FORTY YEARS OF MODEL ROCKETRY

A SAFETY REPORT

Prepared for the National Association of Rocketry

by

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FOREWORD

This report was prepared specifically for those persons interested in the safety of model rocketry and model rocket motors. It describes the technology of the hobby. It summarizes the safety history of the hobby over a 40-year period. It summarizes the current rules and regulations governing the hobby including the endorsements of national, governmental, and civic organizations who have recognized the safe, educational, and recreational aspects of the hobby.

The hobby of model rocketry began in 1957 in response to the launching of the Soviet Sputnik satellites and the beginning of the Space Age. Many young people were hurt trying to build rockets and rocket motors without adequate knowledge, equipment, or safety precautions. Model rocketry was developed as a synthesis of model aviation, pyrotechnics, and professional rocket engineering. From model aviation came materials such as balsawood, paper, and plastic as well as construction techniques, bonding agents, and paints. From the ancient art of pyrotechnics came the inexpensive factory-made solid-propellant rocket motor. From professional rocket engineering came the quality control standards and procedures that elevated the model rocket motor to a professional level of safety and reliability, the aerodynamic principles that ensure safe and predictable flights with full recovery of the entire model, the safety precautions and operating codes that have made model rocketry the safest of all hobbies (except perhaps stamp collecting), and, finally, advanced model rocket motor technology that has continued to allow the manufacture of progressively safer and more reliable motors.

Basically, the safety success of model rocketry has resulted from:

(1) a factory-made, mass-produced solid propellant rocket motor of tested and proven design and predictable performance;

(2) positive control of the launch conditions using electrical ignition;

(3) airframes made from non-metallic materials such as paper, wood, and plastic that are light and strong but will absorb any impact energy by self-destructing;

(4) a recovery system that returns the model rocket safely to the ground in a condition to be flown again by repacking the recovery system and installing a new, factory-made model rocket motor.

An on-going program of quality control testing and retesting is carried out by the National Association of Rocketry (NAR) and the model rocket manufacturers to assure that products — especially model rocket motors — are produced that meet the strict national standards for safety, performance, and reliability of the National Fire Protection Association's NFPA 1122 "Code for Model Rocketry," the National Association of Rocketry's own NFPA-compatible standards, and federal regulatory requirements. In addition, model rocket components and systems have been tested and re-tested for 40 years to determine potential hazards and to reaffirm previous test results. Since 1957, people involved in the hobby and public safety officials have been constantly amazed and pleased by test results that have continued to indicate a higher level of safety than suspected. NAR and the model rocket manufacturers have continually worked to devise and conduct more difficult safety tests that would reflect the environments encountered in manufacture, shipment, storage, and use, probing the "edge of the envelope" of model rocket safety. The tests results often seem incredible, but they are repeatable.

The NAR and the model rocket manufacturers do not recommend that model rocket products by handled or misused in the manner required to perform the tests summarized in this report. If done at all by others than the NAR and model rocket manufacturers, such testing should always be carried out only by public safety officials who may be interested in checking these results. These tests are NOT intended for public demonstration or academic instruction.

Forty years after the hobby began, model rocketeers can proudly boast of about 500 million safe flights. There have been a few burned fingers but only one accident that could be classed as "serious" — a young spectator lost an eye as a result of improper construction and flight operations of a model rocket conducted by a science teacher before a class. ALL of the accidents in model rocketry have been caused by product misuse or failure to read and follow explicit instructions and safety rules. Considering the enormous number of model rocket flights — more than 20 million per year at the present rate — this safety record is better than that of Little League Football or even bicycle riding.

This is in direct contrast to an estimate made in 1957 by a professional rocket society that predicted more than one major injury in each *seven attempts to launch* a non-professional rocket.

Model rocketry's outstanding safety record is a result of a unique long-term co-operative effort between manufacturers, public safety officials, and users to develop, implement, and abide by workable controls and regulations at the manufacturing and distribution levels and simple yet explicit common sense safety rules at the user level. In these litigious times, manufacturers do not wish to produce unsafe products. Public safety officials don't want to be burdened by over-regulating something that has proved to be safe. Users want success, not accidents and injuries. Model rocketry's safety record has thus depended upon informed self-interest at all levels...and it has worked!

This report will show how and why this unique system has evolved and will strive to answer the most commonly-asked questions and allay the most commonly-held fears.

After 40 years, safety is still the top priority in model rocketry. But safety is no longer something that should be of critical concern to public safety officials, school officials, and other public servants. Indeed, many of them built and flew model rockets when they were young — many still do — and the contents of this report will hopefully be useful to them in convincing those who weren't model rocketeers when they were young.

PART ONE

WHAT IS MODEL ROCKETRY?

Model rocketry is:

(a) an educational tool;
(b) a "technical recreation" or hobby.
(c) an international aerospace sport;

Who says so?

The National Fire Protection Association (NFPA)
The National Aeronautics and Space Administration (NASA)
The United States Air Force (USAF)
The United States Navy (USN)
The United States Army (AUS)
The Federation Aeronautique Internationale (FAI)
The International Astronautics Federation (IAF)
The American Institute of Aeronautics and Astronautics (AIAA)
The National Aeronautics Association (NAA)
The National Science Teachers Association (NSTA)
The Civil Air Patrol (CAP)
The 4-H Clubs of Ammerica
The YMCA/YWCA/YMHA/YWHA
The Boy Scouts of America

What is a model rocket?

A model rocket is an aerospace model having the following characteristics:

1. It is made of paper, plastic, wood, and other non-metallic materials without any metal as a structural part.

2. It weighs less than 3.3 pounds (1500 grams) and uses less than 4.4 ounces (125 grams) of rocket propellant in accordance with the standards of the NAR and the NFPA.

3. It uses a factory-made solid propellant rocket reaction motor. This motor may either be expendable or reloadable. This eliminates any hazard of compounding and mixing rocket chemicals by the user.

4. Its model rocket motor is ignited electrically from a distance of at least 15 feet using a low-voltage electrical source and a launch controller with safety features established by the standards of the NAR and NFPA.

5. It contains a recovery system to lower it safely and gently back to the ground so that it can be flown again.

Who so-defines a model rocket?

A. The National Fire Protection Association NFPA 1122 Code for Model Rocketry.
B. The Federation Aeronautique Internationale Sporting Code, Section 4b.
C. The American National Standards Institute.
D. Federal law: Section 307, 72 Statute 749, 49 U.S. Code 1348, "Airspace Control and Facilities."

Is a model rocket a toy?

No. A flying model rocket is a scientifically-designed educational aero model, not a toy. It is capable of attaining speeds of more than 200 miles per hour. It should be used only as instructed in accordance with all safety codes.

How long does it take to build a model rocket?

Some model rockets are available as carefully-designed almost-ready-to-fly models requiring little or no skill on the part of the user; they can be launched within minutes by preparing the recovery device and installing a model rocket motor. Simple model rocket kits can be assembled with ordinary hobby tools and glue in thirty minutes while others require more time. Complex scale models and advanced high-performance model rockets often take weeks or months to assemble.

What is required to fly a model rocket?

A flying model rocket is but one part of a system consisting of the model itself, a model rocket motor, a launch pad, an electrical launch control device, an electrical igniter for the model rocket motor, and a source of 6-volt or 12-volt electricity such as a battery.

How does a model rocket operate?

Ignition of the model rocket's motor is accomplished electrically by the user at a distance of 15 feet or more from the launch pad.

