Second Edition

Model Rocket
Design and Construction

How to create and build unique and exciting model rockets that work!

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 Published by Apogee Components, Inc., 630 Elkton Dr., Colorado Springs, CO 80907 USA.

Publisher's Cataloging-in-Publication
(Prepared by Quality Books Inc.)

Van Milligan, Timothy S.
Model rocket design and construction : how to create and build unique and exciting model rockets that work. / Timothy S. Van Milligan — 2nd ed.
p. cm.
Includes bibliographical references and index.
ISBN: 0-9653620-1-9

1. Rockets (Aeronautics)—Models. 2. Rockets (Aeronautics)—Models—Design and construction. 3. Rocketry—Amateurs' manuals. I. Title

TL844.V36 2000 629.4'750'228
QBI99-500581

Printed in the United States of America

About the Author

Timothy Van Milligan has been designing and flying his own model rockets since 1976. After obtaining his degree in Aeronautical Engineering from Embry-Riddle Aeronautical University in 1988, Tim worked as a launch operations engineer for McDonnell Douglas Corp. In this position, he helped assemble and launch the highly successful Delta II rocket for NASA and the U.S. Air Force. The author has also worked as a model rocket designer at Estes Industries. A few of the many rockets he has designed include: CATO, Skywinder, Terrier/Sandhawk, TurboCopter, and Omloid.

Tim has written many articles on the various types of model rockets for a number of magazines and newsletters, and been an active competitor in national and international model rocket competitions as a member of the F.A.I. Spacemodeling team.

Currently, the author is the president of Apogee Components, and is involved in helping modelers have a lot more fun with rocketry.

The author is very interested in the success of your rocket designs. If you have any comments about this book and how it might be improved in future editions, or if you have designed a unique model rocket, send a photograph and description of the rocket to him in care of Apogee Components, Inc.

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Getting Started

A basic sport model. (photo by Steven A. Bachmeyer)

Designing and building successful model rockets is a step-by-step process with several different phases. This book will discuss each part in sufficient depth to help you develop successful rockets, but first it is important to know what makes a successful rocket flight— the goal of every rocketeer.

A flight is considered successful when it safely completes the five individual phases: ignition, lift-off, stable flight (including the coast phase), recovery system deployment, and safe landing. Without any one of these five phases, the flight would be termed "unsuccessful."

Successful Flight Criteria

1. Ignition
2. Lift-off
3. Stable ascent
4. Recovery system deployment
5. Safe (damage free) landing

The Design Process

The "design" process begins with a concept or idea. This is usually the hardest step of the process to accomplish, because every rocket builder wants to create a new and unique model that no one has ever thought of before. Ideas are easy to copy, but new and different ones are very difficult to come up with. If you have an idea, sketch it out on paper. If you don't, turn in this book to the section that describes the different types of model rockets (page 10). You can also find ideas in the section on the various methods of returning your model to the ground (page 12). These methods are called recovery systems. Other places to get ideas for concepts is in the "payload" (page 114) and "styling" sections of this book (page 14). But, if you've already paged through this book, you will have noticed that this book is full of "ideas" for new types of rockets. Many great models are developed by selecting the best parts from several different rockets.

Whatever your idea, first sketch out the model, or at least write down a paragraph describing it or its purpose.

Second, determine the size and general layout of the rocket. At this point, you should go directly to the section on basic rocket stability (page 18), and familiarize yourself with all the concepts on how to make your rocket fly straight. This is the most important part of the design, as it will directly affect whether or not your model is successful. Choosing the size of the rocket is completely up to the designer (you), but you might want to consider some design constraints that would affect how big your rocket is. These might include: what engines the model will be powered by, the size of the

field you plan on using to launch your rocket, and the available materials you will use to build the model.

At this point you should be getting into the specifics of what the model should look like, or how it should function. There are several sections in this manual that should help you to refine the design. Such sections include: “Parts of a Model Rocket” (page 17) shows the basic layout of a typical model rocket, which should help you to determine which components you will need to build your model; “Drag Reductions and Aerodynamics,” (page 26) describes ways to streamline your rocket to achieve very high altitudes; and “Streamer and Parachute Recovery Systems;” (page 82) describes how to determine the recovery system’s size so that the model will return safely to the ground. Chapters 11 and 12 (page 86 and 105) give tips on designing gliders and models that return to the ground using helicopter recovery.

