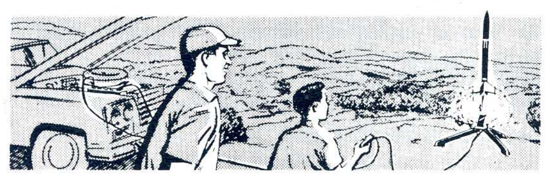
FIGURE 34 TYPICAL FIRING CIRCUIT

FIGURE 35
LAUNCH SYSTEM



Attach the Micro-Clips firmly to the igniter wires, making sure that the igniter wires do not cross, and that the clips do not touch. Also, make sure that both clips are not touching the metal deflector on your launcher.

When using a car battery or ignition power, it is not necessary to remove it from the car, as shown in the diagram below.



LAUNCHING PROCEDURES

The following launching procedures are recommended for use with the ignition circuit above:

1. Disconnect battery from ignition circuit, turn all switches to "OFF" position.

2. Attach micro-clips firmly to nichrome wires at rocket.

3. Return to Firing Position, connect battery into ignition circuit.

4. Safety check the area for personnel on the ground and aircraft above. "HOLD" on launching until aircraft have passed and ground area is "CLEAR".

5. Close first safety switch – check warning light to make sure panel is armed.

6. Begin "COUNTDOWN" 10–9–8–7–6–5–4–3–2–1–0 "FIRE". Press firing button firmly and hold until engine ignites.

7. Turn off all switches – Observe "LIFT-OFF" – Watch for actuation of the recovery system.

RECOVERY SYSTEM

In Model Rocketry all recovery systems are actuated in some way or another by the ejection charge❖ of the model rocket engine.

In the case of a parachute, when the ejection charge activates, the wadding, parachute and nose cone will be pushed out of the body tube, and the parachute will deploy.

PREPARING AND INSTALLING THE PARACHUTE

Although there are many ways to fold a model rocket parachute, the following method is one of the most popular and most successful.

Hold canopy at its center and flatten out the pleats. Fold canopy and shroud lines as shown.

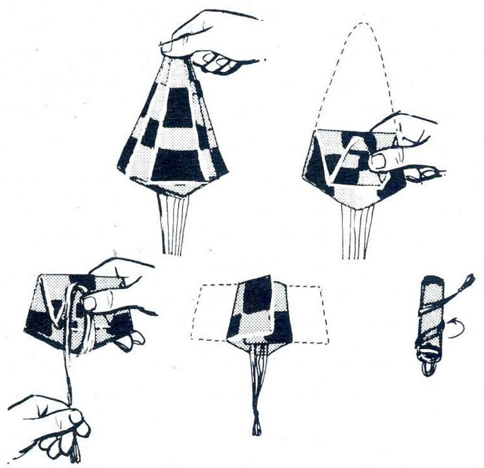


FIGURE 37 PREPARING THE CHUTE

The parachute or streamer should be folded and packed just prior to launching.

When using a parachute or streamer recovery system in your rocket, it is necessary to protect them from the hot gases of the ejection charge. This is done by placing a wad of flameproof cotton, tissue, or wadding between the engine and the chute.

Insert a piece of wadding, just large enough to seal off the engine section from the chute section, into the body tube first. Next, insert the shock cord, followed by the parachute and nose cone.

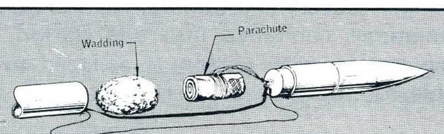


FIGURE 38 INSTALLING THE CHUTE

There are a variety of recovery systems from which to choose. The following examples are typical of some of the more popular designs.

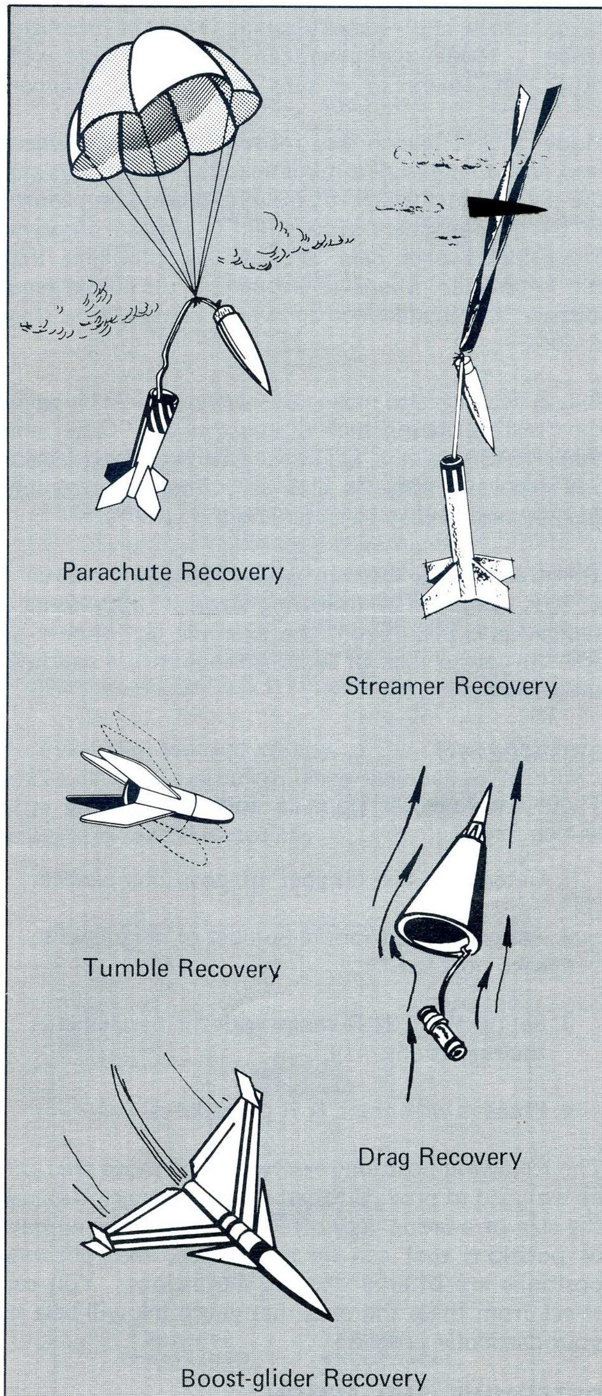


FIGURE 39 RECOVERY SYSTEMS

❖ The ejection charge, in addition to actuating a recovery device, can also be used to activate mechanisms and scientific devices carried within or attached to the model rocket.

LAUNCH AND RECOVERY RANGE

Whenever several people are launching model rockets in the same location, it is to their advantage to organize a launch and recovery range. With an organized range, a model rocketeer can fly his rockets with other rocketeers in a safe and orderly manner.

Model rocket launch and recovery ranges are organized and operated like miniature Cape Kennedys and the participants follow many of the same procedures as the professionals in our nation's space program. These procedures help alleviate the problems that can be created whenever people set up at the same location and then launch anywhere and any time they choose.

A L & R range also makes the rocketeer feel closer to the "real" situation such as exists at the "Cape" and other NASA launch facilities. An organized launch and recovery range is also very impressive to any spectators that may be observing the activity.

There are many ways in which one could set up a L & R range. The following situation represents a typical example. From the example you should be able to get an idea of what a range is like and how they operate.

ORGANIZING

There are four (4) steps to follow in setting up a launch range.

1. Determine the number of positions needed.

2. Assign an appropriate number of personnel to each position.

3. Set-up the L & R range with the personnel at their positions.

4. Proceed with the L & R procedures.

The following positions are typical of those that can be assigned to provide for an effective range. Because the size of a group very often determines the number of positions that can be established, the following positions are offered only as suggestions. You can select from these the ones that you think will best fit your particular program.

DETERMINE AND ASSIGN

Typical positions are listed and described below. The most important of these positions is the Range Safety Officer.

(S.O.) The Safety Officer — is usually the adult who is in charge of the program. He is responsible for the safe operation and total organization of the entire range. He is in command and has the final word on all situations. All of the other positions must answer to him.

In addition to checking all of the other positions, he usually checks models prior to their flight and carries a safety key to the launch panel so that not even the Launch Officer can launch without his permission. In some programs, a student is assigned to this position with an adult watching over his actions.

(L.O.) The Launch Officer — is in charge of the (launch) panel. He is the one that usually pushes the launch button after all systems have been checked and permission is received from the S.O. At some ranges the student who owns the rocket to be launched is allowed to push the launch button. No matter which method is used, the L.O. is the one responsible for setting up and operating the panel.

(T.O.) The Tracking Officer — is the person in charge of the total tracking system. Most ranges make use of two (2) tracking stations. The T.O. is in charge of setting up and making sure that all the personnel are at each tracking station.

A tracking station usually consists of an instrument for measuring angles and a group of personnel that could consist of several people; one to operate the tracking device, one to follow the rocket from lift-off to recovery, one to record the data, one to communicate with range control, etc.

(R.O.) The Recovery Officer — is the person in charge of all the recovery operations. A range can have several recovery crews (e.g., North, South, East and West crews or any other convenient arrangement). The R.O. is in charge of setting up and making sure that all of his personnel are at their stations. Each recovery station could make use of several people; one in command and others as runners to recover the rockets and return them to Range Control.

(C.O.) The Communications Officer — is in charge of all the communications equipment. The number of pieces of equipment (walkie-talkies and telephones) will determine how many communication stations can be set up. The C.O. usually operates the communication equipment at Range Control. The C.O. is in charge of setting up and making sure that all of his personnel are at their stations. If no equipment is available, "runners" and/or flags can be used for communication purposes.