The launch pad provides support for the model rocket during pre-flight operations and provides the initial guidance for the model rocket as it begins its flight when its airspeed is too low for the fins to stabilize the model rocket.

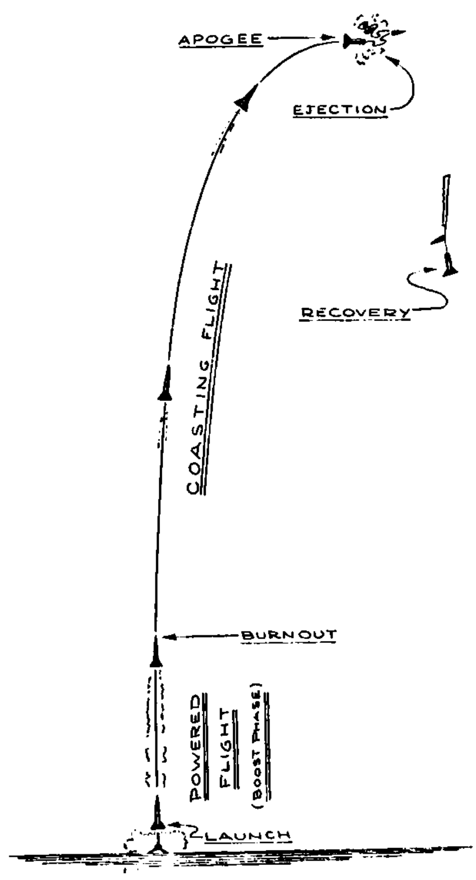
At the end of powered flight after a rocket motor thrust period varying from 0.2 seconds to as long as 10 seconds (depending upon the type of model rocket motor chosen by the user), the model rocket may be 50 to 500 feet in the air and moving straight up at a speed of 100 miles per hour or more. Some advanced model rockets have reached the speed of sound.

Following the thrust phase of the flight, a time-delay element in the model rocket motor is automatically activated, permitting the model rocket to coast upward for several seconds to its peak altitude (apogee).

At or near apogee and at a pre-determined time after ignition — pre-selected by the user in choosing the type of model rocket motor to be used for the flight — the recovery ejection charge in the model rocket motor activates. This produces a retro-fire puff of gas that pressurizes the inside of the hollow body tube, forcing the recovery device forward to dislodge the nose. (For further technical details on the operation of a model rocket motor, see Part Two of this report.) Some models use more complex mechanisms activated by the ejection charge. The recovery device —a parachute, streamer, helicopter rotor, or gliding wing — then deploys. Parachutes and streamers are the most commonly-used recovery devices. The entire model rocket with all its parts tied together then returns to the ground in a gentle manner so that it's undamaged and can be prepared for another flight.

Another flight can be made almost at once. The user re-packs the recovery device and installs a fresh model rocket motor and electrical igniter in the model rocket.

Some model rockets have flown more than 100 times.



What are the parts of a simple model rocket?

Most model rockets, regardless of their size, construction, and performance capabilities, usually have the following components:

a. A hollow plastic or balsawood aerodynamically-shaped nose that can come off the model.

b. A light-weight, hollow plastic or paper body tube that is also the main structural airframe part.

c. One or more launch lugs affixed to the size of the body tube that in turn slip over the guide rod of the launch pad.

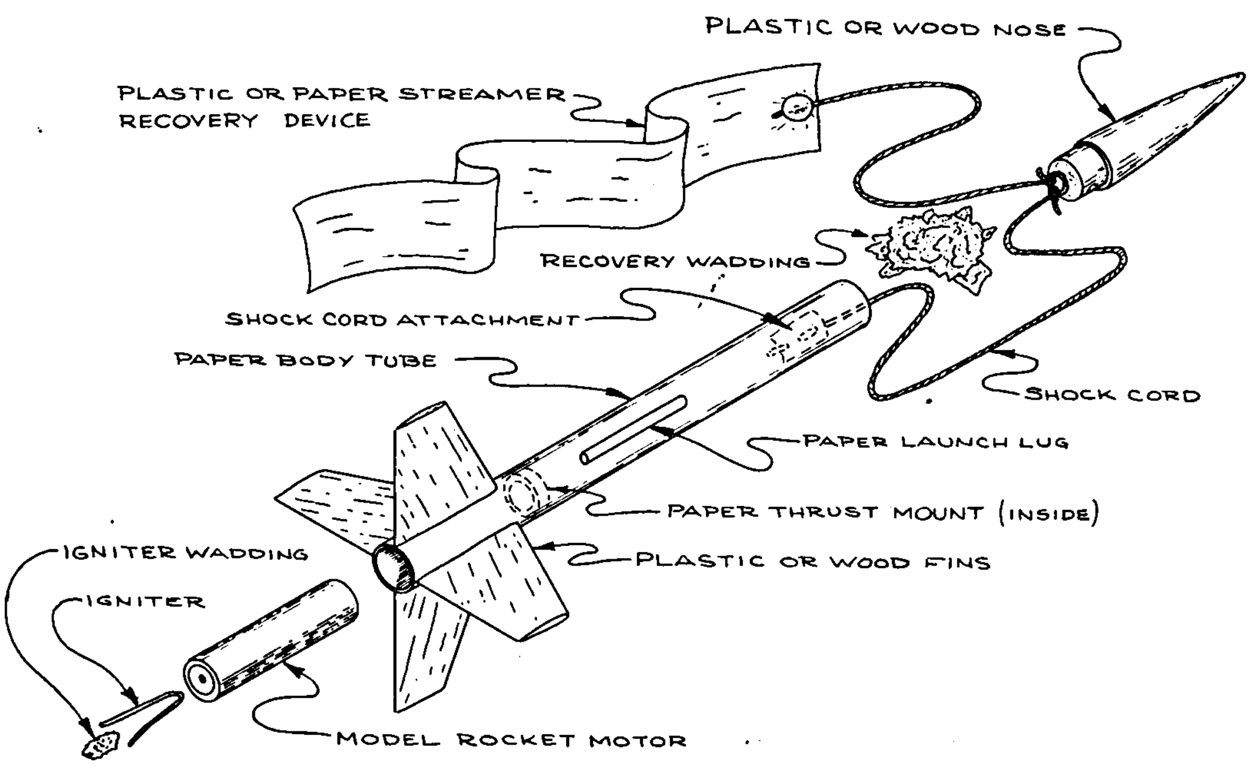
d. A recovery device such as a plastic or nylon parachute or a simple plastic streamer that is packed inside the body tube and ejected forward by a "retro-fire" action of the model rocket motor at a predetermined time in the flight at or near maximum altitude or apogee.

e. A replaceable factory-made, mass-produced solid propellant model rocket motor of tested performance quality along with the thrust mount and retainer that hold it properly in the model rocket airframe. Model rocket motors are usually one-use expendable units, but advanced model rocket motors may be reloaded using materials manufactured and intended for this purpose.

f. Fins made of plastic, balsawood, paper, or plywood which keep the model rocket travelling in a predictable flight path like fletching feathers on an arrow.

g. Expendable, non-flammable, bio-degradable wadding or an internal baffle system to protect the recovery device from the retro-fire action of the model rocket motor.

h. An electrical igniter to start the model rocket motor.



How is a model rocket recovered?

The means used to recover a model rocket depend upon the design, construction, and weight of the model. Plastic parachutes or streamers are the most commonly-used recovery devices. However, airframe tumbling, deployment of helicopter rotors, and gliding are also used in advanced model rockets. If the model is designed to separate into two or more parts for recovery, each part must be lowered by a recovery device. The basic concept is to allow all parts of the model rocket to return to the ground safely and gently so the model rocket can be flown again by repacking the recovery system and installing a fresh model rocket motor.