Arranging these parts within your design is much easier with the use of a good computer program. I recommend *RockSim*, which is also a product of Apogee Components, Inc. This program will help you design your rocket and pre-determine wether or not the model will be stable when flown. It will also give you an indication of how the prototype will fly with different rocket motors, and in varying wind conditions. Knowing all this information prior to the actual construction of your rocket will help make the launches safer. I highly recommend this “tool” to aid in designing any rocket.

Marc Lavigne preps a dual glider model for launch.

When you’ve decided on the size and shape of the model, develop a list of materials you’ll use to build it. Again, the *RockSim* computer program will help make this task as simple as clicking a button. From this list you may want to order specialized parts from your favorite rocket kit manufacturer, or you may want to build these parts from materials you have on hand. If you choose the latter, the sections “Working with Paper” (page 64) and “Creating Custom Parts” (page 65) will help you.

You are now in the final stage of your rocket design. Some additional sections you might want to read are “Building Higher Powered Rockets,” (page 67) “Clustering” (page 123) or “Staging” (page 117) if your design will include any of these special features.

If you haven’t already done so, make a good drawing of your model rocket design. If your model is complex this drawing should be to scale, but otherwise it could be a simple sketch.

The Design Phase

1. Generate concept or idea
2. Determine size and general layout of rocket
3. Select components and final appearance
4. Determine type and size of recovery system
5. Generate list of materials to be used
6. Make final drawing of rocket.

Construction Phase

1. Gather all parts to be used
2. Make patterns and templates
3. Construct model

An assortment of unique rockets designed and built by Randall Redd (photo by Marc Lavigne).

4. Apply finish or paint model
5. Apply decals

Launch

1. Select proper rocket engine
2. Prep rocket
3. Launch and recover rocket

Construction

Moving into the construction phase of your project, the first step is to gather together all the materials that will be needed. Any patterns or templates should be made, and special parts should be ordered or constructed at this time. Actual construction should proceed smoothly now that you are armed with your drawing and with a complete set of parts to build your model. Reading all of Chapter 4 "Construction" will help you perform the actual assembly steps.

Painting and decorating your model is the final phase of the construction of your model rocket. Chapter 8, "Painting and Decorating," describes how to obtain a smooth, high quality appearance, which by itself will make your rocket unique.

With the rocket completed, you should now prepare your rocket for launch. Selecting the proper rocket engine is very important to a successful flight. Read Chapter 17, "Rocket Engines" to find out how to properly select a rocket engine.

"Repair Techniques", Chapter 9, gives instructions on how to bring back that "showroom-new" appearance to those older rockets you have.

You will find that the above steps comprise a "cycle," where several steps are repeated. The reason for the repetition is that by reviewing your design, you will constantly see ways to improve it. And once a change has been made, it may be necessary to repeat a step or two to make sure that one change didn't affect other parts of the design. Take your time designing your rocket; it takes a lot longer to repair a problem than to do it right the first time.

To help you understand a word or phrase which is unfamiliar, the final section of this book is a glossary of terms. It is one of the most extensive rocketry glossaries in print with over 500 terms, covering not only rockets, but gliders too.

Once everything has been completed, your rocket will be the envy of all those who see it. If you come up with a truly unique rocket and want to share it with others, send a photo of the model to me, care of Apogee Components, Inc., with a description of how it works; maybe a future edition of this book will display your model. I wish you success in your building endeavors!

Safety

Safety is the most important design constraint you must consider when designing and building your rocket. You are the only person who can make sure that the rocket will function in a safe manner. It is your responsibility to see that it is designed, constructed and flown so that nothing is damaged when the rocket takes off.

To help all model rocket designers and flyers, a safety code has been developed to guide and promote safety in the hobby of model rocketry. This safety code was developed over a period of 40 years by the National Association of Rocketry (NAR). Please do not skip over this important section. Read it! Understand it! And commit yourself to following it!