"Tracking, Recovery and Communication Stations" — are sometimes combined into one station called a tracking station with personnel assigned to and responsible for the individual sections. The Tracking Station Officer (T.S.O.) is usually the title of the person in charge of a station that incorporates tracking, recovery and communication equipment.

(L.P.O.) The Launch Pad Officer – is in charge of the launch panel and checks to see that all rockets are mounted correctly. He is available for assisting others in mounting their rockets properly. When all of the rockets are ready, he takes his place at the Range Control table.

(D.O.) The Data Officer – is in charge of all the information (data) concerning the rockets to be flown. His responsibilities include:

1. Pre-checking the models under the direction of the S.O. for proper mounting of the engine, wadding, and recovery device. He may also check the stability of model rockets of questionable design.
2. Recording all pre-flight information on a special sheet.
3. Announces the model to be flown, including type, color, engine, recovery device and owner's name.
4. Records all tracking information on the sheet. A Data Reduction crew can be assigned to these jobs under the direction of the D.O.

LAUNCH AND RECOVERY PROCEDURES

When the Safety Officer thinks that everything is ready, he will initiate the L & R procedures. The procedures could be similar to the following example. The following statements represent typical responses from the various personnel.

The Safety Officer will check with each of the following to see if they are ready. He may ask each in turn: "Is Your System "GO"?"

D.O. – "Data is GO". This means that the rockets on the launch pads have been checked and all of their pre-flight information is recorded. The Data Reduction crew is now ready for the tracking information to complete the data on the rockets.

L.P.O. – "Launch Pad is GO". This means that all rockets on the launch pad are mounted correctly and are ready for ignition.

C.O. – "Communications is GO". This means that the communications equipment and personnel are ready for the launch.

T.O. – "Tracking is GO". This means that the tracking equipment and personnel are ready for the launch.

R.O. – "Recovery is GO". This means that the recovery teams are ready for the launch.

L.O. – "Launch Pad is GO". This means that the launch pad is ready for launching the rocket. (All electrical connections are ready).

S.O. – (Checks surrounding area). "Range is GO". (He inserts the safety key in the panel, if safety key is used, and gives permission to Launch Officer).

D.O. – "The rocket to be launched (e.g., is on pad #1. It is a red and white single-stage model using an "A" type engine and a parachute for recovery. It was built by John Doe). "All systems are "GO", launch at T minus 5–4–3–2–1–IGNITION.

L.O. – Pushes launch button.

After launching the rocket, the launch panel should be made safe (disconnected) so that no accidental ignitions can take place. The tracking crew should obtain the angles necessary for altitude computation. The recovery crew closest to the landing (touch-down) area should recover the model and return it to the D.O. at Range Control. When the model has been returned to Range Control (or is in the hands of the recovery team), the L & R procedures can be repeated.

If during the countdown any of the range crew personnel develop a problem, they may call a "HOLD". After the problem has been corrected, the L & R procedures can be re-cycled.

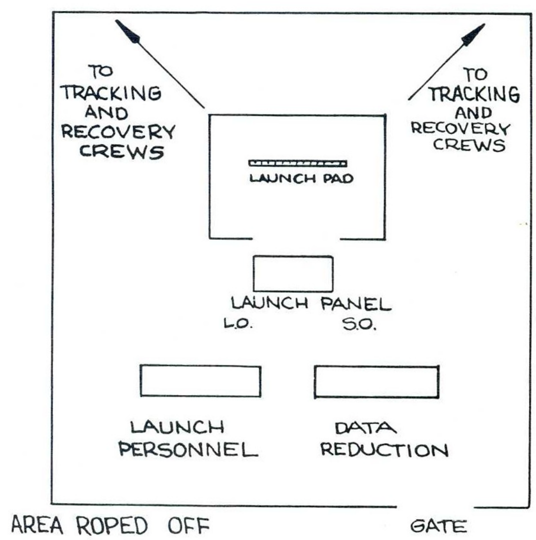


FIGURE 40

IDEALIZED LAUNCH & RECOVERY RANGE

NOTES

5 ALTITUDE TRACKING

One of the first questions that is asked by nearly everyone that participates in Model Rocketry is: Can you determine how high your rockets go? The answer is yes!

Although you will be without a fancy radar scope and you won't have any of NASA's elaborate tracking equipment, you can set up a very good optical✤ tracking system of your own at little or no expense.

THE TRACKING STATION

A tracking station usually consists of an instrument for measuring angles and a few rocketeers. The rocketeers operate the instrument, record the data, handle the communications, etc.

Instruments for measuring angles come in all shapes and sizes – they can cost anywhere from a few cents to many thousands of dollars – you can buy them or make your own.

Two of the popular designs used by model rocketeers are shown in Figures 41 and 42.

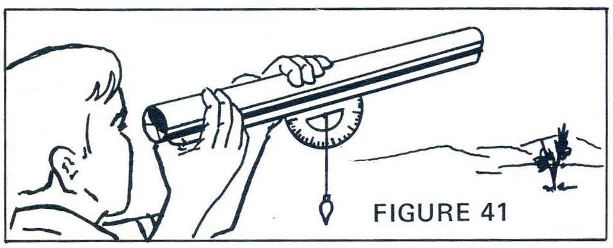


FIGURE 41

A simple device that measures angle of elevation only.

These instruments will help you to obtain the altitude achieved by your rocket and allow you to compare the performance of various designs.

Although there are many ways in which these tracking devices can be used, we will discuss three of the more commonly used methods to give you some idea as to how you can use altitude tracking in your Model Rocketry Program.

The methods are arranged in order of difficulty with the easiest one first and the most reliable one last. All of the methods are related and you should study them in the order they are presented making sure you understand each method before going onto the next.

✤ Optical tracking simply means use your eyes to follow the flight of your rocket.

FIGURE 42

A theodolite or (altiazimuth scope) that can measure angles of elevation and azimuth.✤✤

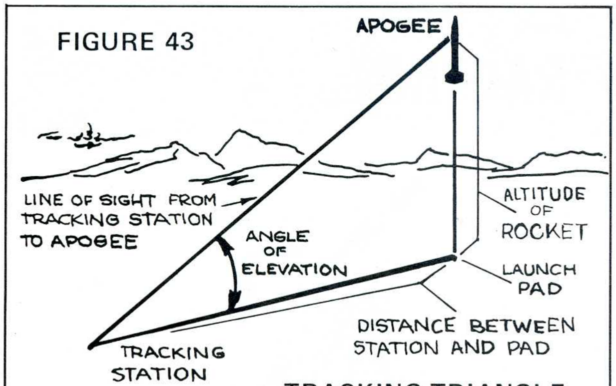
METHOD #1 SINGLE STATION ELEVATION ONLY

With your angle measuring device set up at a known distance from the launch pad you will be able to determine the altitude of your rocket using either of two very simple techniques.

Before we discuss these two techniques you should become familiar with the geometry of tracking (Figure 43).

✤✤You are probably familiar with the fact that an angle of elevation is an angle measured vertically. Angles of azimuth are measured horizontally (e.g., if you are facing North and you turn and face the East, you will have turned through a 90° angle of azimuth. An instrument that can measure both angles of elevation and angles of azimuth is called a theodolite.

FIGURE 43



TRACKING TRIANGLE

To determine the altitude, you must know:

1. The distance from the station to the launch pad, which can be measured in many ways, and

2. The angle of elevation, which is measured with your tracking device.

TECHNIQUE #1
(Scaling)

This technique involves your students in the making of a scale "model" of the tracking triangle on a piece of paper.

Let's assume that we have measured the distance from the pad to the station and found it to be 1,000 feet. Assume also that the rocket was tracked to its highest point (apogee) and that the angle of elevation was 30^{o}.

The altitude can be computed in the following manner:

1. Mark off the distance from the station to the pad to a certain scale (e.g., 1 inch equals 100 feet). This line will be referred to as the base line (Figure 44).

2. Construct a line perpendicular (at right angles) to the base line at the point marked pad (Figure 45).

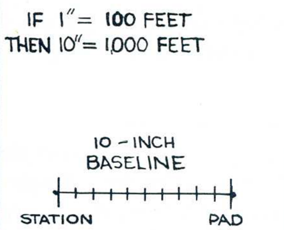


FIGURE 44

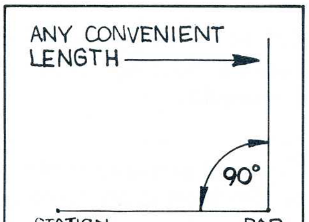


FIGURE 45

3. Construct the angle of elevation to the base line at the point marked station (Figure 46).

4. Draw the line of sight from the station by extending the one side of the angle of elevation (Figure 47).

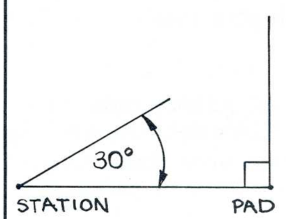


FIGURE 46

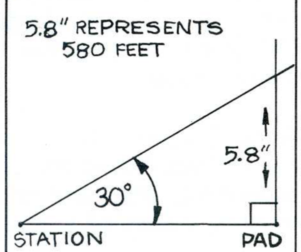


FIGURE 47

This completes the construction.

5. To obtain the altitude, simply measure the length of the line from the pad to the rocket's apogee and scale it to the "real" value. For example, in our problem this line would equal 5.8 inches. From our scale of 1 inch to 100 feet we can compute our altitude — 580 feet.

The accuracy of this technique can be improved by using extra care with your construction and measurements and by using a more accurate scale.

TECHNIQUE #2
(Trigonometry)

Although the study of Trigonometry can become very complex, the beginning concepts which we will employ can be understood by students even at the elementary level.

For our brief study we will say that Trigonometry is an area of mathematics that deals with the relationship between the sides and angles of a triangle. Because we are dealing with a triangle (the tracking triangle) we can make use of this type of mathematics.

