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ROCKET EXPERIMENT SAFETY

By Atlantic Research Corp.
Alexandria, Virginia

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This is a reprint from the *Quarterly*, the technical journal of the Association, which is sent to all members as published. The material published herein has been reprinted because of its technical value to students of fire safety. Other publications sent to members include the monthly *Fire News*, standards on fire prevention and fire protection, special reports and bulletins, the *Year Book*, the *Advance Reports*, and the *Proceedings* of the annual meetings. Ask for our free "Story" and "List of NFPA publications."

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Rocket Experiment Safety

By Atlantic Research Corp., Alexandria, Virginia

> This article was written by two members of the staff of the Atlantic Research Corp., in answer to requests for safety suggestions for rocket hobbyists in and around Alexandria.
>
> The intent of this article is to discourage unsupervised amateur rocketry which has been the cause of much loss of life and serious injury. It shows the extent of the hazards involved and gives safety guidance to those who have genuine scientific interest in rocketry.
>
> Other NFPA material on rocketry includes "Supervision of Teen-Age Rocketeers" by Carroll E. Shaw (October 1958 QUARTERLY) and "Amateur Rocketry — This Is Science?" (May 1958 *Fire News*).

It is impossible to give complete safety instructions for such a complex activity as rocket making and testing. Even were it possible, the most elaborately detailed instructions would be useless if the rocket experimenter did not read them attentively and then keep safety — his own and the community's — uppermost in his mind.

This article does not pretend to be an authoritative guide to every phase of amateur rocket work. Whole books have been written on the subject. We urge that no one regard the instructions contained in this article as a guarantee of safety in rocket work. It only attempts to outline the areas of greatest hazard and to give a few suggestions to minimize the danger. Its purpose is to fill an immediate need and its brevity has been dictated by the urgency of that need.

The public's reaction to the rocket hobby has ranged from qualified approval to demands that all such activity be banned. The authors, as individuals, believe the interest in this hobby is so intense that an official ban will merely drive the activity underground, making the situation worse than it is now. They further believe that the rocket hobby can yield positive good in science education if it is conducted with the guidance of adult sponsors who appreciate the need for proper precaution.

It is hoped that a careful reading of this article and the references listed in it, joined with serious acceptance of safety responsibility by competent adult sponsors and the individual hobbyist, will make amateur rocketry at least as safe as some other popular hobbies. It should be remembered that serious injuries do occur, although infrequently, even in such seemingly harmless activities as competitive sports.

Safety Is Where You Begin

Rocket experimentation is a fascinating hobby and offers many opportunities to learn the laws of nature that will make it possible for man to travel through space. Engineers and scientists have been working such a short time in the development of rocket propulsion techniques that much is yet to be learned about the principles and designs that will make our rockets of the future more efficient than those we have today.

High school and college students who take up this hobby in the right way will be making a good start toward a later career in rocketry or other technical fields.

A rocket accident is not a good start toward anything. It hurts — or kills. It costs your hand, your eyes, or your life. It completely wastes your knowledge and abilities, grieves your family, and frightens others away from an activity that can be made reasonably safe by foresight, knowledge, and caution.

Your first step in rocket experimentation must be to understand just why safety is so important in rocket work. There are three basic reasons:

First, a rocket propellant is a chemical mixture that is only a hairline removed from an explosive compound. Heating it, grinding it, or sometimes merely shaking it can detonate it like TNT. Many deaths and serious accidents have occurred when propellants detonated while being mixed on the workbench.

Second, a rocket propellant within a rocket case is literally a bomb unless both are properly designed. Even a safe propellant in a badly designed rocket case will explode the rocket, scattering shrapnel like a bursting artillery shell.

Third, the rocket itself is a projectile. It can move at such speed that it can readily kill. A good deal of aerodynamic knowledge is needed to design and make a rocket that will fly where it is supposed to fly.

"Well," you may be saying now, "I only planned to build a very *small* rocket." Good! But what do you mean, "small"? A 12-gauge high-velocity shotgun shell contains less than half an ounce of powder (a propellant), and it can kill. The hazard involved in handling propellant increases very rapidly as the amount increases:

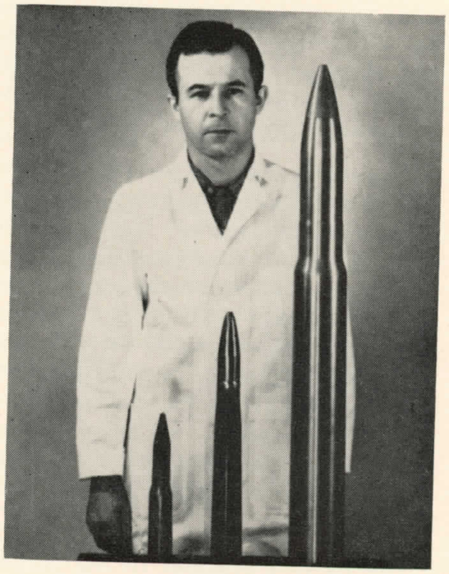
2 ounces of propellant is *8 times* as dangerous as *1* ounce.

5 ounces of propellant is *125 times* as dangerous as *1* ounce.

10 ounces of propellant is *1,000 times* as dangerous as *1* ounce.

Look at Figure 1, to get an idea of the energy present in various amounts of propellant. It takes only 4 pounds of propellant to hurl a 3-inch shell over 5 miles.

This article is meant to help you keep safe while learning how to experiment with rockets. It also suggests a number of interesting ways in which you can demonstrate to yourself the basic principles of rocket science. Serious experimentation of this kind is a worthwhile hobby if carried out safely. But no matter how serious and worthwhile your aim, experimentation without care and caution is senseless and dangerous playing with fire.



30 MM	40 MM	3-in.
1/5 lb.	3/4 lb.	4 lb.

Figure 1. The gunpowder in these large caliber gun shells contains about the same explosive energy per pound as the energy in a rocket propellant. The type and weight of propellant are indicated under each shell.