NAR Safety Code

1. **Materials:** My model rocket will be made of lightweight materials such as paper, wood, rubber, and plastic suitable for the power used and the performance of my model rocket. I will not use any metal for the nose cone, body, or fins of a model rocket.
2. **Engines:** I will use only commercially-made NAR certified model rocket engines in the manner recommended by the manufacturer. I will not alter the model rocket engine, it parts, or its ingredients in any way.
3. **Recovery:** I will always use a recovery system in my rocket that will return it safely to the ground so it may be flown again. I will use only flame-resistant recovery wadding if required.
4. **Weight Limits:** My model rocket will weigh no more that 1500 grams (53 oz.) at lift-off, and its rocket engines will produce no more than 320 Newton-seconds of total impulse. My model rocket will weigh no more than the engine manufacturer's recommended maximum lift-off weight for the engines used, or I will use engines recommended by the manufacturer for my model rocket.
5. **Stability:** I will check the stability of my model rocket before its first flight, except when launching a model rocket of already proven stability.
6. **Payloads:** Except for insects, my model rocket will never carry live animals or a payload that is intended to be flammable, explosive, or harmful.
7. **Launch Site:** I will launch my model rockets outdoors in a cleared area, free of tall trees, power lines, buildings, and dry brush and grass. I will ensure that people in the launch area are aware of the pending model rocket launch and can see the model rocket's liftoff before I begin my audible five-second countdown.
8. **Launcher:** I will launch my model rocket from a stable launching device that provides rigid guidance until the model rocket has reached a speed adequate to ensure a safe flight path. To prevent accidental eye injury, I will always place the launcher so that the end of the rod is above eye level or I will cap or disassemble my launch rod when not in use and I will never store it in an upright position. My launcher will have a jet deflector device to prevent the engine exhaust from hitting the ground directly. I will always clear the area around my launch device of brown grass, dry weeds, or other easy-to-burn materials.
9. **Ignition System:** The system I use to launch my model rocket will be remotely controlled and electrically operated. It will contain a launching switch that will return to "off" when released. The system will contain a removable safety interlock in series with the launch switch. All persons will remain at least 5 meters (15 feet) from the model rocket when I am igniting the model rocket engines totaling 30 Newton-seconds or less of total impulse or less and at least 9 meters (30 feet) from the model rocket when I am igniting model rocket engines totaling more than 30 Newton-seconds of total impulse. I will use only electrical igniters recommended by the engine manufacturer that will ignite model rocket engine(s) within one second of actuation of the launching switch.
10. **Launch Safety:** I will not allow anyone to approach a model rocket on a launcher until I have made certain that the safety interlock has been removed or that the battery has been disconnected from the ignition system. In the event of a misfire, I will wait one minute after a misfire

A large scale model of the Saturn 1B is ready for launch (photo by Tim Van Milligan).

(Photo by Patrick McCarthy)

before allowing anyone to approach the launcher.

11. Flying Conditions: I will launch my model rocket only when the wind is less than 30 kilometers (20 miles) an hour. I will not launch my model rocket so it flies into clouds, near aircraft in flight, or in a manner that is hazardous to people or property.

12. Pre-Launch Test: When conducting research activities with unproven model rocket designs or methods I will, when possible, determine the reliability of my model rocket by prelaunch tests. I will conduct the launching of an unproven design in complete isolation from persons not participating in the actual launching.

13. Launch Angle: My launch device will be pointed within 30 degrees from vertical. I will never use model rocket engines to propel any device horizontally.

14. Recovery Hazards: If a model rocket becomes entangled in a power line or other dangerous place, I will not attempt to retrieve it.

This is the official Model Rocket Safety Code of the National Association of Rocketry. Note: The largest "model" rocket engine defined by the CPSC is an "F" (80 N-s). To launch rockets weighing over 1.36 Kg (3 pounds) including propellant, or rockets containing more than 62.5 grams (2.2 ounces) of propellant, you must obtain a waiver from the Federal Aviation Administration (FAA). Check your telephone directory for the FAA office nearest you. They will be able to help you obtain permission to operate larger rockets than those listed above.

Model Classification

There are several different types of model rockets you can design and build. They are usually classified according to their specific purpose. The categories listed below describe several of the different types of model rockets, some of which are more complex than others. This book contains special sections describing additional design criteria that you will want to consider when dealing with those models.