Before we explain how we can use Trigonometry to determine the altitude of a model rocket, we will present some of its fundamental concepts. Trigonometry tells us that if we know any three parts of a triangle (at least one of the parts being a side) we can find any of the other parts. The three angles and the three sides make up the six parts of a triangle. A common method of labeling a triangle is shown in Figure 48.

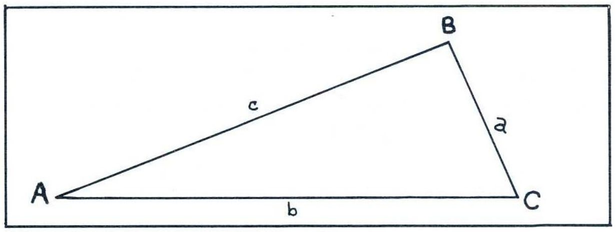


FIGURE 48

Capital letters are used to represent angles and corresponding small letters are used to represent the sides opposite the angles (i.e., the side opposite angle A is side a, the side opposite angle B is side b, etc.).

We will begin our explanation by describing two basic relationships as they exist in a right triangle — the basic triangle of Trigonometry.

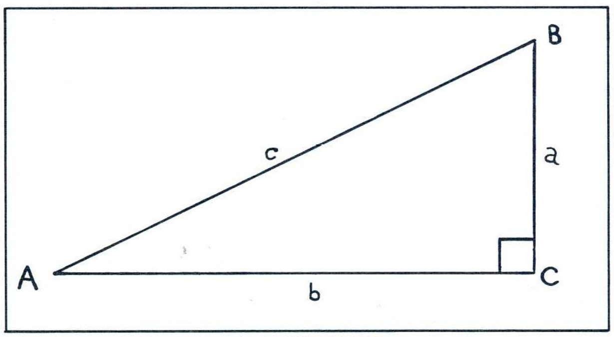


FIGURE 49

Terminology: Side a is said to be opposite angle A, side b is adjacent to angle A and side c. (The side opposite the right angle is called the hypotenuse).

First Relationship

If we divide the length of side a by the length of side b, we will obtain a quotient that is related to angle A (i.e., if angle A increases — the quotient increases, and if angle A decreases — the quotient decreases).

This quotient is called the tangent* of angle A. This relationship is expressed as follows: The tangent of angle A is equal to the quotient of side (a) divided by side (b). The mathematical expression is:

$$\tan A = \frac{a}{b}$$

---

*The tangent of an acute angle of a right triangle is equal to the opposite side divided by the adjacent side. (Although tan is used as an abbreviation, it is still read as tangent).

Second Relationship

The sine* of angle A is equal to the quotient of side (a) divided by side c. The mathematical expression is:

$$\sin A = \frac{a}{c}$$

Trigonometric tables contain all of the quotients for the various angles.**

TRIGONOMETRY TABLES

Angle in Degrees	Sine	Tangent	Angle in Degrees	Sine	Tangent	Angle in Degrees	Sine	Tangent
0...	0.000	0.000	31...	0.515	0.601	61...	0.875	1.804
1...	0.017	0.018	32...	0.530	0.625	62...	0.883	1.881
2...	0.035	0.035	33...	0.545	0.649	63...	0.891	1.963
3...	0.052	0.052	34...	0.559	0.675	64...	0.899	2.050
4...	0.070	0.070	35...	0.574	0.700	65...	0.906	2.145
5...	0.087	0.088						
6...	0.105	0.105	36...	0.588	0.727	66...	0.914	2.246
7...	0.122	0.123	37...	0.602	0.754	67...	0.921	2.356
8...	0.139	0.141	38...	0.616	0.781	68...	0.927	2.475
9...	0.156	0.158	39...	0.629	0.810	69...	0.934	2.605
10...	0.174	0.176	40...	0.643	0.839	70...	0.940	2.747
11...	0.191	0.194	41...	0.656	0.869	71...	0.946	2.904
12...	0.208	0.213	42...	0.669	0.900	72...	0.951	3.078
13...	0.225	0.231	43...	0.682	0.933	73...	0.956	3.271
14...	0.242	0.249	44...	0.695	0.966	74...	0.961	3.487
15...	0.259	0.268	45...	0.707	1.000	75...	0.966	3.732
16...	0.276	0.287	46...	0.719	1.036	76...	0.970	4.011
17...	0.292	0.306	47...	0.731	1.072	77...	0.974	4.331
18...	0.309	0.325	48...	0.743	1.111	78...	0.978	4.705
19...	0.326	0.344	49...	0.755	1.150	79...	0.982	5.145
20...	0.342	0.364	50...	0.766	1.192	80...	0.985	5.671
21...	0.358	0.384	51...	0.777	1.235	81...	0.988	6.314
22...	0.375	0.404	52...	0.788	1.280	82...	0.990	7.115
23...	0.391	0.425	53...	0.799	1.327	83...	0.993	8.144
24...	0.407	0.445	54...	0.809	1.376	84...	0.995	9.514
25...	0.423	0.466	55...	0.819	1.428	85...	0.996	11.43
26...	0.438	0.488	56...	0.829	1.483	86...	0.998	14.30
27...	0.454	0.510	57...	0.839	1.540	87...	0.999	19.08
28...	0.470	0.532	58...	0.848	1.600	88...	0.999	28.64
29...	0.485	0.554	59...	0.857	1.664	89...	1.000	57.29
30...	0.500	0.577	60...	0.866	1.732	90...	1.000	∞

If we now understand how the angles and sides of a triangle can be related let's return to our original problem (Distance = 1000 feet and angle = 30^{o}).

To use Trigonometry you should first diagram your problem and then figure out which relationship you need to solve the problem. For instance, (Figure) draw and label the triangle with the quantities you know and then with those you wish to find.

---

*The sine of an acute angle of a right triangle is equal to the opposite side divided by the hypotenuse. (Although sin is used as an abbreviation, it is still read as sine).

**Although there are four other basic relationships, we will be dealing with only the two that were defined.

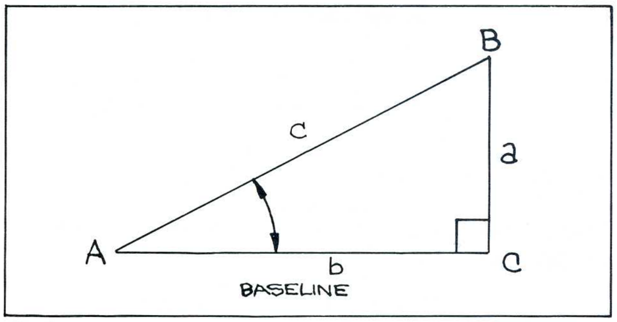


FIGURE 50

In our problem you know (b) the base line and the angle of elevation (A) and you wish to find (a), the altitude. Which function should you work with? Because we are dealing with an angle, its opposite side and its adjacent side we can use the tangent function.

The tangent function states:

$$\tan A = \frac{a}{b}$$

This can be transformed to read:

$$(a) = (b) \times (\tan A)$$

This tells us that we can easily find the altitude by substituting into the equation the proper values: If

$$b = 1000 \text{ and angle } A = 30^{\circ}$$

then,

$$a = (1000) \times (\tan 30^{\circ})$$

From the Trigonometry tables, we find that:

$\tan 30^{\circ}$ equals .58

therefore,

$$a = (1000) \times (.58)$$

or,

$$a = 580 \text{ feet}$$

which compares with the answer in Technique #1.

The Trouble With Method # 1

Method #1 works very well if the rocket always ascends vertically — but this is seldom the case. Because model rockets weathercock, Method #1 is not very reliable. The reason for this is that your mathematical expression describes a certain set of conditions, and if the conditions change, your expression will give you an incorrect answer.

For example, if you are downwind and your rocket weathercocks and flies into the wind your trigonometric expression will give you an answer that is too small (Figure 51). If you were upwind, you would get an answer that is too big.

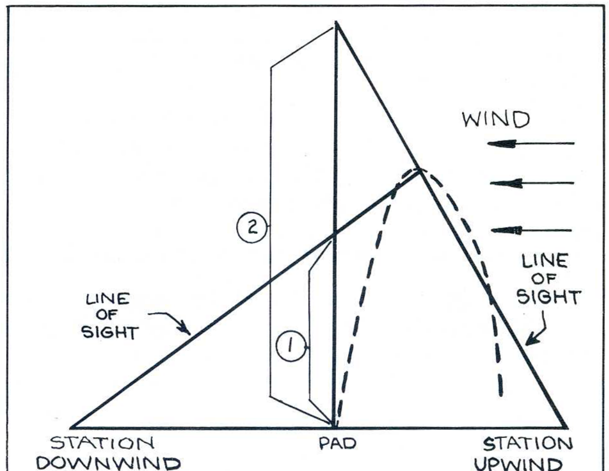


FIGURE 51

If the rocket weathercocks and flies (------dotted line) upwind, the downwind station will get an answer equal to (1) which is too small, and the upwind station will get an answer equal to (2) which is too big.

One way to partially solve this problem is to set up your tracking station on a line that is perpendicular to the direction of the wind.

One other way to correct for this problem is to use two stations, one upwind and one downwind. We will discuss this method next.

In Review

1. A single station, measuring angles of elevation, should be placed on a line which is perpendicular to the direction of the wind.
2. You need to know the angle of elevation and the distance between the station and the pad.
3. You can compute the altitude by scaling the dimension, or
4. With the trigonometric formula:

$$\boxed{a = (b) \tan A}$$

where (a) is the altitude achieved by the rocket, (b) is the length of the base line and (tan A) is the value found from the trigonometric table when you know the angle of elevation (A).