Who are the model rocketeers?

Model rocketeers range in age from 8 to 80 and include men and women as well as boys and girls. Most young people involved in the hobby are about 13 years old. More than 50% of the model rocketeers are adults, some of whom started building and flying model rockets when they were teen-agers. For 40 years, model rocketry has shown itself to be an outstanding parent-child activity, and many old-time model rocketeers are now guiding their children into the hobby because model rocketry appeals to such a broad spectrum of age groups. A parent can use model rocketry to teach children many things beyond the simple activity of putting together a model rocket kit and flying it. Most of the people involved are interested in science and technology and are highly intelligent. A study conducted among students in Pennsylvania indicated that a model rocketeer has an average I.Q. of 141.

Is there a minimum age for a model rocketeer?

Experience indicates that children less than 10 years old may have the enthusiasm but not the necessary manual skills to build a model rocket without adult supervision and assistance although they are certainly capable of operating the simpler "ready-to-fly" model rockets. The instructions and safety rules that accompany every model rocket kit are simple, visual, and easy to understand. Decades of experience have showed that people, young and old, will follow good instructions and observe reasonable and understandable safety rules because they want success. All model rocket manufacturers, however, recommend adult assistance and supervision in building and flying model rockets for those children under 12 years of age. (This is no longer considered mandatory as it was 30 years ago by the NFPA and other organizations.) Adult supervision is recommended because a young rocketeer's enthusiasm and excitement could cause him to overlook some important point in the pre-flight sequence; the "double-check" feature of adult supervision can often prevent mistakes made in haste and excitement. However, it's fair to point out that model rocketry's safety record has NOT depended upon adult supervision and that all mistakes made in haste and excitement were non-hazardous in nature and result. The adult presence merely helps assure the important element of success.

Is model rocketry a learning tool?

Yes, it's a learning tool in disguise. Science and industrial arts teachers have discovered that model rocketry is a useful and motivating adjunct to academic studies. Since model rocketry combines modern science and technology, craftsmanship and shop practice, individual creativity, and group co-operation in the pursuit of a goal with a healthy outdoor activity, model rocketry isn't confined to young students; many universities have model rocket clubs. Sportsmanship, craftsmanship, self-reliance, discipline, and pragmatic approaches to problems are areas in which model rocketry excels. The hobby has been used with both high-achievement students and disadvantaged or handicapped youngsters because, if the simple rules and instructions are followed, a successful flight is a certainty — and for many of these young people, it may be the first successful thing they've ever done.

Among adults, printers, insurance salesmen, photographers, artists, business executives, rocket engineers, museum directors, recreation directors, and school teachers are included among the five million-plus model rocketeers in the United States.

What does it cost?

A complete model rocket "starter set" consisting of a model rocket, a launch pad, an electrical launch controller, model rocket motors, and electrical igniters is available in various levels of complexity and cost ranging from $25.00 up. Components may be purchased separately. The price of a model rocket motor ranges from $1.00 up. The larger the model rocket and the more powerful the model rocket motor, the higher the price. This economic factor acts to concentrate the majority of youth model rocket flying in the "low performance area of the flight envelope" while more affluent adults are the ones able to purchase the more complex and costly high-performance model rocket equipment. This cost factor also tends to mitigate the purchase of model rocket equipment for deliberate misuse; it costs too much as well as requiring some intelligence to use.

Is model rocketry dangerous?

On the basis of 40 years of public experience and about 500 million model rocket flights, it is possible to state categorically that model rocketry is not dangerous if done in accordance with established and tested safety rules *just like every other human activity*. The majority of accidents thus far have involved such injuries as minor burns. *All incidents have been caused by failure to read and follow the simple instructions and safety rules.* On the basis of an established record, model rocketry is safer than swimming, boating, bicycling, baseball, football, and nearly every other hobby and sport. There is no question that model rocket equipment can be misused just like every other hobby and sport item. After all, a baseball bat can be turned into a lethal club. Because of the early perceived potential for misuse of model rocket equipment leading to injuries, it is truly surprising that the record shows surprisingly little of this.

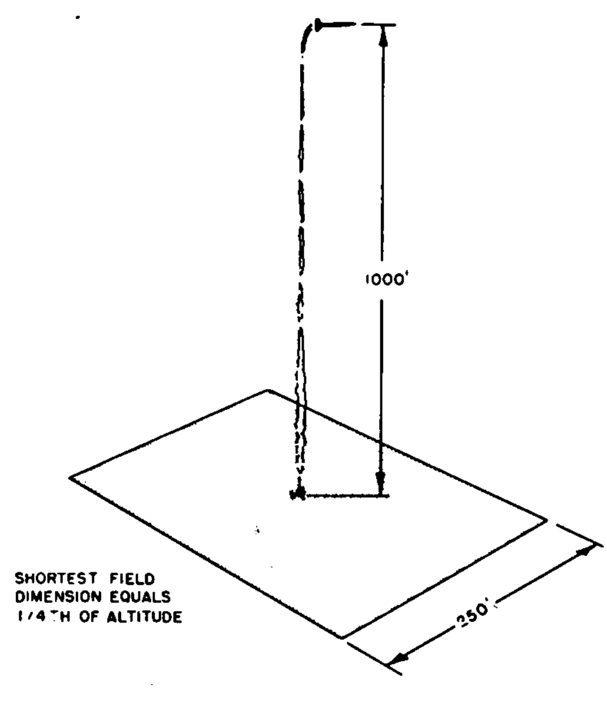
Model rocketry is the safest of all hobbies except perhaps stamp collecting.

How much room is needed to fly model rockets?

Model rocketeers like to fly in the largest available open area so they can get their models back. The biggest problem faced by a model rocketeer involves trees in which descending parachutes and streamers can become snagged.

To determine the shortest dimension of an open area to be used for flying model rockets on a relatively calm day, divide the expected altitude of the model rocket by 4. The flying field should have no horizontal dimension shorter that this number expressed in feet.

For most model rockets propelled by NAR Type A through Type C model rocket motors, a ground area the size of a football field is usually adequate. Model rocket flight demonstrations have been successfully and safely conducted thousands of times on airport ramps, outdoor civic plazas and parks, and even in such places as the Houston Astro-Dome during half-time of a Blue Bonnet Bowl before tens of thousands of people.



Are model rockets a hazard to aircraft?

No. The NAR has conducted comprehensive tests to confirm this. Aircraft face a far greater hazard from bird strikes, foreign objects on a runway, and hail. All jet engines are designed to ingest 4-pound birds and continue to operate. At a national competition, a Cessna-152 flew into a model rocket which disintegrated into a cloud of balsa and paper pieces.

The NAR Model Rocket Safety Code requires that model rockets not be flown into clouds or when aircraft are present over the flying site. This effectively eliminates any potential aircraft hazard. It should also be noted that neither the NAR or the Federal Aviation Administration have any restrictions against flying model rockets within 5 miles of an airport.

The chances of a model rocket actually hitting an aircraft in flight are so vanishingly small as to be insignificant. The U.S. Department of Defense has had to develop very expensive and highly complex multi-million-dollar guided missiles in order to deliberately hit airplanes.

However, it is not recommended that model rocketeers set up flying sites in the approach and landing zones of airport runways. The pilot of an airplane taking off or landing has plenty to do without worrying about model rockets. Several national championships and two international World Championships have been held in the middle of active airports where aircraft operations were not affected. As long ago as 1959, model rockets were part of airshows with no hazard to aircraft and no complaints from some of the world's finest civil and military pilots.