Making Your Own Rocket

The Fuel

When you became interested in the rocket hobby, probably the first thing you thought of doing was making your own propellant. Unfortunately, propellant formulation, which seems so simple, is actually the most uncertain and dangerous part of the entire rocket field. Even the experts cannot predict whether an experimental propellant will actually turn out to be a high explosive.

Experienced propellant chemists conduct their initial tests of a new propellant mixture with tiny quantities of less than a gram. They use remote control equipment whenever they can. If they must handle their materials directly, they protect their eyes with safety glasses. They test their samples against heat and shock, not only when the sample is freshly made, but also after storage for days, weeks, and months. They have found that many things can make the difference between a propellant and an explosive. The chemicals used, their proportions, the particle size of the powders, even the minute impurities present in the ingredients can make the difference.

Some substances are so sensitive or so toxic that professional rocket makers either do not use them at all or will only use them in the presence of very complex and expensive safeguards. Here is a partial list:

Chlorates: The commonly available chlorate compounds are sodium chlorate and potassium chlorate. Both explode so readily when rubbed, ground, or mixed, that professional rocket makers do not use them at all.

Powdered Metals: Iron, zirconium, lithium, beryllium, magnesium, nickel, boron, and aluminum powders (in particle sizes smaller than iron filings) when poured from one container to another, or shaken, can produce an explosive dust mixture with the air.

The dust of pure iron, zirconium, lithium, beryllium and certain forms of aluminum and magnesium can ignite spontaneously when dispersed in the air.

Beryllium dust or the dust of its oxides, even in very minute quantities, is extremely toxic.

When any of the powdered metals described above are mixed with an oxidizing agent, they can become highly sensitive to impact and shock.

Metallic Sodium: It may ignite when exposed to the air if water, even in the form of moisture, is present.

Metallic Potassium: It spontaneously ignites when exposed to air.

Yellow Phosphorus: It spontaneously ignites when exposed to air.

Fluorine· Fluorine is both extremely toxic and very dangerous to handle. The fumes of its gaseous form are deadly and many of its compounds with chlorine, bromine, or iodine are toxic. Fluorine itself will react violently with most organic materials such as human flesh, wood, paper, etc., and with any of the common metals when heated to the ignition temperature.

Sulfur: It will ignite readily under impact or friction when it is mixed with an oxidizing agent. If its dust is mixed with air, a spark will explode the mixture.

Potassium Ferrocyanide and Potassium Ferricyanide: Both react readily with oxidizing agents and will explode if mixed with the chlorates.

Nitrocellulose (Guncotton): It will not only burn in the air when ignited, but can also explode, even in the absence of air, when subjected to shock or heat.

NITROGLYCERINE: It is extremely shock-sensitive and detonates readily. It is sensitive to heat as well.

STRONG HYDROGEN PEROXIDE (70% or higher concentration): It will spontaneously set fire to many substances.

HYDRAZINE: It will spontaneously ignite in the presence of many oxidizing agents, such as strong hydrogen peroxide and strong nitric acid. Its fumes are toxic.

FUMING NITRIC ACID: It will spontaneously set fire to many substances. Its fumes are toxic and corrosive.

This partial list should demonstrate to you that it is wise to know what you are dealing with. You can find more complete information in these two books:

Fire Protection for Chemicals, by C. W. Bahme, published by the National Fire Protection Association, 60 Batterymarch St., Boston 10, Mass.

Chemical Safety Data Sheets, published by the Manufacturing Chemists' Association, 1825 Connecticut Ave., N. W., Washington 9, D. C.

Mixing, grinding and fuel-charge forming methods generally become more hazardous if heating or violent treatment is required. A mortar and pestle readily produces enough impact shock to set off many propellant mixtures. Heating a mixture to make a fuel charge that can be poured into a mold produces added hazard, since many mixtures are much more likely to detonate when hot than when cold. Even air bubbles in the formed propellant can cause the rocket to explode. Furthermore, the combustion products of many substances are even more toxic than the substances themselves.

For these reasons, rocket hobbyists should mix their own fuels only if their work can be carried out with the personal guidance of a professional propellant expert.

In time, propellant companies may develop rocket fuel ingredients designed for the use of advanced rocket hobby clubs. However, no such products are now known to be available. Any products of this type offered to the hobbyist should be accompanied by detailed information on the burning rate and shock sensitivity of the propellant at different temperatures and pressures, in the various ingredient proportions for which the materials are suited. The manufacturer should also include instructions for processing the ingredients into the rocket fuel charge, and the precautions that must be taken.

The Charge and Case Design

The advanced rocket hobbyist will find many interesting challenges in the rocket motor design problem. For instance, there is the problem of designing the solid fuel charge.

The two most common types of solid propellant "grains" (fuel charges) are the end-burning grain and the internal-burning grain.

The end-burning grain (Figure 3a) completely fills the motor case; when ignited, it burns as a cigarette burns, from one end inward. This is the simplest type of solid propellant grain and in some ways the safest for amateurs to make. A danger point is that, as the propellant burns, the inside of the motor case is exposed to hot gases which will heat and erode it. These effects may weaken it until it explodes. However, proper insulation within the case can prevent this.