METHOD #2
TWO STATIONS – ELEVATION ONLY

If you have two angle measuring devices (one upwind and one downwind with the station anywhere in between) and you know the distance between them you can determine the altitude of your rocket using techniques similar to those described in Method #1.

TECHNIQUE #1
(Scaling)

This technique is similar to that which we employed in Method #1 – Technique #1, except that we must measure three things instead of two.

Let's assume that we have measured the distance between the stations and found it to be 1000 feet. Assume also that Station #1 tracked the rocket to 35° and Station #2 tracked the rocket to 50°. (Remember that the pad can be anywhere between the two stations).

The altitude can be computed in the following manner:

1. Mark off the base line to scale.

2. Construct the angle of elevation at Station #1.

FIGURE 52

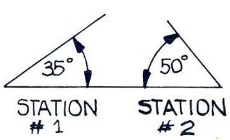


FIGURE 53

3. Construct the angle of elevation at Station #2.

4. Draw the two lines of sight from the station by extending the sides of the angle of elevation.

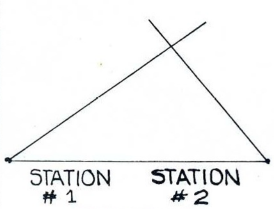


FIGURE 54

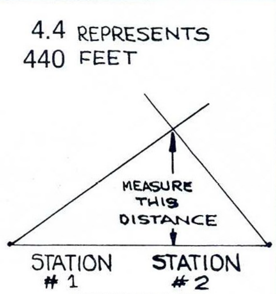


FIGURE 55

This completes the construction.

5. To obtain the altitude, simply measure the distance between the intersection of the two lines of sight and the base line and scale it to the "real" value. From our scale of 1 in to 100 ft and a distance of 4.4 inches, we can compute our altitude to be 440 feet.

The accuracy of this method can be improved in the same way as Method #1, Technique #1.

TECHNIQUE #2
(Trigonometry)

To understand how Trigonometry applies to this problem, we should first examine a diagram of our new tracking situation.

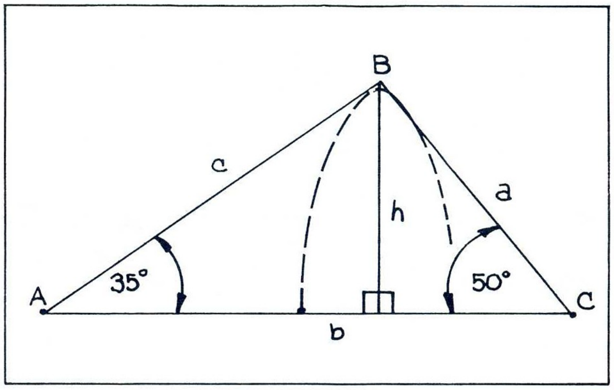


FIGURE 56 TRACKING TRIANGLE

When we discussed the two basic relationships from Trigonometry, we pointed out that in a right triangle the sine of an angle $= \frac{\text{opposite side}}{\text{hypotenuse}}$.

From our diagram this means: $\sin A = \frac{h}{c}$

It can also mean: $\sin C = \frac{h}{a}$

These two expressions can be respectively transformed into:

$$h = (c) \times (\sin A) \text{ and } h = (a) \times (\sin C)$$

If the right-hand side of both of the above quantities are equal to the same thing (h), they must be equal to each other. Therefore,

$$(c) \times (\sin A) = (a) \times (\sin C)$$

which can be transformed into:

$$\frac{a}{\sin A} = \frac{c}{\sin C} \;*$$

---

*In a similar manner you can also show that $\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$ which is the Law of Sines.

If we now understand the above relationships, we can use it to compute the altitude of the rocket. The computation requires two distinct steps. Step (1):

Step (1): Find side a or c.

The equation from the Law of Sines can be transformed

from: $$\frac{a}{\sin A} = \frac{b}{\sin B}$$

to: $$a = \frac{b \sin A}{\sin B}$$

(Our values were b = 1000 feet and angle A = 35°). Angle B = 95° because the three angles of a triangle equal 180° and our two angles add up to 85° (i.e., 35 + 50 = 85) and (180 - 85 = 95°).

Therefore,

$$a = \frac{(1000)\ (\sin 35^{\circ})}{(\sin 95^{\circ})} ❖$$

$$a = \frac{(1000)\ (.57)}{(.99)}$$

$$a = 575$$

We could have found c in the same manner.

Step (2): Find the altitude or height (h)

if: $$\sin C = \frac{h}{a}$$

then: $$h = (a) \times (\sin C)$$

From our first step, (a) = 575 and from our problem, angle C = 50°. Substituting:

$$h = (575) \times \sin 50$$

The trigonometry tables gives sin 50° = .77.

$$h = (575) \times (.77)$$

$$\boxed{h = 443}$$

which compares with the answer in Technique #1.

IN REVIEW

1. Two stations measuring angles of elevation (only) should be aligned with the wind in such a way so as to have one station upwind of the pad and one station downwind with the pad anywhere in between.

2. You need to know the two angles of elevation and the distance between the stations.

3. You can compute the altitude by scaling the dimensions, or

4. With the trigonometric formula:

$$\boxed{h = \frac{b \times \text{Sin A} \times \text{Sin C}}{\text{Sin B}}}$$

where (h) is the altitude or height achieved by the rocket, (b) is the length of the base line and the sines of the various angles are found in the trigonometry table. (This expression was obtained by combining Step 1 and Step 2).

The Trouble With Method #2

1. It may not be feasible to always set up your tracking stations in line with the wind.

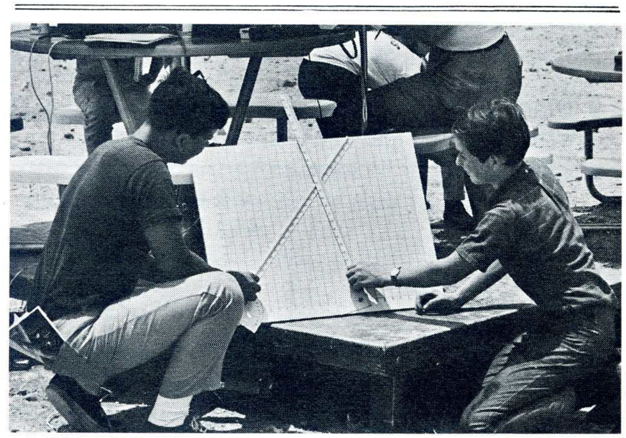
2. If the wind changes, you have to change your stations.

3. Because the wind does not blow evenly, the rocket will probably not fly in a "nice" convenient straight line.

The one way to solve these problems is to use a system that does not depend on where the stations are located or which way the wind is blowing. Such a system is described in Method #3.

❖ The sine of an angle greater than 90° is equal to the sine of its supplement. The supplement of an angle is obtained by subtracting the angle from 180° (e.g.: the supplement of 95° equals 85° because 180° - 95° = 85°). This rule tells us that if sin 85° = .99 then sin 95° = .99.

The scaling methods described in Methods No. 1 and No. 2 can be incorporated into a scaled altitude plotting board (picture below).



ROCKETEERS
WITH ALTITUDE PLOTTING BOARD

METHOD #3
TWO STATIONS
ELEVATION AND AZIMUTH

A_1 is the azimuth angle for Station #1.
A_2 is the azimuth angle for Station #2.

E_1 is the elevation angle for Station #1.
E_2 is the elevation angle for Station #2.

b is the base line.

You can determine the altitude of your rocket by positioning two theodolites in any convenient manner just so long as you know the distance between the two stations.

By convenient manner we mean:

1. You must be able to see the rocket's flight path from both stations, and
2. The stations must be able to "see" each other.

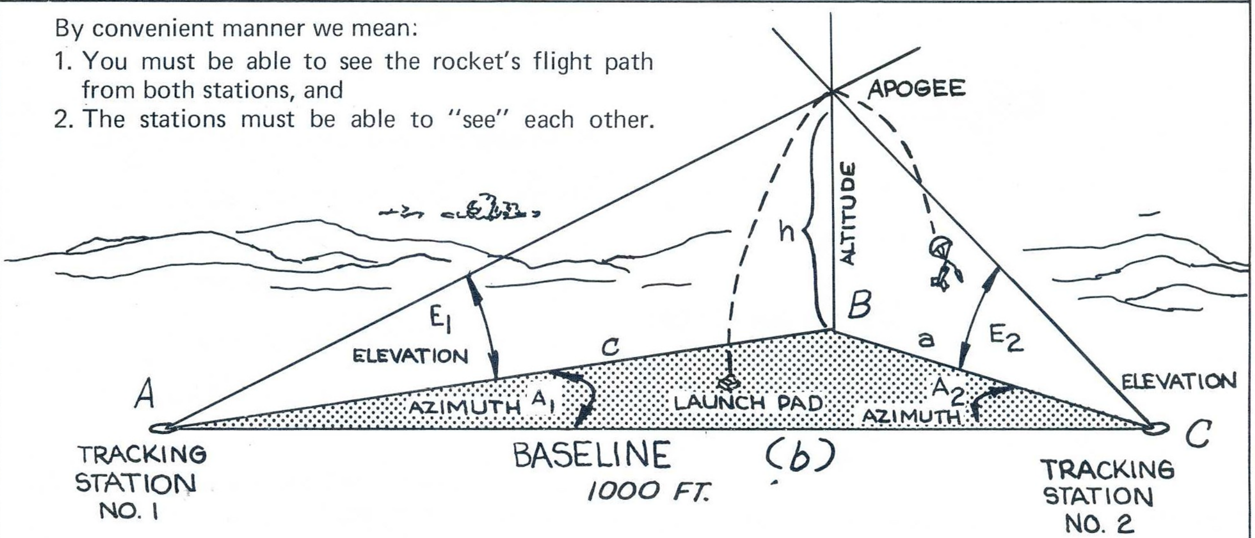


FIGURE 57 TRACKING TRIANGLE

From the diagram you can see that it doesn't make any difference which way the rocket flies. With the theodolite, diagramed in Figure , you can follow the rocket to its highest point and lock the instrument in position. From each theodolite you will be able to read two angles (elevation and azimuth).❖

Knowing the four angles (two from each station) and the distance between the stations, you can compute two separate altitudes from the following two formulas. If the average of the two altitudes is within 10% of the average altitude, the average altitude will constitute an acceptable value. This system is used in national competition.