Sometimes a rocket may not fit perfectly in one category. It may be a combination of one or more different types—for example, a rocket might be a combination glider and cluster model. The purpose of this section is to give you many different ideas to build your own model rocket fleet.

Sport Rockets: A sport rocket is any rocket that is built strictly for the fun and enjoyment of model rocketry. It usually serves no secondary purpose other than to make you or others happy. This category is very broad and can be broken down into sub-categories based on how the rocket is powered.

Single Engine Sport Rockets: This is probably the most common type of model rocket built and flown. As the name describes, the rocket is powered by a single engine, and is usually recovered by a streamer or parachute. Most rocket kits sold in stores are this type.

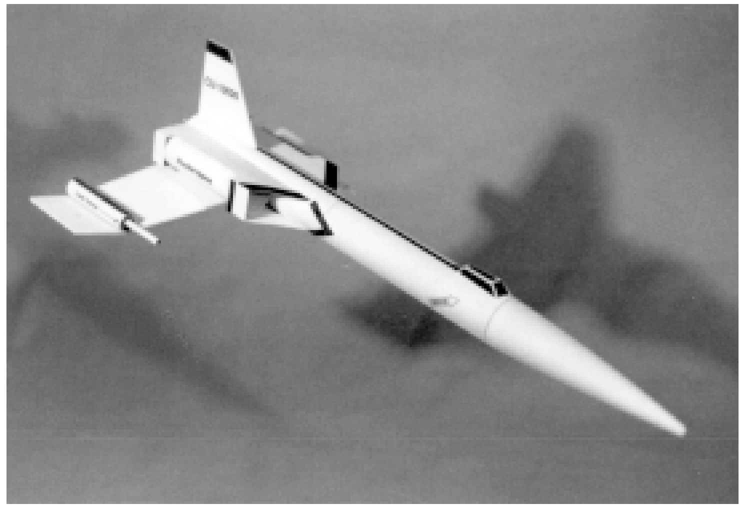
Cluster Engine Sport Rockets: A cluster engine sport model uses two or more engines ignited simultaneously, and is designed to operate as a single propulsion unit. Because of the extra power, cluster models fly higher than single engine models, or they can be used to carry heavier payloads into the sky. Chapter 16, "Clustering" describes the design criteria that need to be met for this special type of model.

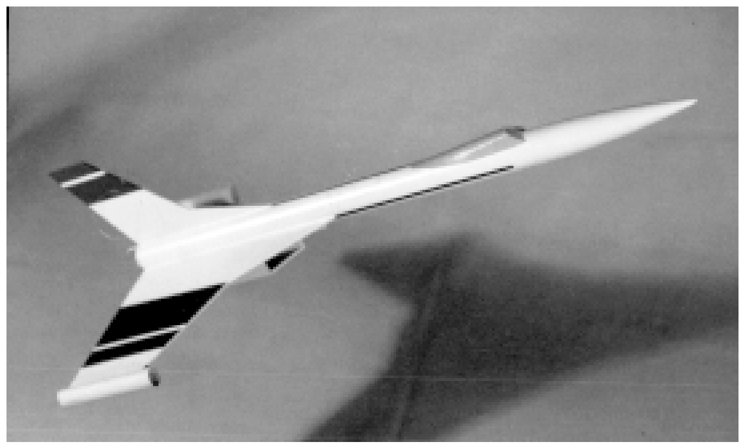
Multi-Staged Sport Rockets: Multi-staged rockets use two or more rocket engines stacked one on top of another and ignited in sequence. The purpose of these rockets is to achieve very great altitudes. See Chapter 15 if you are designing multi-stage rockets. It explains how to get the models to reliably stage at the proper time.

Functional Rockets: Functional rockets are those that have a secondary purpose or unique feature that gives additional value and enjoyment over the basic sport model. As in the sport rocket type of model, there are several different categories of functional rockets, but here they are differentiated by the secondary purpose or feature of the rocket. Functional type rockets can include gliders and helicopter type models, which are described later in Chapters 11 and 12.

Scale Model Rockets: A scale rocket is a miniature replica of an actual flying missile or rocket. The level of detailing and the exactness of dimensions determines whether or not the model is actual scale, or semi-scale. Some tips on building scale models are given in Chapter 13, "Scale Models."