The internal-burning grain (Figure 3b, c, d) has a hole or "perforation" running down its length. Combustion takes place in the perforation, burning out radially. Designing internal-burning grains is much more complex. For

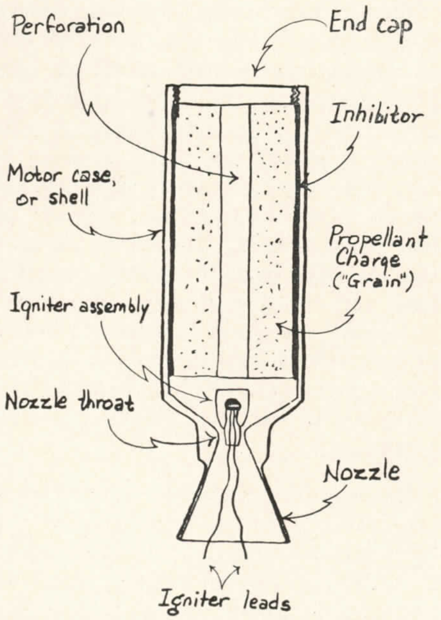


Figure 2. The parts of a typical rocket are shown.

example, the initial cross-section area of the perforation, called the "port," must be at least *three* times the area of the nozzle throat. Otherwise extremely high pressures will be generated and explode the case. A long, narrow grain should have a larger perforation than what is needed in a short, stubby one.

Internal-burning grains should be prevented from burning on their outside surface, that is, "inhibited." Professional rocket makers coat the outside of their grains with various substances, such as epoxy resins, which will limit the burning to the area meant to burn. The inhibitor must be suitable to the propellant type, or it will not do its job.

The effect of high temperature and pressure on the strength of any solid propellant grain must be carefully predicted. If firing the grain causes it to break into pieces or clog the nozzle, explosion is certain.

The ideal fuel charge design is one that will produce gases at a constant rate. The end-burning grain is very satisfactory in this respect, since the burning surface area remains the same from one end to the other. Internal-burning grains, however, present difficulties. The perforation must be so shaped that the area of the burning surface stays the same all the time that the fuel burns outward.

These are some of the interesting problems of rocket fuel charge design. The design of the rocket case presents further problems.

Before you can design a safe motor case you must know how much gas the propellant you have chosen will generate, and how fast it will be generated.

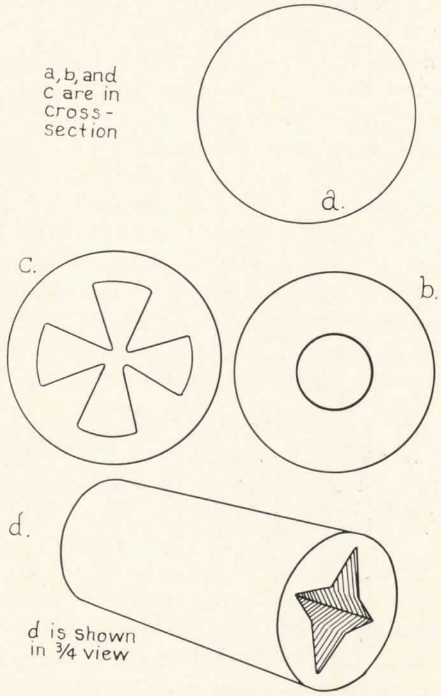


Figure 3. Types of solid propellant grains are shown. The perforations in grains *c* and *d* are shaped so as to keep the burning surface area the same throughout the time the fuel is burning out radially.

High temperatures and pressures, which develop quickly within the case once the propellant is ignited, increase the propellant's burning rate and therefore the rate at which gases are generated. When you know the maximum operating pressure within the motor case, you will be able to choose a material and thickness that will withstand this pressure. Since your calculations will be somewhat inexact, and since your rocket motor case material may have hidden flaws, you must allow a liberal margin of safety, *at least a margin of 4.*

What materials should you use? This depends on the power of your propellant, and the size and shape of your rocket case. To select the right material for safe operation, you should find out about the properties, such as tensile strength, compressive strength, and shear strength of the materials you are considering. These properties of strength are not the whole story. Some very strong materials are nevertheless very brittle, and cannot stand the shock of rocket firing. For this reason, never use cast iron. And do not use seamed pipe, which is unreliable. You should ask a person who is experienced in mechanical engineering or a related field to help you with your design, or at least look over your completed design to see if it is reasonably satisfactory.

Once you have chosen the materials, you still have the problem of joining the various parts of the motor case. Particularly important is the method you use to fasten in the head end and the nozzle. A weak joint at either end means that either can become a death-dealing projectile. Rocket manufacturers use various methods to secure strong joints, such as welding, brazing, threading and pinning. In the case of a threaded joint, remember what great pressures you are working with, and seal the threads against gas leakage.

The high temperature at the throat of the nozzle may call for the use of temperature-resistant materials like graphite to keep the throat from burning open to a larger diameter. Efficiency is lost if the nozzle opening is not well matched with the rate at which gases are produced while the fuel charge burns. Insulation to protect the tube from the burning propellant, and the choice of the tube material itself, are good subjects for study if you can learn enough about propellant burning temperatures, heat transfer, and materials to calculate the best design combination.

When you have assembled your rocket case, it is a very good idea to give it a hydrostatic strength test before loading it. A $10 grease-gun can give you pressures up to about 10,000 pounds per square inch, which you can measure with a simple pressure gage.

Finally, there is the problem of designing the rocket igniter. For the igniter material you should choose a substance which is suitable for the propellant you are using. Substances such as fulminate of mercury are too violent in their action, and are likely to damage the propellant grain. Since igniter compositions burn extremely fast, they should be placed in a relatively open area within the motor case or they may rupture the grain.

To be safe, the rocket motor igniter must permit operation from a remote location. This can be arranged by means of a simple electrical circuit. Safer still is an electrical circuit with safety interlocks, such as is described under "Testing Your Rocket."

These problems of rocket design require a lot of knowledge and a lot of work to overcome. The work can be shared among the members of your rocket club. Your rocket club sponsor and the readings listed below can provide the knowledge.

Many of these readings are highly technical, but all of them contain sections that give important basic information in language any high school student can understand.

History

V-2, W. Doernberger (Viking Press)

The Men Behind the Space Rockets, H. Gartmann (McKay)

Development of the Guided Missile, K. W. Gatland (Philos. Library)

Rockets, Missiles & Space Travel, W. Ley (Viking Press)

Men, Rockets and Space Rats, L. Mallan (Messner)

The Viking Rocket Story, M. W. Rosen (Harper & Bros.)