Model rockets may be operated without clearances or waivers from the Federal Aviation Administration (FAA).

What are model rocket manufacturers doing about safety?

In addition to following the national standards established by the National Fire Protection Association in NFPA 1122 "Code for Model Rocketry" and NFPA 1125 "Manufacture of Model and High Power Rocket Motors," the general policy of model rocket manufacturers is this: If it isn't safe, it won't be produced and sold. This is because (a) a tradition of 40 years must be maintained, (b) the hobby was originally created to solve the safety problem of young people trying to make their own rocket motors, not to create a new safety problem, and (c) in this litigious culture, any manufacturer who doesn't produce a reasonably safe product will not long remain in business.

Model rocketry was founded upon the principle of self-policing by manufacturers and users alike. All are well aware that if they don't police themselves, public safety officials and government regulators will step in to do it...and the results may not be palatable to either manufacturers or users.

In pursuit of these goals, all model rocket manufacturers do the following:

1. A copy of the NAR Model Rocket Safety Code is enclosed in each model rocket kit and with every sealed package of model rocket motors.

2. Complete instructions for assembly and use are included in every model rocket kit and package of model rocket motors.

3. All products meet or exceed the standards established by the NAR and set forth in NFPA 1122 Code for Model Rocketry.

4. All model rocket motor types are tested and certified as meeting NFPA standards by the NAR's Standards & Testing Committee.

5. All publications, catalogs, and other printed material from model rocket manufacturers stress safety and the scientific approach to model rocketry.

6. All model rocket manufacturers establish and maintain close co-operative liaison with safety officials at all levels of government, cooperate with the NAR, and participate in the activities of the NFPA's Technical Committee on Pyrotechnics.

What is the National Association of Rockertry?

The National Association of Rocketry (NAR) is a not-for-profit organization of unpaid volunteers who are model rocketeers, NAR is the primary U.S. consumer organization for model rocketry. NAR has thousands of members of all ages, most of them organized into local clubs. NAR membership is reasonable in cost and includes a subscription to *Sport Rocketry* magazine published every two months by the NAR and *The Model Rocketeer* newsletter published in alternate months. Liability insurance coverage for members, clubs, and third parties is available from the NAR at a reasonable cost.

Under the provisions of NFPA 1122 Code for Model Rocketry, the NAR tests all model rocket motor types produced for sale in the U.S. to ascertain they meet NFPA standards. Model rocket motor types bearing the triangular NAR logo have been certified by NAR as meeting or exceeding these standards. The NAR also conducts random sampling tests of production model rocket motors purchased from retail stores around the country. Model rocket motor types are re-tested and recertified on a regular schedule.

The NAR maintains close liaison and co-operates with various government agencies such as the Consumer Product Safety Commission and public safety organizations such as the Fire Marshal's Association of North America. Since 1967, NAR has played an active role on the Technical Committee on Pyrotechnics of the National Fire Protection Association.

Further information about the NAR may be obtained by writing to NAR Headquarters, 1311 Edgewood Drive, Altoona WI 54720, calling 800-262-4872, or visiting the NAR's Internet web site at:

http//www.nar.org.

or the e-mail address:

narhq@eau.net

PART TWO

THE HOW AND WHY OF A MODEL ROCKET MOTOR

What is a model rocket motor?

A model rocket motor is a small reaction propulsion motor designed and manufactured to stringent national standards relating to quality control, safety, and performance limits. It is intended to propel a model rocket into the air and to activate the model rocket's recovery device at the proper time in flight. All current model rocket motors use solid propellants.

What is a solid rocket propellant?

A solid rocket propellant is a mixture in solid form of a fuel (something to burn) and an oxidizer (something for the fuel to chemically combine with and burn). Various types of solid propellants also contain other chemicals that control the burning rate, storage stability, and other safety factors.

What solid propellants are used in model rocket motors?

Two types of solid propellants are used in model rocket motors.

One type of model rocket motor uses a highly-refined form of black powder whose oxidizer is potassium nitrate (KNO_3) with a fuel and binder consisting of carbon and sulfur. The characteristics of this rocket propellant are well-known and highly predictable. It has the lowest energy content (thrust produced per unit weight of propellant consumed, called "specific impulse" by rocket engineers) of all commercially available propellants. It is dead-pressed into the model rocket motor casing by hydraulic pressure in a motor-making machine. Practically all black powder solid-propellant model rocket motors are made by automatic loading machinery. Black powder is primarily used in small model rocket motors ranging from Type ¼A to Type D. More than 95% of the model rocket motors sold and used since 1958 have been black powder model rocket motors.

A second type of model rocket motor uses a "composite" solid propellant of the sort originally developed in 1942 to provide takeoff rocket boost (JATO) for heavily-laden military aircraft. Since then, composite propellants have been technically refined and improved for military missiles and space launch vehicles. The composite propellant used in a model rocket motor uses ammonium perchlorate (NH_4ClO_4) as an oxidizer in a binder/fuel that is an organic elastomer such as synthetic rubber. Various chemicals are added to control stability, ignition temperature, and burning characteristics. Unlike black powder that must be physically dead-pressed into a motor casing to form a propellant charge or "grain," a composite propellant is usually cast and cured in the motor casing (although it may also be cast in molds and later inserted into the casing). Composites have two to three times the specific impulse (thrust produced per unit weight of propellant consumed) of black powder. Composites are normally used in larger model rocket motors ranging from Type D to Type G. The production process of composite solid propellant model rocket motors does not readily lend itself to mass production by automatic machines as in the case of black powder model rocket motors. Therefore, composite model rocket motors tend to be more expensive.

What's inside a model rocket motor?

Regardless of whether a model rocket motor uses black powder or a composite propellant, the design and operation are basically the same. Please refer to the drawing of a "generic" expendable model rocket motor which shows the location of the various parts and ingredients as though the motor were cut lengthwise down the middle to reveal the interior.

The casing is a tube with carefully controlled dimensions. It may be made from convolutely-wound paper or from thermosetting plastic material. Reloadable model rocket motors discussed later use 6061-T6 aluminum motor casings.

The rocket nozzle is formed of dead-pressed ceramic material or, for some composite propellant model rocket motors, machined or molded high-temperature phenolic plastic. It has the distinctive shape of a "de Laval" nozzle used on all rocket motors. The size and alignment of the narrowest portion or "throat" is carefully controlled during manufacture. The throat size determines such parameters as internal combustion pressure and exit gas velocity (and therefore thrust) while careful nozzle alignment ensures that the motor's thrust force goes through the centerline or center of gravity of the model.

The propellant is a solid piece (or several solid pieces in a reloadable model rocket motor) of material having known and controlled combustion or burning characteristics dictated by its shape, density, and composition. Further details may be found in Part Three of this report that deals with the internal ballistics of the model rocket motor.

The time delay is made up of propellant-like material with much slower burning characteristics. It does not produce measurable thrust. It acts as a time delay element between the thrust-producing propellant and the ejection charge.

The ejection charge consists of approximately 0.3 to 0.5 grams of either black powder or granulated composite propellant — less material that in a .22-long cartridge. It is initiated by the end-of-burning of the time delay.