Formula #1:

$$h = \frac{(\sin A_1)(\tan E_2)(b)}{\sin[180 - (A_1 + A_2)]}$$

Formula #2:

$$h = \frac{(\sin A_2)(\tan A_1)(b)}{\sin[180 - (A_1 + A_2)]}$$

The best way to understand these methods is to work an actual problem. Let's assume that Station #1 reports an elevation angle of 50^o and an azimuth angle of 45^o and Station #2 reports an elevation of 60^o and an azimuth of 70^o. We'll assume the base line to be 1000 feet.

It helps to organize your data.

$A_1 = 45^o$ $\quad A_2 = 70^o$
$E_1 = 50^o$ $\quad E_2 = 60^o$
$b = 1000$ feet

Formula #1 gives:

$$h = (\sin 45)(\tan 60)\frac{1000}{\sin[180 - (45 + 70)]}$$

$$= (.71)(1.73)\frac{1000}{.91}$$

$h = 1350$ feet

❖ (An angle of elevation is at zero when the "pointer" is horizontal or level with the ground. An angle of azimuth is at zero when the two stations are pointing at each other).

Formula #2 gives:

$$h = (\sin 70)(\tan 50)\ \frac{1000}{.91}$$

$$h = (.94)\ (1.19)\ \frac{1000}{.91}$$

$$h = 1230 \text{ feet}$$

The average of the two values is:

$$\frac{1350 + 1230}{2} = \frac{2580}{2}$$

$$= 1290$$

$$10\% \text{ of } 1290 = 129$$

Do the two altitudes lie within $\pm$ 129 feet of 1290 feet? Yes!

$$\begin{array}{r} 1290 \\ +\ \underline{129} \\ 1419 \end{array} \qquad \begin{array}{r} 1290 \\ -\ \underline{129} \\ 1161 \end{array}$$

Both 1350 and 1230 lie between 1419 and 1161. Therefore, the average (1290) is considered to be the correct altitude of the rocket.

This method provides a check on the accuracy of your angle measurements. If you wish you can design a scaling technique for this method also. A three-dimensional device must be used instead of the two-dimensional devices we discussed earlier (refer to Figure 58 for a diagramed example).

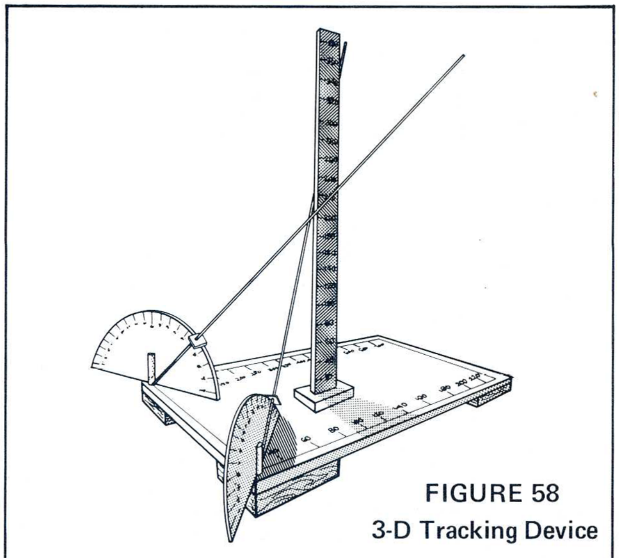


FIGURE 58
3-D Tracking Device

With this device you turn the protractor to the proper azimuth (horizontal) angles first and then rotate the rods to the proper elevation (vertical) angles. To obtain the altitude you can slide a scaled measuring device to the intersection of the rods and read the altitude directly from the measuring device. The protractor must pivot around points located at a distance equal to the scaled base-line length. The rods will probably never touch each other. If they are "close enough", however, you can "sight in" the average altitude. "Close enough" implies an error not greater than 10% according to the scale.

At this point one may ask: Why didn't we present just the third method if it is the most reliable and is the only one used in important competition events.

There are several reasons:

1. We wanted to give you some ideas as to how you might develop a unit in mathematics.

   a. You can start at the beginning.

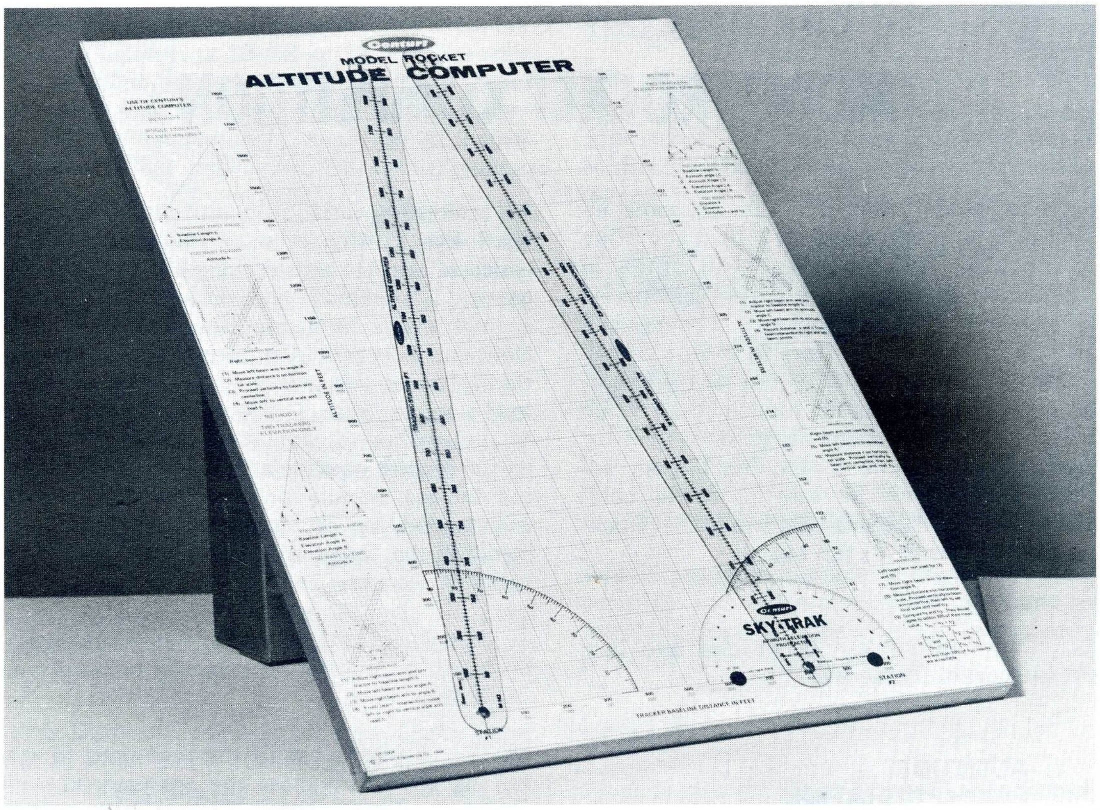
   b. You can show the advantages and disadvantages of mathematics.

   c. You will have at least one method that can be used at any level.

2. We wanted to demonstrate the conditions that need to be considered in setting up a reliable tracking situation.

We hope we have given you a few ideas.

FIGURE 59



Plotting board used for finding altitudes with either Method 1 or 2.

Derivation of the formulas used in Method 3.

The two formulas can be developed in the following manner. Refer to Figure 57as you study the following material. From the Law of Sines, we obtain:

$$\frac{a}{\sin A} = \frac{b}{\sin B} = \frac{c}{\sin C}$$

which when applied to our problem gives us:

$$\frac{a}{\sin A_1} = \frac{b}{\sin B} = \frac{c}{\sin A_2}$$

Therefore:

$$a = \frac{b \sin A_1}{\sin B}$$

and

$$c = \frac{b \sin A_2}{\sin B}$$

From the tangent function, we obtain:

$$\tan E_1 = \frac{h}{c} \text{ or, } h = (c)\ (\tan E_1)$$

and

$$\tan E_2 = \frac{h}{a} \text{ or, } h = (a)\ (\tan E_2)$$

Substituting the values of a and c into these equations we get:

$$h = \frac{b \sin A_1}{\sin B} \times \tan E_1$$

and

$$h = \frac{b \sin A_2}{\sin B} \times \tan E_2$$

Angle B equals $[180-(A_1 + A_2)]$.

6 MODEL ROCKET COMPETITION

This branch of Model Rocketry can, in some instances, prove to be more stimulating than any other part of the hobby. By competing with others in either a classroom situation or in a meet sanctioned by the National Association of Rocketry, a youngster's interest can be spurred in an effort to meet the challenge of competition. Whether or not he realizes it, he is learning more than basic fundamentals when trying to build a more efficient design or system for competition. The student is teaching himself advanced concepts that will increase his overall comprehension of science, mathematics, and Model Rocketry tremendously. And, it's fun too!

Model rocket competition can be divided into four basic event categories. These are:

1. ALTITUDE
2. FLIGHT DURATION
3. RESEARCH & DEVELOPMENT
4. SCALE MODELING

As each has many variations and two or more events can be combined into a single comprehensive category, only a few of the specific events will be discussed.