The Rocket Pioneers, B. Williams & S. Epstein (Amer. Rocket Society)

Jet Propulsion Magazine, (Journal of the American Rocket Society), November 1955

Basic Engineering

Handbook of Chemistry & Physics, C. D. Hodgman, ed. (McGraw-Hill)

Handbook of Chemistry, N. A. Lange, ed. (Handbook Publishers, Inc.)

Mechanical Engineers Handbook, L. S. Marks (McGraw-Hill)

Chemical Engineers Handbook, J. H. Perry, ed. (McGraw-Hill)

Fire Protection for Chemicals, C. W. Bahme (National Fire Protection Assn.)

Accident Prevention Manual for Industrial Operations, National Safety Council

An Introduction to Scientific Research, E. B. Wilson (McGraw-Hill)

"*Recent Research on Explosibility of Dust Dispersions*," Industrial & Eng. Chemistry, April 1948

Materials Engineering

Metals Handbook, American Society for Metals

Materials Handbook, G. S. Brady (McGraw-Hill)

Strength of Materials, J. P. Den Hartog (McGraw-Hill)

Engineering Materials Manual, T. C. Dumond, ed. (Reinhold)

Strength of Materials, A. Morley (Longmans, Green)

Theory of Plates & Shells, S. Timoshenko (McGraw-Hill)

Strength of Materials, S. Timoshenko (Van Nostrand)

Rocketry and Propulsion

"*The Physics of Rockets*," *Amer. Journal of Physics*, Jan. and May, 1947

Aerodynamics, Propulsion, Structures & Design Practice, E. A. Bonney, M. J. Zucrow, C. W. Besserer (Van Nostrand)

Rocket Propulsion, E. Burgess (MacMillan)

Rockets and Guided Missiles, J. Humphries (MacMillan)

"Liquid Propellant Handling, Transfer & Storage," *Industrial & Eng. Chemistry*, April, 1956

"The Toxicity & Health Hazards of Rocket Propellants," *Jet Propulsion*, July-August 1954

Rocket Propulsion Elements, G. P. Sutton (Wiley)

Interior Ballistics of Sold Fuel Rockets, R. N. Wimpress (McGraw-Hill)

Principles of Jet Propulsion, M. J. Zucrow (Wiley)

Rockets, Guns & Targets, J. E. Burchard, ed. (Little, Brown)

Rockets, R. H. Goddard (Prentice-Hall)

Rocket Development, R. H. Goddard (Amer. Rocket Society)

Testing Your Rocket

Thrust Stand Experimentation

Rocket experts often make hundreds of tests on a thrust stand before they ever launch a rocket of new design into the air. The measurements made in these tests help them find ways of improving the performance and reliability of the rocket.

Thrust stand experiments are one of the best ways for you to learn the field of rocketry and experiment with your own design ideas. They give you the opportunity to make measurements and tests on the rocket while it is actually burning. These measurements and tests

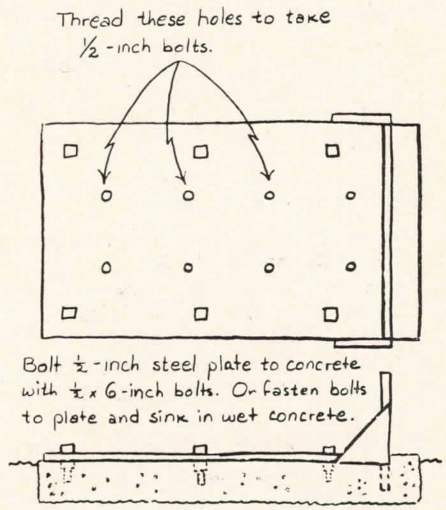


Figure 4. A basic rocket mooring plate is shown. Your rocket must be firmly fastened down. This mooring plate can be used for experiments in which you are measuring temperature, as in Figure 12, or pressure, as in Figure 13.

cannot be made on a rocket in flight except with the aid of extremely elaborate and costly electronic telemetering equipment few amateurs can build or afford. Tests on the thrust stand can be made safe more easily than flight tests. Small rockets (containing, say, less than a quarter pound of propellant) can be tested on a thrust stand with reasonable safety if the thrust stand is placed in an enclosure in the center of a 5- or 10-acre field. But safe flight tests of even small hobby rockets require so many hundreds of acres of range that it is hardly practical to carry them out anywhere but on a government reservation used for artillery testing or an industrial rocket testing range. Finally, testing your rocket on the thrust stand gives you a much better chance of recovering the parts of a rocket that blows up. These parts may be usable in a later test, and examining them may reveal why the rocket failed.

Professional rocket makers are very careful to protect themselves and others against explosion hazards. They have found that *the only safe way to test a rocket is to assume that it will explode, and take the appropriate precautions.* They choose test locations that are remote from houses and traffic, and encircle them with strong fences that keep out wandering hunters and fishermen and curious passers-by. Second, they build massive test structures of steel-reinforced concrete, and place the rocket to be test-fired inside, fastening it down securely. Third, they use a warning system, a klaxon horn or a bell, which notifies all the people in the area that a test is about to take place and that they must take cover. Fourth, they close the switch that fires the rocket at a location distant from the rocket and protected from any possible explosion. Fifth, the electrical circuit is so arranged that a series of actions, such as closing a succession of switches, is required before the circuit is closed and the rocket fires — this guards against accidental or premature firing.

Some of these precautions may sound too elaborate or expensive for your group. Since you will be working with relatively small rockets, some of the precautions can be modified — a lighter structure instead of the reinforced concrete structures professionals use, a simpler electrical firing circuit. But none of these five precautions should be disregarded.

Figure 4 shows a basic rocket mooring plate, for you to use when you do not plan to measure the rocket's thrust; Figure 5 shows two designs for rocket supports; and Figures 6a and 6b show simple schemes to prevent accidental or premature firing.