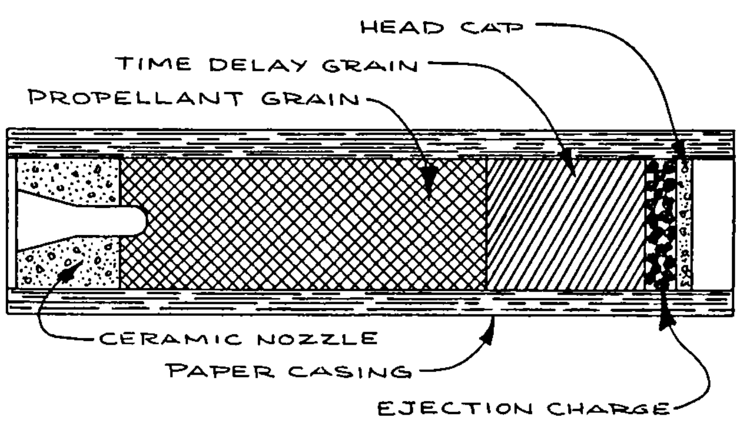
The ejection charge is held in place either with a paper cap or a thin layer of ceramic.

How does a model rocket motor work?

An electrical igniter must be used to start a model rocket motor. An igniter consists of two electrical lead wires terminating in a high-resistance electrical element coated with a few grains of chemical "squib" material. The igniter is inserted into the nozzle of the model rocket motor by the user in a manner specified by the manufacturer in the operating instructions. Igniters inserted in most black powder model rocket motors are simply pushed up the nozzle until they are in contact with the propellant, then held in place by tape or a special nozzle plug. A composite-propellant model rocket motor must have the igniter installed in a specific manner detailed in the instructions.

The electrical resistance of a model rocket igniter is usually about 0.4 ohms and requires 0.5 amperes at 6 volts DC to initiate the squib material.

The temperature of the propellant in both black powder and composite propellant model rocket motors must be raised to at least 550° F to initiate com-



bustion of the propellant. In order to ignite and burn, most composite solid propellants must also be under pressure from the gas liberated by the combustion of the squib material.

Once ignited, the propellant burns *only on its surface*. Most black powder model rocket motors use an "end-burning" propellant grain configuration that is ignited at the rear and burns progressively forward. Composite propellant model rocket motors usually have "core-burning" propellant grains with one or more specially-designed voids or holes running lengthwise through them with the propellant grain burning from the center or near-center outward toward the casing. The burning rate and therefore the volume and pressure of the gas generated is controlled by the shape of the propellant grain that is undergoing combustion at any given instant.

All combustion of the rocket propellant takes place inside the motor casing.

The design of model black powder model rocket motors is such that the propellant burns at a temperature of about 2,300° F and a pressure of around 100 pounds per square inch (psi), producing about 2,000 cubic inches of combustion gas for each ounce of propellant burned. Composite propellants operate with combustion temperatures around 4,200° F at pressures of about 500 psi also producing about 2,000 cubic inches of combustion gas for each ounce of propellant consumed.

The combustion gas rushes out of rocket nozzle in the rear end of the motor casing, its temperature and pressure dropping as it passes through the nozzle. As it leaves the nozzle, it is at or near atmospheric pressure. Black powder model rocket motors have an exhaust temperature of about 540° F and a velocity of about 2,650 feet per second (about 1,800 miles per hour). Composite propellant model rocket motors have an exhaust temperature of about 2,000° F and a velocity of about 7,000 feet per second (about 4,800 miles per hour).

The exhaust jet of a model rocket motor is NOT a flame. No combustion takes place outside the motor casing. Most model rocket motors produce a jet of luminous gas.

This rearward rushing gas produces a thrust force that propels the model rocket through the air. Because the amount of propellant under combustion at any given instant can be determined in advance by proper propellant formulation and grain design, the instantaneous thrust of a model rocket motor can also be controlled and tailored to the requirements of model rocket flight.

Once the propellant is exhausted, the time delay is automatically ignited. This produces no thrust and allows the model rocket to coast upward on its momentum. The time delay charge of most model rocket motors contains a chemical that produces a smoke trail so that model rockets may be seen and tracked in flight.

When the time delay is exhausted, it automatically ignites the ejection charge.

When the model rocket is recovered, the expendable model rocket motor casing is removed and discarded. An expendable model rocket motor casing, once used, should not be used again.

Can the propellant be easily removed from an expendable model rocket motor?

No. It is totally enclosed in a thick paper or plastic casing. With a sharp knife, a lot of time, and considerable patience, it's possible to remove the propellant. However, it is much easier to get the gun powder out of a shotgun shell. When the fire marshal of a large New England city once asked if the propellant could be removed, he was given a Type C motor and invited to do so. After five minutes of carving, he finally gave up.

Although it *is* possible to remove the propellant, the result is a solid cylinder of dirty black material. It will only burn with a bright flame.

Opening an expendable solid propellant model rocket motor is a difficult and time-consuming way to get combustible material. Far easier and cheaper methods are available.

Are all model rocket motors expendable, single-use units?

No. Some model rocket motors are now specifically designed to be reloadable. "Reloads" evolved as a result of improved composite propellants and motor casing materials.

Reloadable hobby rocket motors were introduced into model aviation in 1947 with the British "Jetex" units. These motors used a very slow-burning propellant that did not produce enough thrust to safely propel a model rocket in vertical flight; Jetex motors were used in winged model airplanes that climbed in slow spirals under the low thrust. They used aluminum casings that grew very hot during operation. Jetex rocket motors were standard off-the-shelf hobby products for about 30 years before importation by American Telasco ceased.

Modern reloadable model rocket motors were first made available in the late 1980s.

A cross-section drawing of a typical reloadable solid-propellant model rocket motor is shown in the accompanying figure.

By NAR and NFPA standards, the motor casing is fabricated from seamless 6061-T6 aluminum. Casing design minimizes fragmentation should the motor undergo a "catastrophic dis-assembly." The end closures are usually assembled using threads although some designs use snap-rings.

The rocket nozzle is usually machined from thermosetting plastic and must be replaced after each use.

The time delay grain and the ejection charge are pre-packaged units that fit into the casing.

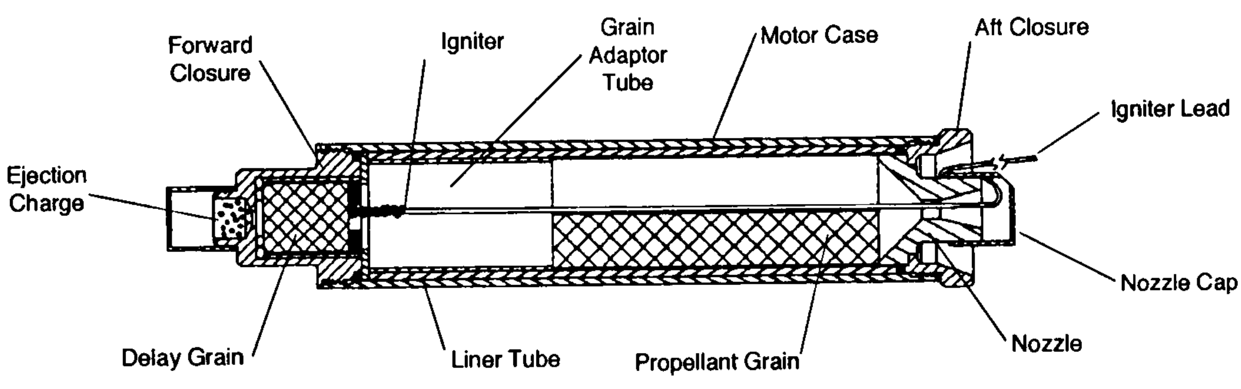
The propellant grain may be in two or more modules. It is normally enclosed in a cardboard or insulating tube from which it cannot be removed. The maximum weight of a reloadable solid-propellant grain is 62.5 ounces under NFPA 1122 "Code for Model Rocketry," and the NAR standards for certification of model rocket motor types.