However, pursuit of competitive events other than those presented here is encouraged.

As events in this unit will be discussed with reference to the latest edition of the U.S. Model Rocket Sporting Code of the National Association of Rocketry, it is suggested that the ideas put forward in the Code be followed in model rocket competition, as well as in all model rocket activities.

ALTITUDE

This category is centered about the design efficiency of a model rocket. The object of altitude competition is to reach the highest possible altitude with a model while placing restrictions on the total weight (engine included) of the model and on the maximum total impulse of an engine to be used in the model. An example of this would be the NAR Class I Altitude event which requires that a model entered weigh no more than 60 grams (2.12 ounces) and uses an engine which has a total impulse rating of between 2.51 and 5.00 Newton-seconds (0.29 – 0.56 pound-seconds).

An interesting variation of altitude competition is the NAR Egg Lofting event. This competition is one which is open to entries weighing no more than 500 grams (1.1 pounds) and powered by an engine or engines whose total impulse does not exceed 80.00 Newton-seconds (17.75 pound-seconds) in combination. The vehicle will carry as a totally enclosed payload a single, fresh, Grade A hen's egg. The purpose of the event is to carry the extremely fragile payload to the highest possible altitude and to recover it without damage. Simulation of a manned suborbital flight is intended by overcoming the problems of withstanding the forces of acceleration and the shock of re-entry, recovery, and landing.

The results of an unsuccessful egg-loft flight would no doubt encourage more careful preparation by the rocketeer.

NOTE: A plastic bag of the type used to wrap food can be used to enclose the egg payload within the capsule and will reduce the area affected by shell breakage.

DURATION

Duration events for Model Rocketry are those which are concerned with either the total flight time of a parachute recovery model, a streamer recovery rocket, or a boost-glide vehicle. The three events are similar in that with each type model the in-flight duration times are recorded (usually with a stop-watch) from instant of ignition to model touch-down. This is used as the basis for judging. Weight and total impulse restrictions are also made in NAR duration events.

Parachute Duration is one event where numerous "trade-off" situations are encountered. When preparing for a parachute event, a rocketeer often assumes that he will win if he uses the largest parachute possible in his model and if he employs the largest allowable engine to boost his duration "bird" aloft. However, this is not always the case. Certain important factors must first be considered. Most outstanding of these is the prevalent weather conditions of the launch site. According to NAR rules, a chute duration model must be recovered if its time is to be considered valid. In order to win the event, you must have your rocket back. This fact is often ignored by the average rocketeer and he is disqualified as a result. To reduce the possibility of a duration model being lost, a rocketeer must limit the size of his parachute and the type of engine used in relation to the weather conditions which will affect the model's descent. Therefore, a 12, 16, or 18 inch diameter chute may be better to use than a 24 inch one because the larger chute may cause the model to drift a considerable distance. Accordingly, an A5 or A8 motor may be better to use than a B4, B6, or C6 engine.

The Streamer Duration event is one in which all models are restricted within a certain range of engines. The title of this event is deceiving, and the actual object of the competition is generally missed. Streamer Duration is actually an altitude event in which a streamer recovery system is required. Since all of the models will fall at about the same rate of speed, obviously the model which reaches the highest altitude will be the model which will clock the greatest time.

Creating methods of increasing flight duration without reaching the highest possible altitude would be an interesting thing to experiment with. Students or contestants, however, must remain within the rules and restrictions of the event in order to have a truly valid innovation.

Boost-Glide Duration is one of the most exciting and yet complex of all model rocket competitive events. B/G vehicles ascend like most model rockets and the glider portion of the model soars back to Earth. The engine may be safely returned by streamer or may be enclosed in a pod which separates from the glider upon activation of the engine ejection charge. The engine pod method is somewhat superior since it allows parachute recovery of the engine section. B/G design and flight performance is an area where a great deal of experimentation can be done since it combines not only rocket principles, but also the fundamentals of aeronautics.

RESEARCH AND DEVELOPMENT

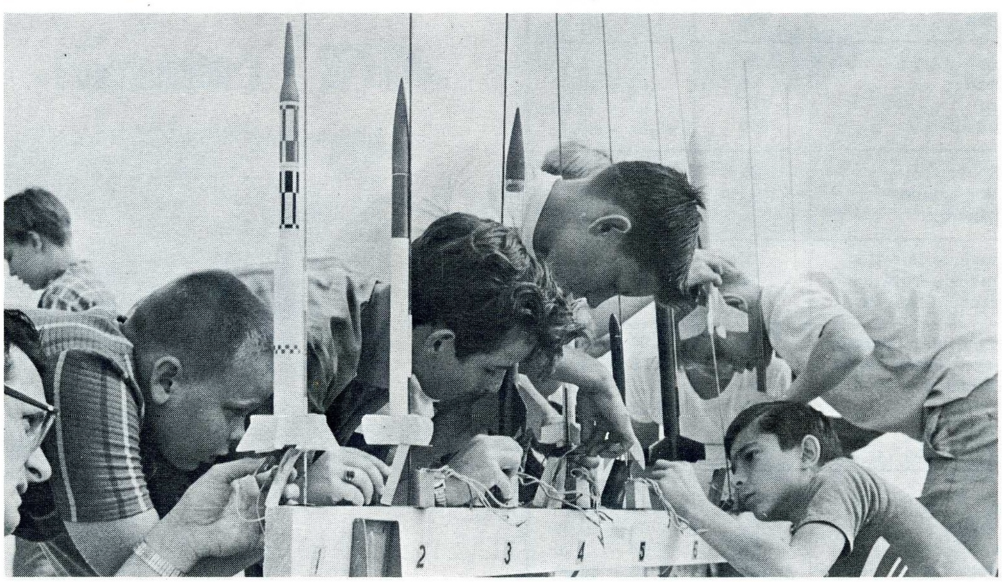
This category can be of great value in the classroom since its object is to stimulate new concepts, new approaches, and new ideas in Model Rocketry. In NAR competition, each R & D entry must be accompanied by a written report on the objectives, approach, equipment, data, results, and conclusions of the project. Demonstrations of each project may or may not be required.

A good example of some R & D work having been done by a young model rocketeer is that which led to the concept of the Krushnic effect. This effect concerns the nullification of a rocket engine's thrust when it is recessed too far up into the body tube of a rocket. It was discovered by Richard Krushnic who used typical model rocket components and engines.

This is just one example of the many research projects that have been carried out by young rocketeers searching for the answers to a variety of questions posed by their inquiring minds.

SCALE

Scale events are those in which a rocketeer obtains information on a certain rocket-powered vehicle and builds a scale model of the same. NAR rules require certain scale data for competition. However, an acceptable scale model can be built from a single photograph (preferably color). Models are judged on authenticity, adherence to scale, workmanship, degree of difficulty, and flight characteristics. Scale Altitude events can be conducted by judging a model first for scale and construction qualities and then for its altitude performance.



ROCKETRY COMPETITION

NATIONAL COMPETITION

Since 1958 the National Association of Rocketry has held an annual competition meet for U.S. model rocketeers. These NARAM's are competitive events on the national scale with modelers from all over the country participating. The meets usually take place over a period of several days with several events held each day. Competition in each event is divided into the three following age groups: Junior (up to 17), Leader (17 - 21), and Senior (21 and over). This is done to somewhat equalize the modeling abilities of competitors. Even though everyone flies as part of the same event, results are recorded and awards are given within the separate age groups. Something similar may be done to act as an equalizing factor for competition among students.

NAR COMPETITION EVENTS

The following are the official NAR competitive events which appear in the new NAR "Pink Book" (Sporting Code). Some have already been discussed in this unit.

EVENTS	MAX. WT.	TOTAL IMPULSE Newton-seconds
Class 0 Altitude	60	0.00 - 2.50
Class 1 Altitude	60	2.51 - 5.00
Class 2 Altitude	120	5.01 - 10.00
Class 3 Altitude	240	10.01 - 40.00
Class 4 Altitude	500	40.01 - 80.00
Class 0 Scale Altitude	60	0.00 - 2.50
Class 1 Scale Altitude	60	2.51 - 5.00
Class 2 Scale Altitude	120	5.01 - 10.00
Class 3 Scale Altitude	240	10.01 - 40.00
Class 4 Scale Altitude	500	40.01 - 80.00
Scale	500	0.00 - 80.00
Super Scale	500	0.00 - 80.00
Space Systems	500	0.00 - 80.00
Pee Wee Payload	90	0.00 - 5.00
Single Payload	90	5.01 - 10.00
Dual Payload	180	10.01 - 40.00
Open Payload	500	40.01 - 80.00
Parachute Spot Landing	85	0.00 - 10.00
Streamer Spot Landing	85	0.00 - 10.00
Open Spot Landing	85	0.00 - 10.00
Class 1 Parachute Duration	85	0.00 - 2.50
Class 2 Parachute Duration	85	2.51 - 5.00
Class 3 Parachute Duration	85	5.01 - 10.00
Hornet Boost-Glider Duration	60	0.00 - 1.25
Sparrow B/G Duration	60	1.26 - 2.50
Swift B/G Duration	60	2.51 - 5.00
Hawk B/G Duration	120	5.01 - 10.00
Eagle B/G Duration	240	10.01 - 40.00
Condor B/G Duration	500	40.01 - 80.00
Drag Race	85	0.00 - 10.00
Egg Lofting	500	0.00 - 80.00
Design Efficiency	500	0.00 - 80.00
Quadrathon	90	0.00 - 5.00
Plastic Model	500	0.00 - 80.00
Predicted Altitude	500	0.00 - 80.00
Research & Development	500	0.00 - 80.00

These events are presented here to suggest further possibilities for model rocket competition. The NAR Sporting Code contains rules and regulations for all of them and is suggested as a guide for competitive Model Rocketry. Nevertheless, the educator can change certain requirements to meet specific circumstances when encountered. But, by using the Pink Book as a guide, very good results and a successful model rocket competition can be held. When involved in competition as well as any other model rocket activity, safety must be kept uppermost in mind. This concept is stressed in the NAR Code and in this Guide.