Figures 7 and 8 show two rocket firing bays that will confine most of the fragments of a small rocket in the thrust stand area. However, since metal parts

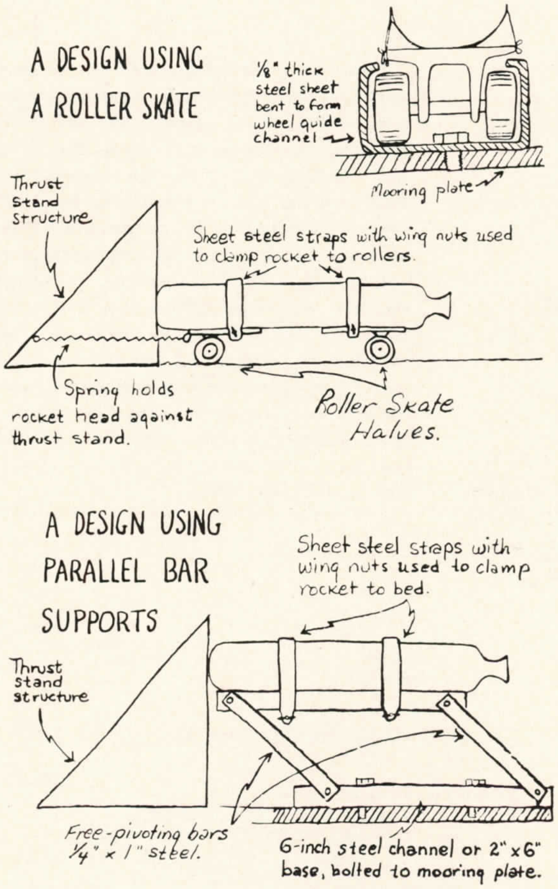


Figure 5. Designs for thrust stand rocket supports are shown. To measure the thrust of your rocket, you must mount it so that it is free to move a limited distance, on parallel bars or on wheels, as here.

can still bounce to a considerable height out of even these enclosures, you must also protect yourself during a firing. You can do this by digging a foxhole, which should be covered by a 1/8-inch sheet of iron; or you can construct a covered barricade of logs or railroad ties. Of course either of these shelters should be well away from the firing bay.

You should think of your rocket firing range as very much like a rifle range, and keep similar safety rules. The principal difference you should keep in mind is that you are burning much larger amounts of propellant than any rifle cartridge contains. And the layout should provide protection in all directions from the rocket, since explosions must be expected.

Some communities, perhaps yours, are making plans now to build hobby rocket test ranges with all the safeguards provided. Look into this.

Every community has explosives handling laws that require public authorities to approve the firing of experimental rockets. Go to your fire marshal and ask him to approve the design of your rocket test structure. He will tell you what supervision is required when you make your tests.

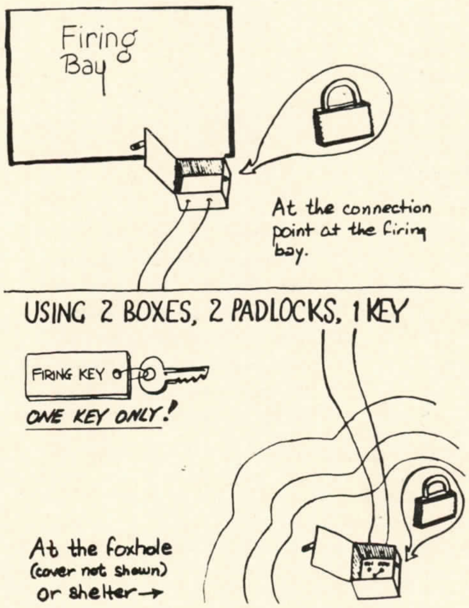


Figure 6a. This firing system should give positive safety protection, keeping others from setting off the rocket while the firing officer is making connections at the firing bay. Enclose the firing switch (in your foxhole or shelter) and the electrical connections (at the firing bay) in strong wooden boxes with lids. Lock the lids with two locks that can only be opened by one key. To begin the test, the Firing Officer sets the firing switch in the OFF position, and locks the switch box. Taking the key with him, he goes to the connection box at the firing bay. He unlocks it, makes the necessary connections, and locks it again. Then he returns to the foxhole or shelter, unlocks the switch box, and is ready to fire.

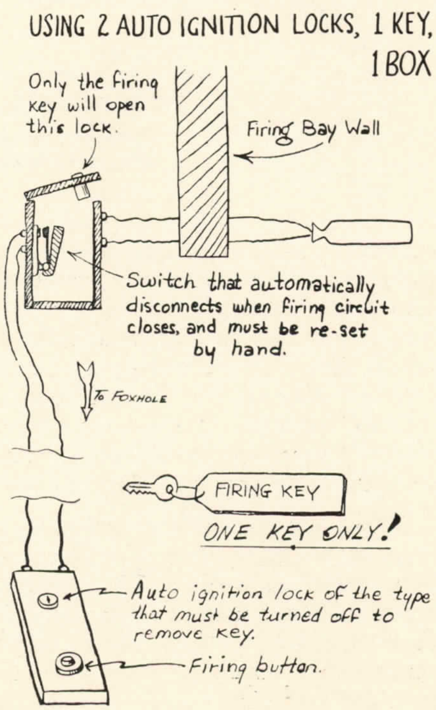


Figure 6b. This safety firing system is even better than the one shown in Figure 6a, but may be harder to put together.