Before first use, the reusable components are cleaned and readied for loading. After use, the interior of the motor casing is coated with carbon-like burned propellant residue that must be cleaned out by the user. Many model rocketeers enjoy the additional physical work required to reload a motor in the field.

Reloadable model rocket motors are normally available from Type D through Type G. Although smaller reloadable model rocket motors have been fabricated and tested, they are usually too small to be easily cleaned and reloaded.

Because the initial expense of such motors is much higher than expendables, they are mostly used by adults who fly a lot of model rockets. A model rocketeer must make an average of three flights with a reloadable model rocket motor before reaching the break-even cost point.

The major problem with reloadable model rocket motors was their departure from the basic paradigm



of model rocketry: the factory-made single-use model rocket motor that required no handling of propellant by the user. Over a decade of tests have shown that "reloadables" are as safe to store, handle, and use as "expendables."

Is the propellant sensitive?

Since 1957, sensitivity tests have been conducted. Model rocket motors have been pounded with a hammer; they wouldn't ignite or explode. Heavy weights were dropped on them, and nothing happened. Calculations made by a reputable national testing laboratory indicate that 4,634 foot-pounds of mechanical energy are required with 100% energy transfer to cause a black powder model rocket motor to ignite. This is equivalent to a 463-pound weight dropping from 10 feet so that the entire energy of impact is simultaneously absorbed by a single model rocket motor. More than a million foot-pounds of energy would be required to cause a full shipping case of model rocket motors to ignite. This is much greater than any impact that would be expected to occur during transportation even if the transporting vehicle were involved in a severe accident.

Tests were conducted in 1978 by the National Association of Rocketry during which a 22-pound weight was dropped 6.5 feet on both black powder and composite model rocket motors. These impacts totally destroyed the model rocket motors but did not cause them to ignite or explode.

Addtional tests have shown that model rocket motors are not susceptible to electrostatic ignition when electric sparks up to 14,000 volts are passed through the propellant grain.

Model rocket motors must not ignite spontaneously during extended exposure to temperaures up to 125°C (257°F).

Transportation and shipping accidents in which model rocket motors are involved must be reported to the Hazardous Materials Transportation Office of the U.S. Department of Transportation. About 500,000,000 model rocket motors have been shipped since 1958, and NO incidents of spontaneous ignition or explosion of model rocket motors from ANY cause have been thus reported.

Is model rocket motor propellant toxic?

Not really and it isn't very tasty, either. The black powder propellant grain of a solid propellant model rocket motor is very hard while composite solid propellant has the consistency of a rubber eraser. Several model rocket motors could probably be eaten with no ill effects. No illnesses have been reported that were caused by people eating model rocket motors. In fact, there are no reports of anyone trying to eat them. N. Irving Sax in his definitive work, *Dangerous Properties of Industrial Materials*, rates both potassium nitrate and ammonium perchlorate as "moderately toxic" and notes that small, repeated doses may lead to weakness, headache, and general depression. Potassium nitrate is also known as saltpeter and, along with carbon (charcoal) and sulfur, has been used historically for medicinal purposes. The NAR and model rocket manufacturers caution that people should not make a *habit* of eating model rocket motors.

Will it explode?

Since 1957, investigators of the National Association of Rocketry have tried to make model rocket motors explode deliberately by hitting them, throwing them in fires, burning them with welding torch, sawing them in half with high-speed band saws, shooting them with 30-caliber hunting rifles at short range, and otherwise mistreating them. The author and others have conducted carefully controlled tests in an attempt to make model rocket motors explode in order to determine the conditions that would cause them to explode. We haven't succeeded in achieving an explosion of a model rocket motor when subjected to experimental conditions designed to determine if, how, and why a model rocket motor would or could explode. We do know that a model rocket motor will ignite and burn under extreme conditions such as being directly exposed for a minute or more to a sustained fire such as the blue flame of an oxy-acetylene cutting torch.

Since 1957, the author has had only three "catastrophic failures" of model rocket motors in which the casing ruptured. One was a large Type F black powder motor that exploded at ignition in 1960 due to improper ignition technique. The other occurred in 1974 with a small mass-produced Type D black powder model rocket motor that had undergone day-night temperature cycling for several years in the Arizona desert environment where the maximum storage temperatures often reached more than 180^0 F and fell to about 20^0 F in the winter. In both cases, the motor manufacturer immediately withdrew the production lot from distribution, tested and determined the cause of the failure, and then corrected the problem. The third incident occurred under safe conditions on a model rocket flying site.

What happens when a model rocket motor accidentally explodes?

Model rocket motors are designed and manufactured under the standards of NFPA 1122 Code for Model Rocketry that requires any explosive failure result in motor components being expelled from the motor casing in a longitudinal direction — i.e., along the center line of the motor forward or backward. Given that millions of model rocket motors are manufactured every year and that one out of 280,000 could statistically fail, NFPA 1122 Code for Model Rocketry and the NAR's Model Rocket Safety Code require that all people remain at least 15 feet away from any model rocket motor or cluster of model rocket motors having a combined total impulse up to 30 Newton-seconds (a mid-range Type E motor) and 30 feet from all model rocket motors exceeding this power limit. (The total impulse of every model rocket motor type is known and published; it must be within plus-or-minus 20% of the mean value established for that motor type.) This distance provides an adequate safety margin should a model rocket motor undergo a catastrophic failure.

When a motor failure occurs, it is usually caused by internal overpressure created by the separation of the propellant grain from the casing. It may also be caused by a void in the grain or incomplete compaction during manufacture. These factors create an increased internal combustion pressure. When this occurs, the "fail safe" design of the model rocket motor causes either the nozzle to blow out the rear or the internal components of the motors to be blown forward into the model rocket body. As mentioned above, model rocket motor casings rarely fail. Hydrostatic tests of paper model rocket motor casings have been made to a pressure of 1,000 pounds-per-square-inch without rupturing. Casings used in composite model rocket motors are designed to withstand internal pressures 2.0 times normal maximum design operating pressures.

Is the exhaust gas toxic?

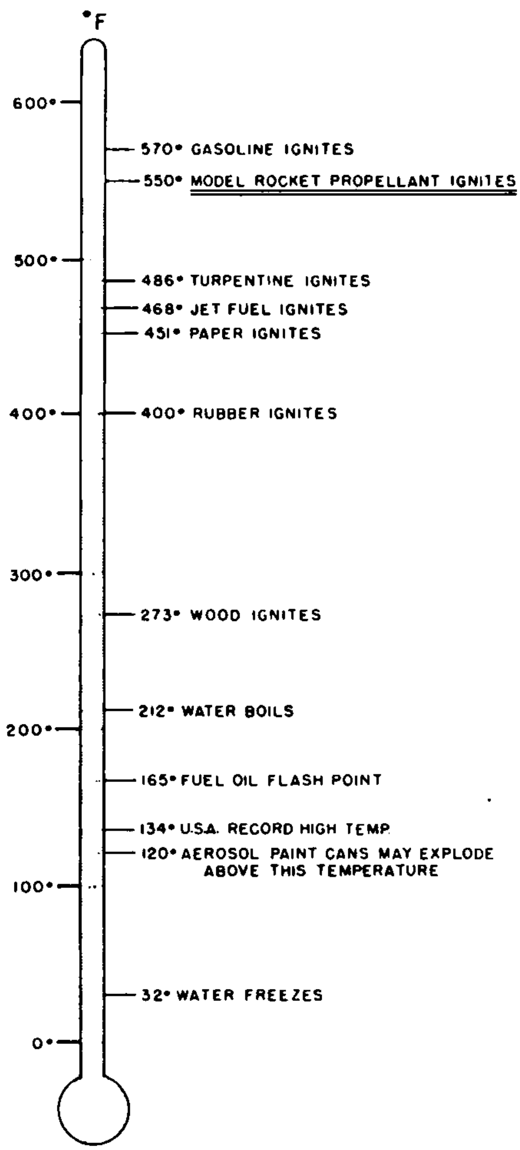
The exhaust gas resulting from the operation of a model rocket motor has not been shown to be toxic in the quantities produced by a model rocket motor. Sax lists as "slight toxicity" the ammonium carbonate solid residue cause by the operation of a black powder rocket motor and as "variable" the potassium sulfide and potassium sulfocyanate solid residues. The gas produced by a composite solid propellant rocket motor is not toxic in the quantities produced by the operation of the largest permissible model rocket motor containing 62.5 grams (2.2 ounces) of propellant. However, when burning, composite propellants produce HCl which, if the motor is operated in an enclosed space, can reach toxic levels.