THE COMPETITION AREA

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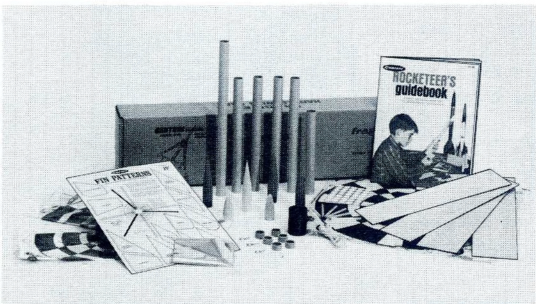

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1	Body Tube	ST-712	1	Balsa Fin Mat'l.	BFM-10	6	Elastic Shock Cord	SC-18
2	Nose Cones	BC-70	2	12" Parachutes	CP-12i	6	Thrust Rings	TR-7
2	Nose Cones	PNC-74	1	16" Parachute	CP-16i	6	Launch Lugs	LL-2
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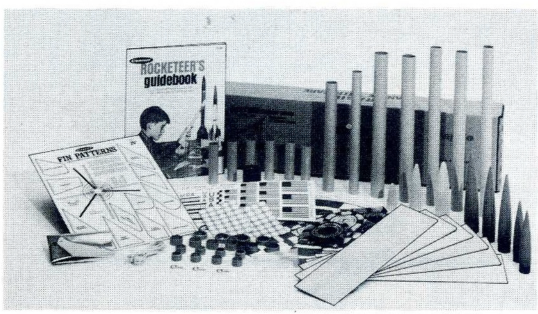

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1	Body Tube	ST-712	3	Thrust Rings	TR-7	2	Sheets Tape Discs	TD-35
1	Body Tube	ST-88	3	Engine Mounts	EM-8	1	Rl. Shroud Line	SL-70
2	Body Tubes	ST-812	2	Engine Mounts	EM-10A	6	Elastic Shock Cord	SC-18
2	Body Tubes	ST-1010	1	Fin Pattern Sheet	FPS-2	6	Shock Cord Fasteners	SCF-1
1	Nose Cone	BC-70	2	Balsa Fin Mat'l.	BFM-8	8	Launch Lugs	LL-2
2	Nose Cones	PNC-74	4	Balsa Fin Mat'l.	BFM-10	1	Flag Decal	DC-35
1	Nose Cone	BC-83	1	Plastic Cap. Tube	CPT-83	3	Screw Eyes	SE-12
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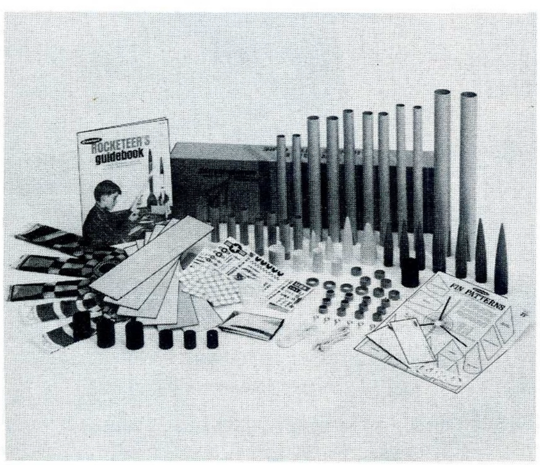

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2	Body Tubes	ST-712	1	Engine Mount	EM-13	1	20" Parachute	CP-20i
3	Body Tubes	ST-812	1	Paper Reducer	PR-713	1	Mylar Chute Mat'l.	MCM-1
2	Body Tubes	ST-1010	1	Paper Reducer	PR-813	3	Sheets Tape Discs	TD-35
2	Body Tubes	ST-1313	1	Balsa Reducer	PR-78	1	Rl. Shroud Line	SL-70
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1	Nose Cone	BC-72	1	Tube Coupler	HTC-8	3	Shock Cords	SC-20
2	Nose Cones	PNC-74	1	Tube Coupler	HTC-10	6	Screw Eyes	SE-12
1	Nose Cone	PNC-76	1	Balsa Connector	BTC-8	6	Launch Lugs	LL-2
1	Nose Cone	BC-83	1	Balsa Connector	BTC-10	3	Launch Lugs	LL-3
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1	Nose Cone	PNC-106	1	Fin Mat'l.	BFM-8	1	Plastic Capsule Tube	CPT-134
1	Nose Cone	BC-132	4	Fin Mat'l.	BFM-10	1	Flag Decal	DC-35
6	Tnrust Rings	TR-7	1	Fin Mat'l.	BFM-12	1	Mil. Insignia Decal	DC-3
						1	Rocketeer's Guidebook	

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TECHNICAL INFORMATION REPORTS

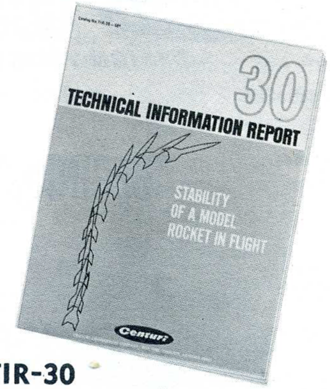
TIR-30 STABILITY OF A MODEL ROCKET IN FLIGHT

Most model rocketeers have heard that a stable rocket flight requires that the center of pressure must lie behind the center of gravity.

What is center of pressure? Why is the rocket balance point called center of gravity? What does the word "stability" really mean? Are there any simple tests which tell you whether or not a new rocket design will be "stable"? How come rockets arc over and head into the wind (weathercock) during thrusting and coasting instead of being blown along with the wind as a feather or piece of paper would?

These and other important questions are fully answered in CENTURI's TIR-30. The report contains a total of 42 illustrations to assist the explanations of the basic principles of model rocket stability. In addition, a section on how the amount of stability can be adjusted to improve altitude performance has been included.

The report was written by Jim Barrowman, an Aerospace engineer at NASA, who uses these same principles in his daily work with aerodynamically stabilized sounding rockets. Jim is the club advisor for the NAR-HAMS section of the NAR, and also will be NARHAM-10 Contest Director this summer at Wallops Island, Virginia.



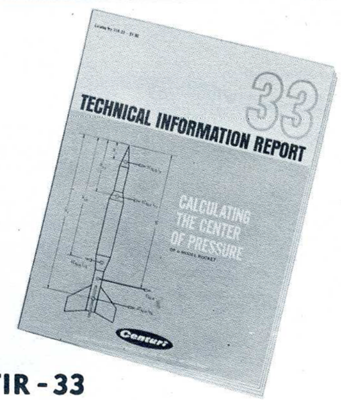
TIR-30
$.75 Postpaid

TIR-33 CALCULATING THE CENTER OF PRESSURE OF A MODEL ROCKET

Once you have read TIR-30 and learned about the "whys" of stability you will be in a position to appreciate and make use of this report. We feel it is a "must" for the competition minded rocketeer who wants to achieve maximum performance together with an adequate stability margin. This report is the scientific tool which enables you to calculate the exact center of pressure of a model rocket. Fully illustrated, it includes all the necessary equations, design tips, and sample problems, along with graphs which eliminate most of the arithmetic steps.

TIR-33 was also written by Jim Barrowman. In fact, the derivation of the basic equations earned him a first place Senior Division R & D Award at NARAM-8.

Armed with this knowledge you can find the exact balance point for your rocket which will both insure stable flights and permit achievement of maximum possible altitudes. The method of analysis presented in this report will help you determine whether or not additional nose weight is necessary to achieve a stable flight and is particularly helpful in balancing those scale designs which have very little fin area.



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TIR-100 MODEL ROCKET ALTITUDE PERFORMANCE

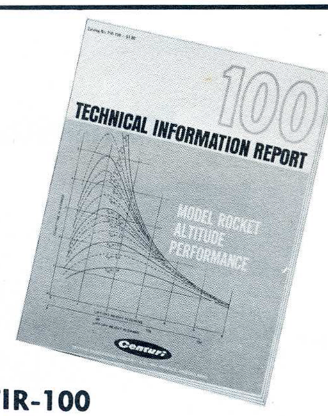
Presents easy-to-use graphs for accurately predicting the peak altitudes which can be reached by single stage rockets using ¼A thru F type engines. Also included are graphs for selecting the best delay time to use. No mathematical calculations, whatever, are involved in finding altitudes or engine delay times. These graphs, along with the numerous discussion sections of this report, should be most useful in helping the rocketeer towards a real understanding of how engine power, rocket weight, and aerodynamic drag on various nose and body shapes are interrelated in their affects on performance.

If you are at all interested in competing in the N.A.R. Aerospace Systems and Predicted Altitude events, this report will be an indispensible tool to earn you more points.

Once you have TIR-100 we are sure you will keep it within easy reach for constant use as a design reference. With it you will easily be able to answer more involved questions, such as:

1. *Will a given rocket go higher with a B6 motor or with the faster burning B14 motor?*
2. *Will an A8 motor, which has exactly twice the TOTAL IMPULSE of a ½A6 motor, lift a given rocket exactly twice as high?*
3. *How much higher does a rocket go on a cold day versus on a hot day? Or, does temperature even make a difference?*
4. *Will a single engine rocket of a given weight reach higher or lower altitudes than a two engine cluster rocket with exactly twice the lift-off weight? What about a three engine bird that weighs three times as much?*
5. *Will a B6 powered bird with a lift-off weight of 1¼ ounces go significantly higher if its weight is reduced down to 1 ounce?*

The answers may surprise you!