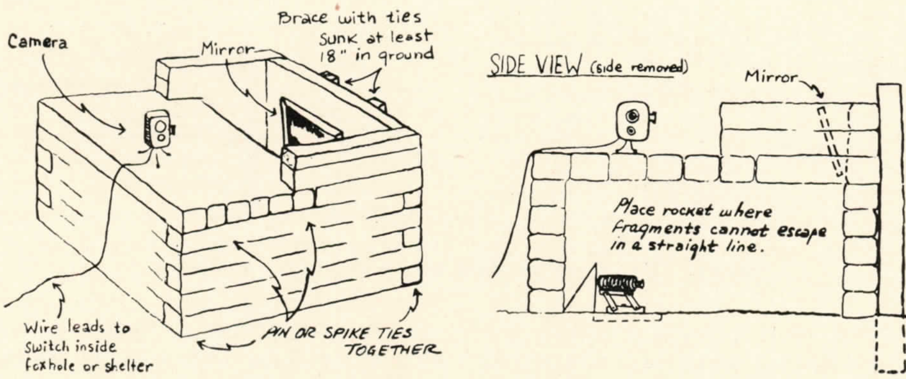


Figure 7. This sketch suggests the design of a firing bay for use with small rockets (up to ¼ pound of propellant). Fasten the railroad ties firmly together.

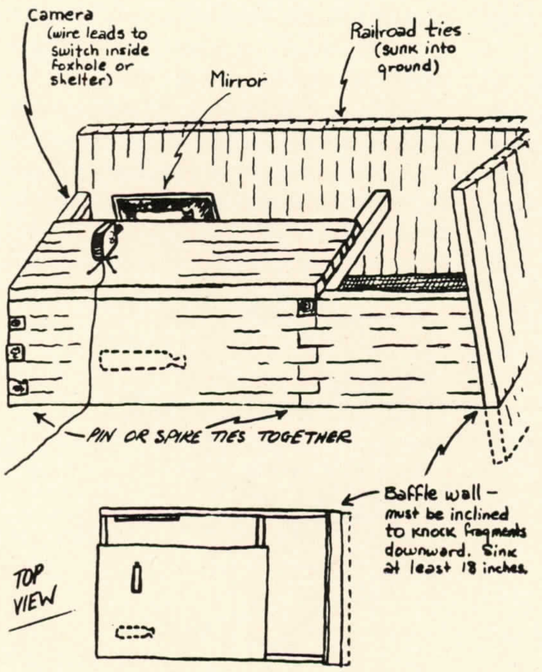


Figure 8. This is an improved design for a firing bay. Propellants which produce much smoke may make photography difficult in the firing bay shown in Figure 7. This improved design, although more difficult to build, allows the smoke to vent and therefore may give you better pictures. Note that the height of the various walls and the placement of the rocket have to be carefully adjusted so that fragments of an exploding rocket cannot escape in a straight line. A high pile of sand may be substituted for the inclined baffle wall.

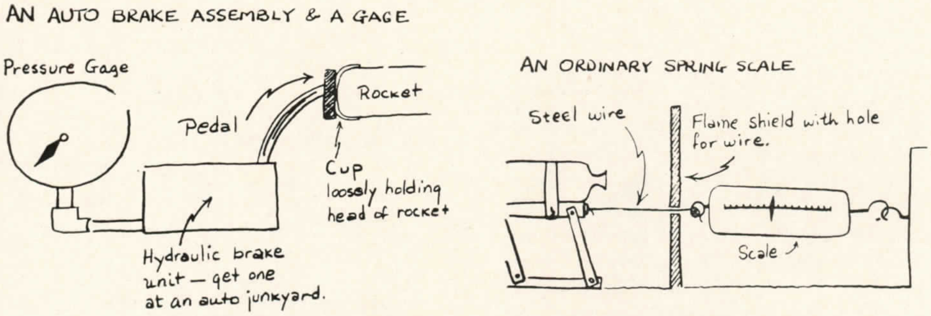


Figure 9. Two test rigs for taking thrust measurements are shown.

When your rocket is fired you may simply want to watch, or you may want to make measurements in some recorded form. If you want to watch, do it by positioning a pair of mirrors so that you can see the rocket without getting in the line of fire. The same mirror arrangement can protect your home movie camera if you are making a record of the firing. You can make records of a thruststand firing in several ways:

To find out how long the rocket burns, you can mount a home movie camera near the rocket. By dividing the frames-per-second speed of the camera into the number of frames of film that show the rocket actually firing, you will arrive at a good close estimate. A more exact method to find the burning time is to put an electrical clock with a sweep-second hand in the camera's view, along with the rocket. It may be necessary to glue a small triangle of paper on the tip of the clock's second hand, to be sure the time record will be visible on the movie film.

Since the camera must be placed closer than it is safe for you to be when the rocket fires, it will be necessary for you to work out a way of starting and per-

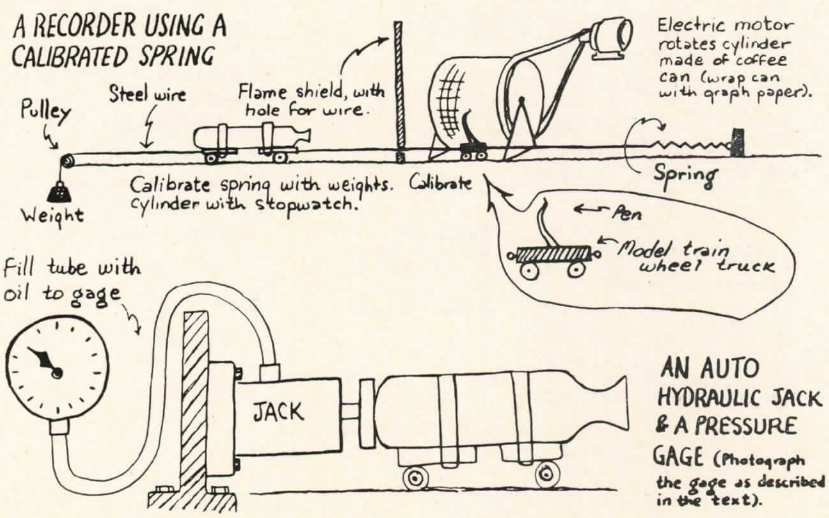


Figure 10. Here are two more test rigs for measuring thrust.

haps stopping the camera from a distance. An electric solenoid or a mousetrap can be used to supply the energy to push the camera starter button, if you do not want to modify the camera mechanism itself.