Does a model rocket motor produce a flame while operating?

No. All combustion of the solid propellant takes place inside the casing. In black powder model rocket motors, the jet is a plume of luminous gas approximately 9 inches long for Type D motors. This glowing plume is caused by the high temperature of the exhaust gas and the luminous microscopic solid products of the internal combustion process. The exhaust plume is similar to the glowing gas plume seen coming from the exhaust pipes of high-performance racing cars.

Does a model rocket motor casing get hot?

In accordance with the national standards set forth in NFPA 1122 Code for Model Rocketry, a model rocket motor type cannot be certified for sale and use in the United States if the external temperature of its motor casing exceeds 200° C (392° F) during or after operation. In a model rocket airframe, the model rocket motor is retained and centered by paper and plastic parts. Paper ignites at 452° F and nylon suffers heat distortion at 400° F. Most paper-cased model rocket motors could be held in a bare hand while operating, but this practice is not encouraged in model rocketry.



What will the exhaust jet do?

In 1970, the author conducted a series of tests to find out. The jet from a typical 18x70-millimeter black powder model rocket motor (a standard size) did not burn a hole through a single sheet of 20-pound white typewriter paper when the jet was directed perpendicularly against the paper at a distance of 12 inches. At a distance of 6 inches, the jet punched a hole through the paper about 1¼ inches in diameter that was self-extinguishing.

Will the exhaust jet cause a burn?

If a someone's fingers are in the jet, they will be burned. This is why specific instructions for the safe and reliable electrical ignition of all model rocket motors are provided in each package of replacement motors. If a person gets burned by a model rocket motor, it happened because instructions were not followed, pre-launch tests were not conducted per instructions, or the product was being misused in direct disregard of all safety rules, common sense, and instructions.

How is such a burn treated if one occurs?

A burn from a model rocket motor jet exhaust should be treated like any other burn. Get the burned area immersed in ice water or cold water was quickly as possible. See a physician immediately. None of the exhaust products are poisonous.

Can a model rocket motor be ignited with a match?

Since 1957, the author and others have tried to do this. During tests conducted by Estes Industries, Inc. in 1966, a Type B3-7 black powder model rocket motor was held vertically, nozzle down, ¼-inch above the flame of a 1½-inch diameter paraffin candle. It did not ignite after 60 seconds of exposure. The paper casing began to smolder but self-extinguished 2 minutes after the candle flame was removed.

Can a model rocket motor be ignited with a fuse?

Although common "green" safety fuse will fit up the nozzle of some model rocket motors, it is difficult, unsafe, and unreliable to attempt ignition of a model rocket motor with a fuse. It is also contrary to the provisions of NFPA 1122 Code the Model Rocketry which forms the basis for laws in all 50 states. NFPA 1122 also prohibits the sale of fuse for igniting model rocket motors.

Under what conditions will a model rocket motor ignite?

The results of various fire immersion tests and flame application tests conducted since 1958 show that a model rocket motor will not undergo spontaneous ignition in a fire unless, literally, the "barn is burning down." A model rocket motor will ignite only if the temperature of the surface of its propellant grain reaches 550^0 F. Numerous burn tests of various black powder and composite model rocket motors and composite reloading kits conducted in 1958, 1966, 1978, and 1992 have confirmed this. Autoignition occurs only if a fire burns away a portion of the paper or plastic motor casing to expose the propellant grain itself to the fire. This is because the model rocket motor casing is an excellent insulator and because a bubble of insulating air becomes trapped in either the nozzle or the forward end of the motor, preventing hot particles or flame from getting into the motor casing and to the surface of the propellant grain. The amount of time required for a fire to burn through a model rocket motor casing varies from 30 seconds when subjected to the intense flame of an oxy-acetylene torch to 3-5 minutes during immersion in an intense wood fire.

Can model rocket motors be mailed?

Yes. Permission was originally received to mail model rocket motors on April 2, 1958. Currently, packages of model rocket motors weighing up to 25 pounds may be mailed. No incidents of fire or explosion have occurred as a result of mailing millions of model rocket motors. (See appended letter.)

Where are model rocket motors sold?

The majority of the nearly 500 million model rocket motors used since 1958 have been sold in hobby stores or in the hobby sections of department or discount stores.

Are model rocket motors "fireworks?"

The U.S. Department of Transportation, the Consumer Product Safety Commission, and the National Fire Protection Association consider model rocket motors to be propulsion devices for aeromodels and *not* fireworks.

The Research and Special Projects Administration of the U.S. Department of Transportation classifies model rocket motors as U.N. Classification Code 1.4S, Model Rocket Motors, NA0323, under the provisions of Section 173.56, Title 49, Code of Federal Regulations (49 CFR).