Fantasy Model Rockets: Rocket models that look like they actually belong in outer space, or on some distant world are called *futuristic* or *fantasy* rockets. Many times these rockets are replicas of spacecraft or rockets found in science fiction movies. Fantasy rockets also include those rockets designed to resemble actual scientific or military missiles. These rockets are sometimes known as *pseudo-scale* model rockets, because they look like they were modeled after a real rocket, although they do not exist in larger versions.





Two different types of futuristic or fantasy type models (photos by Steven A. Bachmeyer).

Competition Model Rockets: Competition rockets are models used in games or contests. Rules for different events vary, but can include highest altitude for a given type of rocket engine or longest duration aloft with a specific type of recovery device. For more information on rocket contests, contact the *National Association of Rocketry,* whose address is listed at the end of this book.

Payload Model Rockets: A payload model rocket is designed to carry some type of special cargo into the air. The cargo, or payload, is usually placed in a special module, called a payload section, which protects the delicate cargo from the heat of the engine's ejection charge. For additional help in designing payload rockets, read Chapter 14, "Payload Rockets."

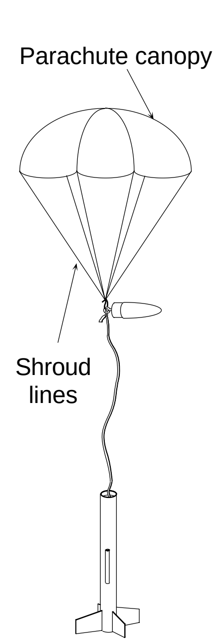
Rocket Recovery Systems

A *recovery system* is any device incorporated into the model for the purpose of returning it safely to the ground. All recovery systems work by developing either lift or additional drag to counteract the force of gravity. You may get an idea for a rocket from the way the model is returned to the ground. Described below are the major methods by which any rocket is returned to the ground in a safe manner.

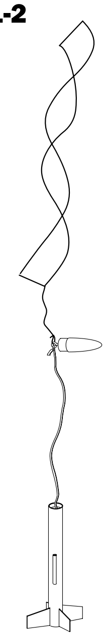
Parachute Recovery: A *parachute* is an umbrella-like device used to retard the descent of a falling body by offering resistance to its motion as it moves through the air. Parachutes are the most common recovery method because of the relative ease of constructing a chute and because they make very slow descent speeds possible. Larger and heavier rockets are almost exclusively returned to the ground by parachute.

Streamer Recovery: *Streamers* are strips of material, generally rectangular in shape, used to slow the rocket down by fluttering in the wind. They are used only on smaller models under 56 grams (2 oz) because they do not create as much drag as a parachute. Streamers are very easy to make and to prep for flight.

On very light rockets it may be possible to eliminate the streamer all together and have the shock cord act as the drag-producing device. If this is done, it is typically called *nose-blow recovery*.

Fig. 1-1


Parachute recovery

Fig 1-2

Streamer recovery

Tumble or Featherweight Recovery: Small, low-mass rockets often tumble or flutter to the ground. If the speed of the rocket is slow enough during its fall, it may not need any other type of recovery device. This is termed tumble recovery. The tumbling action is achieved by changing the relationship of the *center-of-pressure* (CP) and the *center-of-gravity* (CG) of the model. When the CP is forward of the CG, the rocket becomes unstable and begins to tumble end over end. This may be accomplished in two ways: sliding the rocket engine rearward after engine burnout, or by ejecting it entirely from the rocket. If you plan on using this type of rocket, always check its stability before flying it; your