A movie camera can also provide a record of other measurements. Indicating-type instruments, with dials or pointers, such as are shown in Figures 9, 10, 12, and 13, can be photographed during the firing time in the same way you photographed the electric clock. Or, if you do not wish to use a movie camera, you can fit a pen to the pointer of the indicating instrument and make a direct record on graph paper. If you will mount the graph paper on a rotating cylinder, this will give you the best results. Start the cylinder rotating before the rocket fires, so that the pen will draw a "zero line" on the paper. Then, as the rocket fires, the pen will move up on the graph to give a continual record of the changes that occur during the firing. By changing the pulleys that drive the cylinder you can make the graph paper move past the pen at the right speed. By previously timing the movement of the cylinder between two marks on the graph paper you can find out how many inches of graph paper equals a second of time for a particular pulley arrangement.

Set-ups for taking some of the important rocket motor measurements are shown in Figures 9 through 13.

Flight Tests

Measuring the performance of your rocket in flight is quite difficult. Taking motion pictures will provide a record that will allow you to calculate acceleration and velocity for the first few seconds of flight, but will usually permit only a small part of the flight to be followed. If you and your friends have exceptional skill in following the rocket, you can calculate maximum height by the use of two surveyor's theodolites located some distance apart. The fact that the rocket does not ascend in an exact vertical path (rockets rarely do unless equipped with guidance controls) will give you some difficulty. With height, burning time, and time of flight known, and the total impulse determined in thrust stand tests, you may be able to find the effect of air drag by laborious calculations.

In general, worthwhile experimentation through flight testing will require the combined skills of an unusually ad-

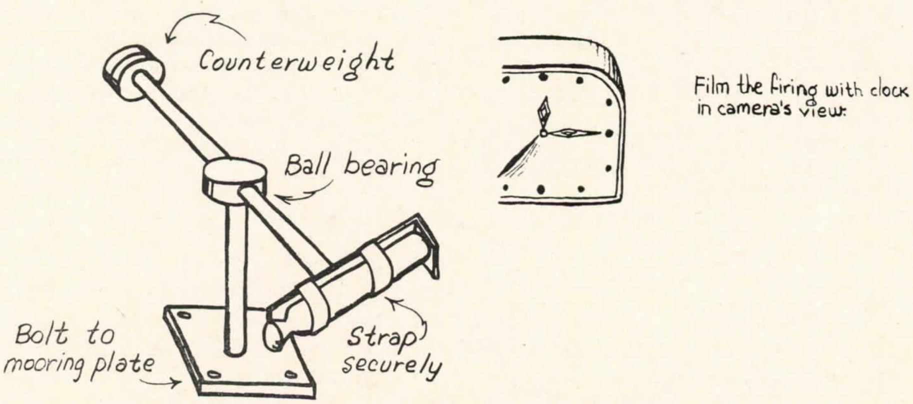


Figure 11. Here is how to measure the total impulse of your rocket. Get the speed of rotation by filming the firing with an electric clock in the camera's view. Calculate the angular inertia of the rotating arm assembly to convert the speed in rpm to total impulse.

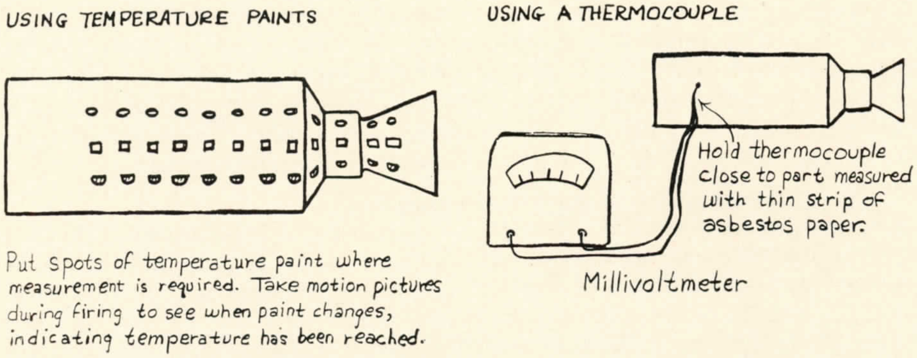


Figure 12. You can measure the rocket case temperature in these two ways. Put spots of temperature paint where the measurement is required, then take movies to record when the paint changes its appearance. Since the paints melt and run, put lower temperature paints at the bottom, higher temperature paints at the top. One commercial paint suitable for this measurement is called "Tempilaq." Or use a thermocouple rig.