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A high-flyer and easy-to-build is the best description of the Astrobee 350. This scale model is an authentic copy of the actual rocket which stands 50 feet tall and is used primarily for atmospheric research.
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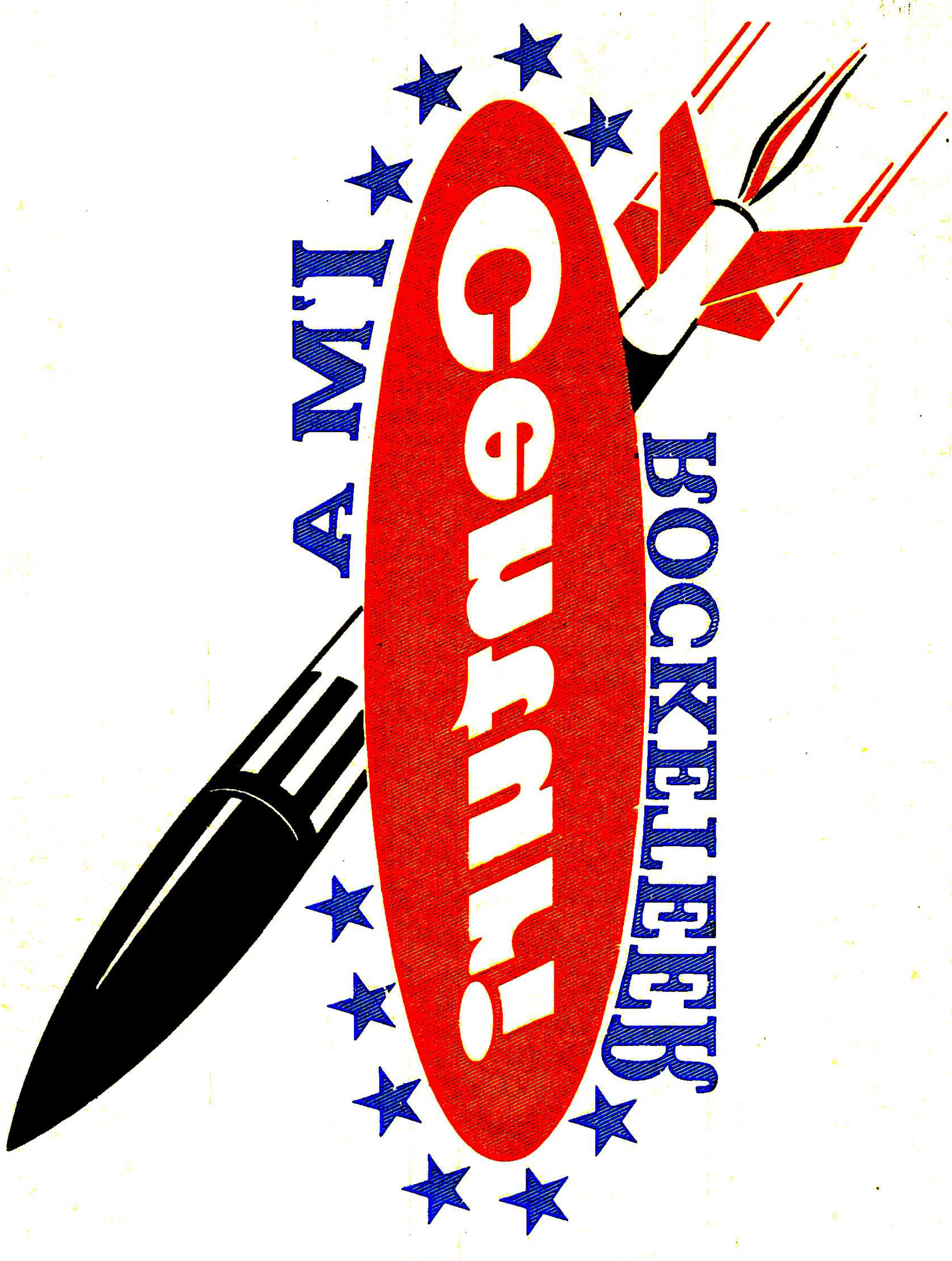
If you like to go with a winner . . . this is the one to get. At the First International Model Rocket Meet in Dubnica, Czechoslovakia in 1966, this rocket won the Parachute Duration event with a 20" parachute. A 12" and 20" chute are both included in this kit.
CLEAR PAYLOAD
There's an old joke about a snipe hunter but this kit has nothing to do with it. In fact—this rocket is a fantastic performer, carries a payload in a clear capsule. Comes with a 12" chute and slick lookin' decals. A really good value.
SCALE MODEL
HONEST JOHN
CATALOG NO. KC-25
SPECIFICATIONS
Body Diameter 907
Length . . . . 13.4"
Net Weight . . . . 1.1 oz.
RECOMMENDED ENGINES
½A6-2 B6-4
A5-4 C6-5
SCALE MODEL
ASTROBEE 350
CATALOG NO. KC-5
SPECIFICATIONS
Body Diameter . . . . 1.0"
Length . . . . 16.5"
Net Weight . . . . 1.1 oz.
RECOMMENDED ENGINES
A8-3 B14-5
B6-4 C6-5
SPORT FLYING
STARFIRE
CATALOG NO. KC-12
SPECIFICATIONS
Body Diameter 907
Length . . . . 16"
Net Weight . . . . 1 oz.
RECOMMENDED ENGINES
½A6-2 B6-6
A5-4 B14-6
B4-6 C6-7
PAYLOAD CARRIER
SNIPE HUNTER
CATALOG NO. KB-13
SPECIFICATIONS
Body Diameter . . . . .757"
Length . . . . 12.5"
Net Weight . . . . 0.85 oz.
RECOMMENDED ENGINES
½A6-2 B14-5
A8-5 C6-7
B6-6



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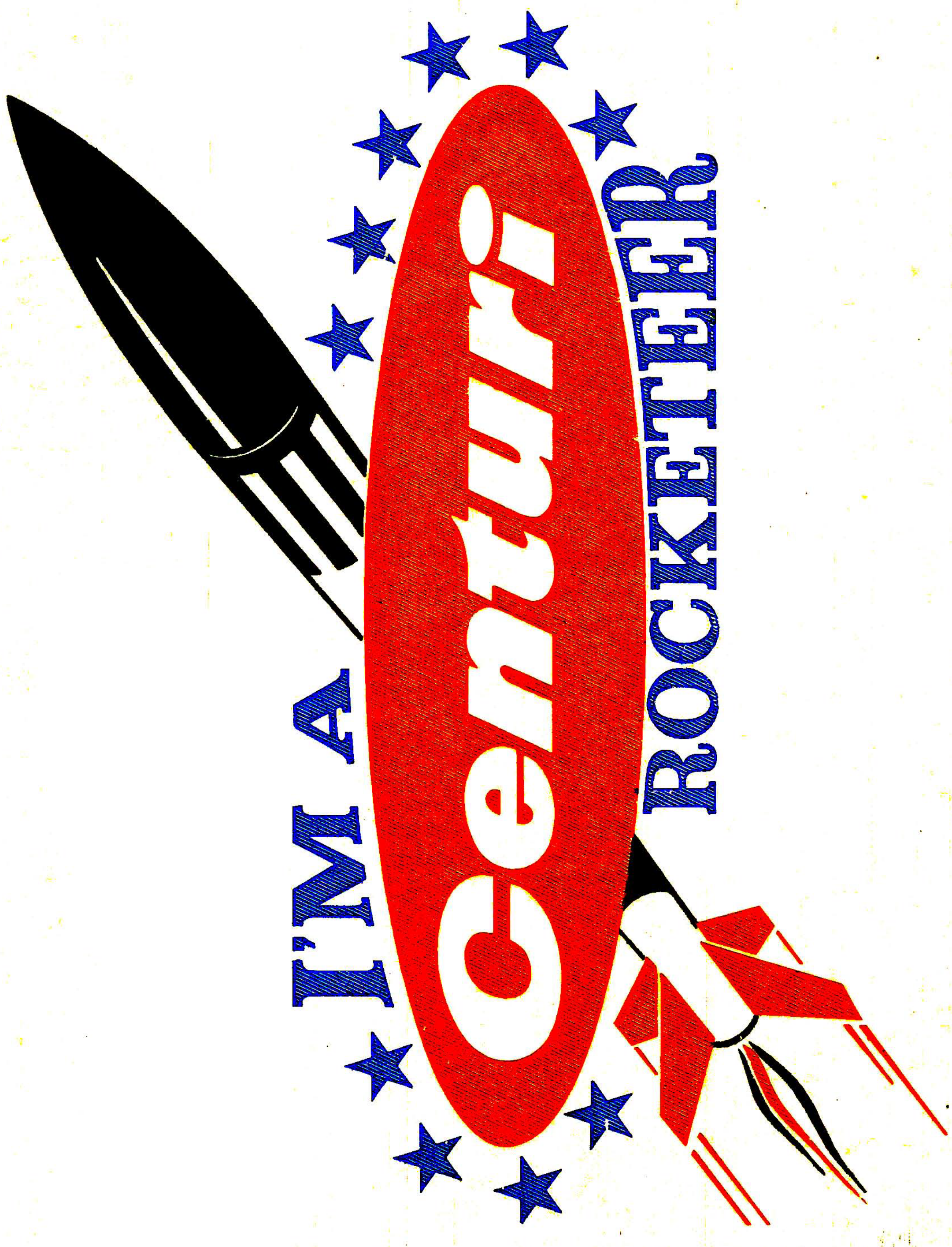

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