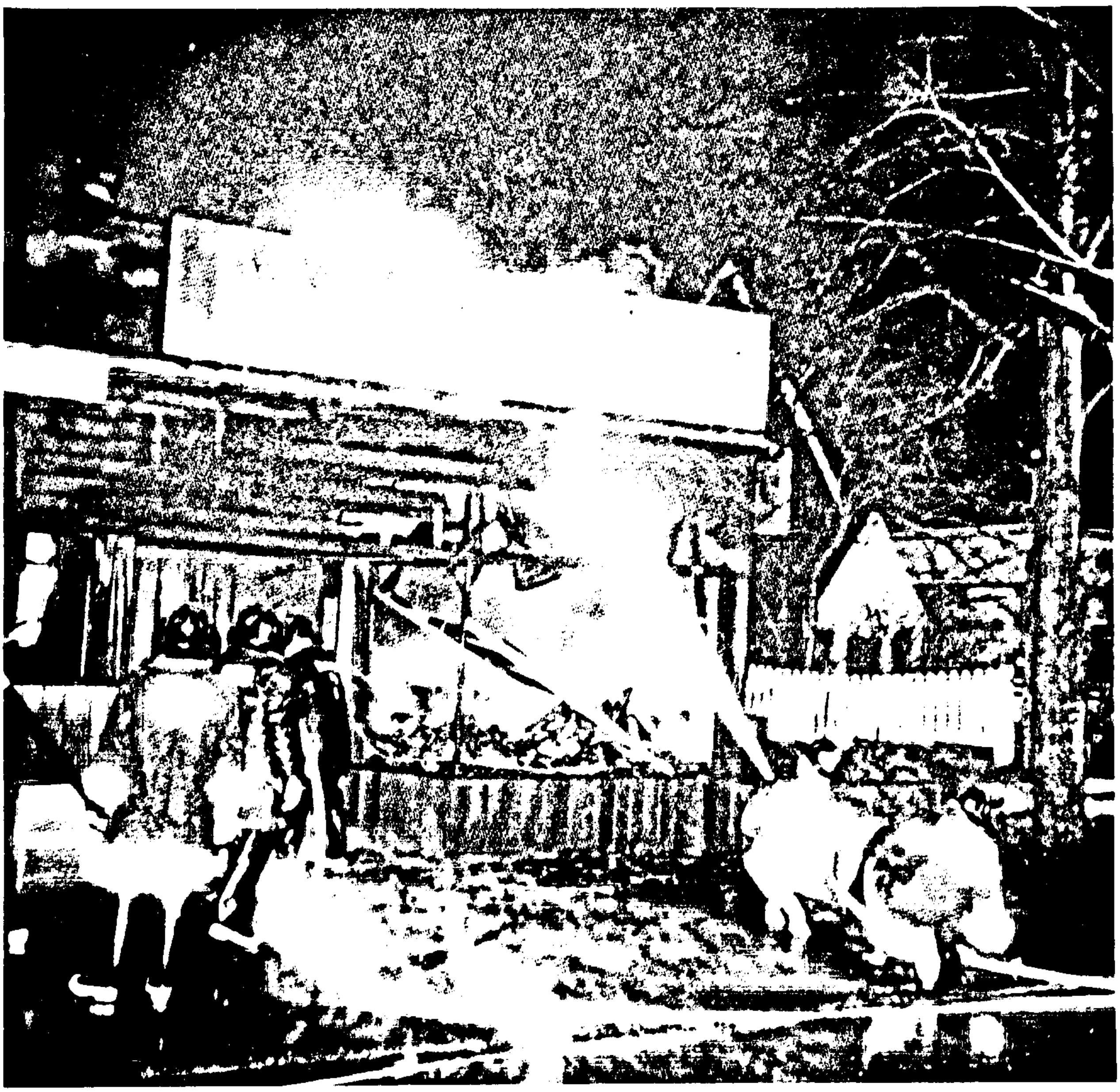
The National Fire Protection Association (NFPA) has a separate code for model rocketry, NFPA 1122 Code for Model Rocketry. The NFPA has specifically exempted model rockets and model rocket motors from consideration as fireworks under NFPA 1123, 1124, and 1126 having to do with the manufacture and use of Class B and Class C fireworks. The NFPA Technical Committee on Pyrotechnics has reviewed NFPA 1122 regularly since its inception as NFPA 41L-T in May 1967 and continues to treat model rockets and model rocket motors separately from all forms of fireworks.

A precedent-setting legal case regarding model rocket motors and fireworks is the Long Island, New York, hobby shop owner who was cited and tried for selling model rocket motors in violation of the New York state fireworks law., Section 270.00. He was acquitted. Reference: People v. Bochter, 1970, 63 Misc. 2d, 219, 211 N.Y.S. 2d 186.

Are model rocket motors a fire hazard?

On February 24, 1970, Toby's Hobby Center on the Post Road in Darien, Connecticut, caught fire and burned to the ground. All of the model rocket motors stored in their shipping packages on the shelves were later retrieved; none had ignited in the conflagration. (See photo.)

Experience has clearly shown that model rocket motors will not significantly contribute to a fire and are less of a fire hazard than other items available and sold in hobby and hardware stores — aerosol paint cans, model airplane fuel, model airplane glue, butyrate dopes in cans and bottles, and other cements and solvents.



PART THREE

TECHNICAL DETAILS OF THE MODEL ROCKET MOTOR

This Part goes into the scientific and technical details of both black powder and composite solid propellant model rocket motors. Its purpose is to reveal the scientific background supporting the contention that model rocketry is a technically-based hobby and recreation making use of the technology, practices, and methodology of full-scale astronautics and professional rocketry.

Internal ballistics, black powder model rocket motors.

A typical black powder model rocket motor is considered. Data was determined with the assumptions that the combustion process is adiabatic and isentropic, is in frozen equilibrium, and is complete. It is also assumed that the nozzle exit pressure is 14.7 pounds-per-square-inch absolute. The exhaust products are assumed to behave as an ideal gas because the solid particles in the exhaust plume are assumed to be less than 0.0001 inches in diameter and thus have no effect on the thermodynamic processes of the exhaust gas. Insofar as possible, calculated results have been checked against measured test results with excellent agreement well within measurement tolerances.

Propellant: Black powder consisting of 74% KNO_3 as an oxidizer and a combination of 15.6% C and 10.4% S as a fuel plus binder. All percentages are by weight.

Delivered specific impulse (I_{sp}): 82 lb_f-sec/lb_m

Exhaust velocity: 2,650 ft/sec

Molecular weight of exhaust gas: 34.75 gm_m/mole

Ratio of specific heats of exhaust: k = 1.29

Nozzle area ratio: 1.75

Propellant density: 0.067 lb_m/in^3

Propellant burning rate: 1.15 in/sec @ 106 psia

Burning area ratio: 19.7

Ignition temperature: 550° F @ 14.7 psia

Chamber temperature: 2,300° F

Throat temperature: 895° F

Exit nozzle temperature: 540° F

Chamber pressure: 106 psia

Reaction products of propellant: 43% gas, 56% solid, 1% water

Gaseous exhaust products by volume: 30.6% N_2; 49.2% CO_2; 2.6% CH_4; 1.8% H_2S; 3.5% H_2

Solid exhaust products by volume: 44.4% K_2CO_3; 20.5% K_2SO_4; 25.8% $K_2S_2O_3$; 3.7% K_2S; 0.5% S; 3.3% KCSN; 1.6% $(NH_4)_2CO_3$; 0.2% C

Chemical equation of combustion reaction: 74 KNO_3 + 96 C + 30 S + 16 H_2O → 35 N_2(g) + 56 CO_2(g) + 3 CH_4(g) + 2 H_2S(g) + 19 K_2CO_3(s) + 7 K_2SO_4(s) + K_2S(s) + 8 $K_2S_2O_3$(s) + 2 KCSN(s) + $(NH_4)_2CO_3$(s) + S(s)

Internal ballistics, composite solid propellant model rocket motors

A typical composite model rocket motor is considered. Data was determined with the assumptions that the combustion process is adiabatic and isentropic, is in frozen equilibrium, and is complete. It is assumed that 100% of the exhaust products are gaseous. It is also assumed that the nozzle exit pressure is 14.7 pounds-per-square-inch absolute. Insofar as possible, calculated results have been checked against measured test results with excellent agreement well within measurement tolerances. Precise formulation of composite propellants varies, depending upon requirements for burn rate and other performance factors. Numerous types of elastomers can be used as both a fuel and a binder. Therefore, a range of parameters is shown.

Propellant: Composite solid propellant consisting of approximately 82% ammonium perchlorate NH_4ClO_4, 18% elastomers such as synthetic rubber, and less than approximately 1% stabilizers, burn rate enhancers, etc..

Delivered specific impulse (I_{sp}): 190 to 220 lb_f-sec/lb_m

Exhaust velocity: 6,112 to 7,077 ft/sec

Molecular weight of exhaust gas: approximately 23.7 gm_m/mole

Ratio of specific heats of exhaust: k = 1.25

Nozzle area ratio: 2.5 to 6.0