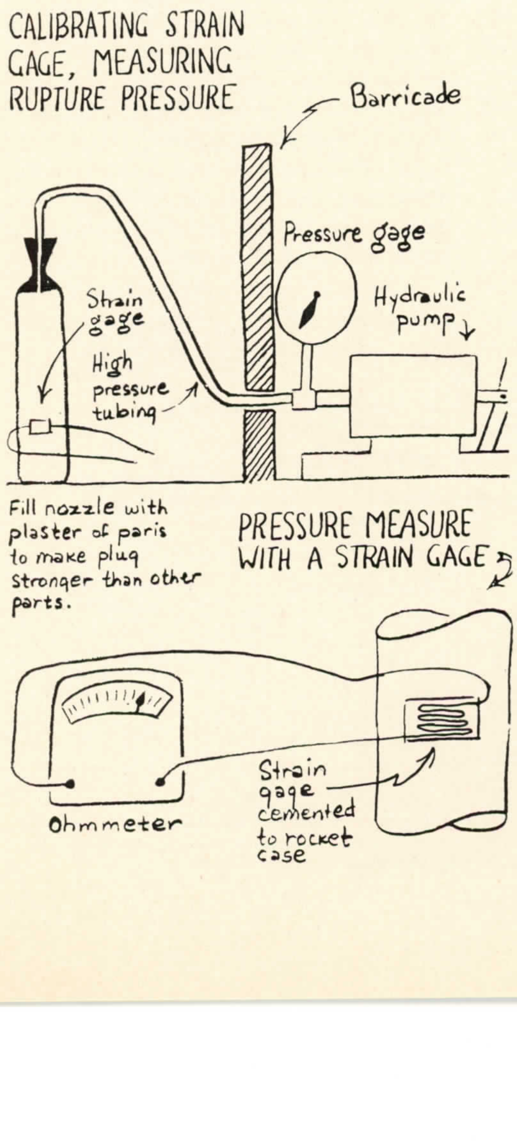


Figure 13. Take pressure measurements on your rocket case in this way. Pump pressure up, comparing the strain gage reading with the pressure, until the case ruptures. If the case and pump system are *completely* filled with liquid, the explosion effect when the case ruptures will be fairly small.

vanced rocket club. Rocket motor knowledge, aerodynamic design knowledge, and mathematical exertion will be required. If you are fortunate enough to be in such an advanced group, you are already acquainted with more information than this brief article can cover.

In deciding how much range will be needed to flight-test your rocket safely, you should assume that the rocket will fly at 45 degrees to the vertical. This is the course that will take it the greatest distance away from the starting point. A circle with this radius will describe the area from which passers-by must be kept during the test. Air drag can be neglected in making your calculation, but you should take into account the reduced weight of the rocket as the propellant is consumed.

A properly barricaded foxhole fifty yards or so away should give you reasonable protection during the test. You should have a system that will allow you to ignite the rocket without leaving your foxhole.

Several rocket clubs that have carried their rocket development through the thrust stand stage have been able to arrange for flight tests on a military reservation. If your club has done a particularly good job in its earlier work, you may even be able to get a professional rocket flight test installation to make records of your rocket's flight with the advanced tracking instruments they possess. A field trip of this sort can be a very rewarding climax to a rocket club project, if it can be arranged.

You should be well along in your thrust stand studies before you ask permission for such a field trip, since your best admission ticket is your record of good work in design and testing. The public relations officer of your nearest Defense Department installation should be able to put you in touch with the people who can tell you whether such a trip can be arranged.

Organizing a Rocket Club

If you expect to go very far into the rocket hobby, you should see after reading this article that your experiments will require you to make quite a few pieces of test apparatus. While the construction of the apparatus is one of the very interesting parts of amateur rocketry, your primary desire will probably be to make actual tests or rocket motors. By working in a club with a dozen or so partners, you can more quickly complete the construction of this apparatus and start the actual testing of your rocket much sooner. You can also get the benefit of working with others whose knowledge, say, of electronics, or whose skill in construction is more advanced than your own. Even a fairly simple rocket test can keep quite a large group busy in design, construction, testing, and calculation of results.

Here is how you can go about organizing an amateur rocket club:

1. *Get at least one adult sponsor.* Your school science teacher is usually a very good person to ask. He will have useful information on his bookshelf, and he may be able to get shop space and special supplies for the club through the school. The father of one of your club members may be willing to be a sponsor. If he has had scientific training, he will be able to help you in your work. However, if your club wishes to build its own rocket, at least one of your sponsors should be an engineer or scientist.

2. *Organize a safety committee.* Every design and test plan should be checked and approved by this committee. Every hazardous part of your activities should be carried out according to the checklist prepared by this committee.

Checklists save lives. Airline pilots never trust their memories where safety is concerned — before every takeoff a pilot checks off every instrument and control in the order they are listed in his safety manual, item by item.

Members of the safety committee can be the range officers whenever you carry out firing tests, and should be responsible for storage and transportation of propellant and live rockets.

3. *Organize a group of project committees.* Each can carry out a different part of the project you are working on. For example, you can assign one committee to each of these functions:

Plan the tests

Design and build special apparatus

Select and set up instruments

Operate and control the test

Calculate the test results

4. *Find a safe place to work together.*

5. *See the fire marshal.* When you have organized your club and decided what kind of rocket work you want to do, go with your sponsor to your local fire marshal's office and tell him about your plans. He will tell you the local laws you must observe, and whether you must obtain permission each time you plan to make firing tests. He may be able to locate a safe place to make your tests.

6. *Get in touch with others.* See if you can swap ideas with other rocket clubs and perhaps work out plans for interclub competitions. Get in touch with national scientific society chapters in your community, such as the local section of the American Chemical Society. They will have suggestions for you, and may be able to help sponsor you.

You Can Help Develop Amateur Rocketry

The rocket hobby is so new that interclub competition is not yet completely organized. It seems likely that, before long, rules for rocket competition will be established, based on classifying rockets by size and power or use of certain standard components. Model airplane clubs compete on this basis. The result of this kind of organized competition is the development of safer and more versatile designs.

Your club can help by concentrating on a specific size or type of rocket, and refining its designs on the basis of careful experimentation. Your safe experimentation will speed the day when rocket hobby work will be recognized and rocket competition is an activity every community will welcome and be proud of.

Not many years ago "hot-rod" racing was in the same situation that amateur rocketeering is in now. With poor organization or none at all, hot-rodders wasted their energies without clearly defined goals. They also endangered the public because they had not developed rules of safety. There was even talk of banning hot rods.

Today hot-rodders are a recognized hobby group whose experiments are of interest even to auto manufacturers. Because they organized their activities and concentrated on careful testing and competition by class, they have succeeded in developing safer and more versatile designs. They have obtained adult sponsorship and follow safety rules for the protection of themselves and others. They have earned their communities' encouragement and respect.

Your own conduct as an amateur rocketeer can bring about the same result, and contribute to the training of the future scientists and engineers our nation needs.

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