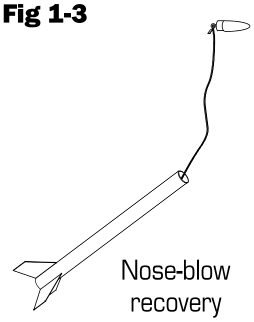
Fig 1-3

Nose-blow recovery

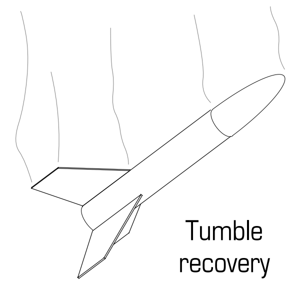
Fig 1-4

Tumble recovery

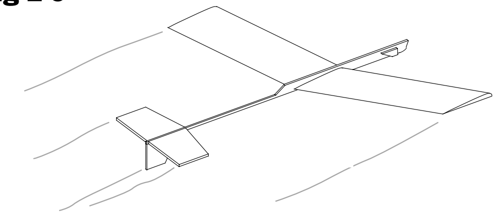
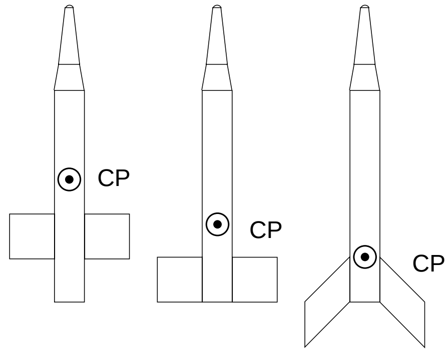
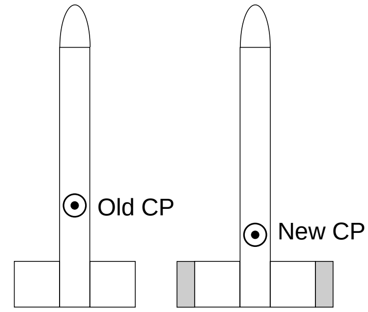
Fig 1-5

Glide recovery

Fig 2-11



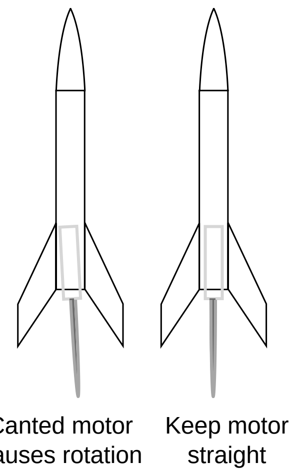
Rearward movement of CP as fins are moved aft, and finally swept rearward

Fig 2-11



Increasing fin area moves CP rearward

Fig 2-12



A canted rocket engine can causes the model to veer off unexpectedly

centerline of the model, the fins will have to be much larger to provide the restoring force needed to overcome the unbalanced force of the engine. This is why you should always keep the thrust forces concentric around the centerline of the model. Otherwise, the model may become unstable as soon as it clears the top of the launch rod.

Besides moving the location of the CP or the CG, you might be able to correct instability by causing the rocket to spin on the way up. This is called *spin stabilization*. The spinning action creates angular momentum, which provides inherent stability (think of a toy spinning top or a gyroscope). The spinning also cancels out any unbalanced forces acting on a rocket, such as that produced by one fin creating more lift that the other fins.

Spinning the rocket can be accomplished in three ways. You can cant the fins on the body tube at some small angle; you can add small canted tabs to the bottom of existing fins; or you can sand each of the fins so they have a cambered airfoil shape. Another way of inducing a spin to the rocket is to use a "spin tower-launcher." These are very rare, but there is a photo on page (18).

The drawback to spinning is the amount of drag it produces. This increase in drag will reduce the overall height that the model rocket is capable of achieving.

Rockets with small fins have a harder time producing the necessary forces to restore the model to the correct flight path. To help increase these forces you can increase the velocity. More air flowing over the fins will produce larger restoring forces. You can increase speed by reducing drag or selecting an engine that produces more

Fig 2-13

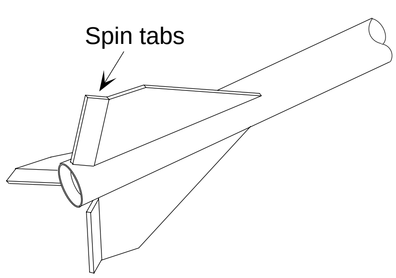
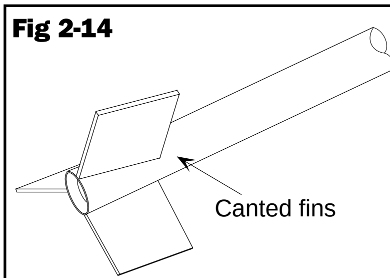


Fig 2-14



Methods of inducing a spin in a rocket's flight

Fig 2-15