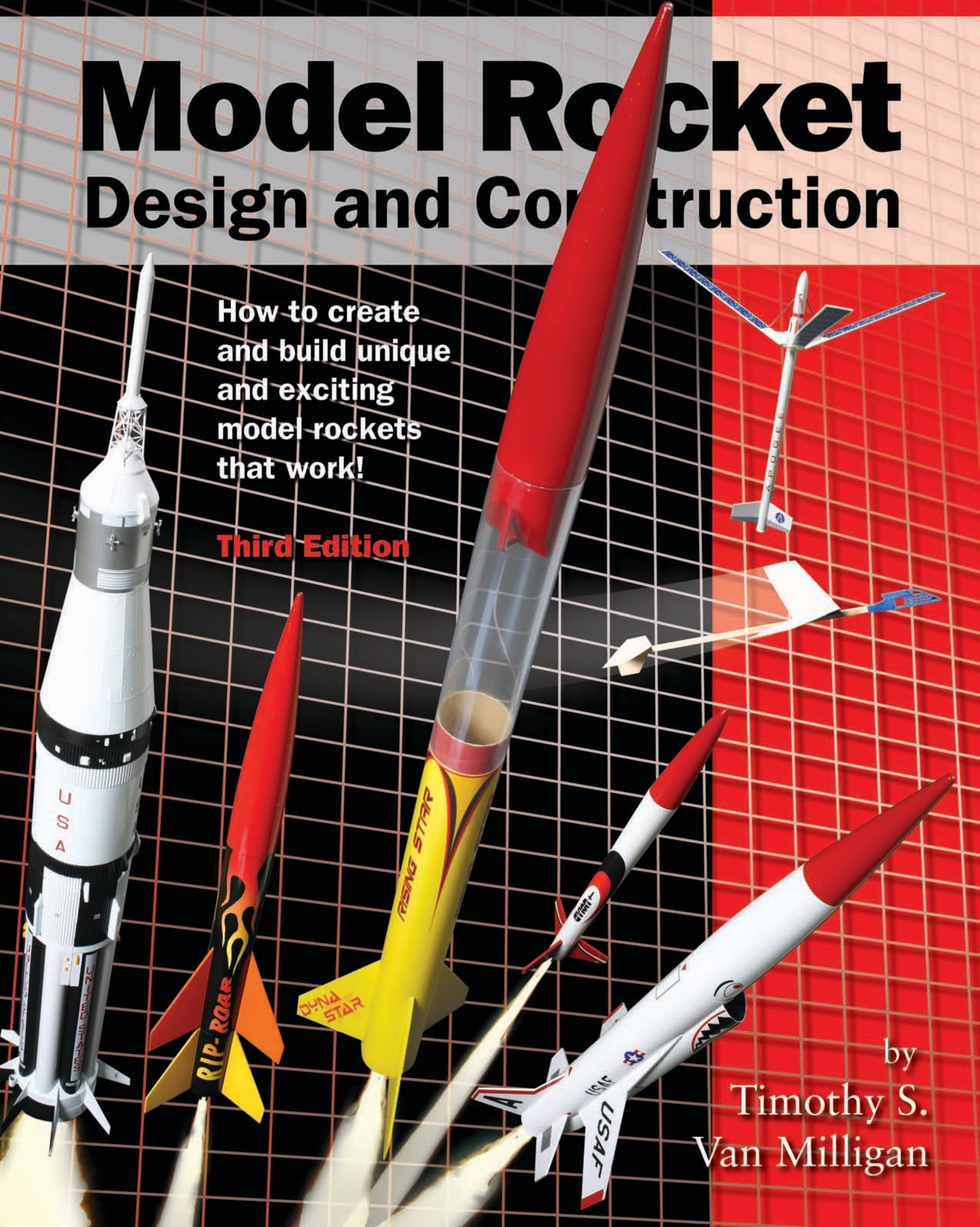
Model Rocket
Design and Construction

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

Third Edition



by
Timothy S. Van Milligan

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APOGEE COMPONENTS

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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 designed for Estes include: CATO, Skywinder, Terrier/Sandhawk, TurboCopter, and Omloid.

Currently, Tim is the president of Apogee Components, Inc in Colorado Springs, Colorado, USA. The company offers a full line of rocket kits, motors, building supplies, books, educational materials for rocketry, and the RockSim model rocket design and simulation software.

Tim has written over 200 articles about the various types of model rockets for the *Peak-of-Flight* e-zine newsletter, which is published by Apogee Components, as well as a number of national magazines and newsletters. He has also been a competitor in national and international model rocket competitions as a member of the F.A.I. Spacemodeling team and N.A.R. His other books include: *69 Simple Science Fair Projects with Model Rockets: Aeronautics, Model Rocket Propulsion,* and *Second Stage Advanced Model Rocketry, Second Edition* as well as video books on rocket construction.

In 2000, Tim was awarded the Howard Galloway Award by the National Association of Rocketry. This recognition is given for outstanding service to all sport rocket flyers.

In his spare time, the author gives educational rocketry presentations for the Space Foundation and for other educational organizations. He can be contacted for speaking engagements.

Dedication

For the many forward-thinking model rocketeers who desire to have more fun flying their own designs.

Acknowledgments

After 30 years in this hobby, I'm still learning new stuff. I would like to thank all those modelers who went before me, blazing trails of their own into the sky, yet who took the time to point other rocketeers, like me, in the right direction. Without these people, model rocketry would not exist as it does today.

Special thanks goes to those who helped with this book—Patrick McCarthy for technical review of the text and help in selecting photographs, Marc (Moose) Lavigne for encouragement, Edward LaCroix and Steven Bachmeyer for taking photographs for the first edition of the book. In this third edition I also received photographs from Scott Oliver, Geoffrey Kerbel, Kenneth Brown, Kent Burnett, Bob Mosely, Moe Bertrand, John Manfredo, and had help with illustrations from Dave Curtis and Eric Vandergriff. George Gassaway graciously allowed me to reprint some of his helicopter plans, and Mike Dorffler provided the scale data drawings of the D-Region Tomahawk and MR-20 sounding rocket.

Thanks also to Sig Manufacturing Co., Inc., for use of the information on the grading and selection of balsa wood. Similarly, thanks to Dr. Gerald M. Gregorek for allowing the reprinting of his boost glider design rules.

Special thanks goes to David Flanagan who allowed me to reprint the sections on cluster parachutes, gliding parachutes and spinning parachutes. Additionally, Norm Dziedzic helped with the section on hemispherical parachutes.

Paul Fossey kept me involved in rocketry by authoring the Rocksim software. That software was birthed by the first edition of this book, and is motivating modelers to tackle some very complex and interesting rockets. They then ask my advice on how to achieve their rocket dreams, which is how and why this third edition came about.

From a production standpoint, thanks goes to Michelle Mason for editing and proofreading and to Jeff Lane (Brandango.us) for page layout and cover design.

Finally, thanks and love to my wife, Cindy, who allowed me the time to write this book in the first place.

Contents

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Getting Started

P 1-1
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.

Successful Flight Criteria

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

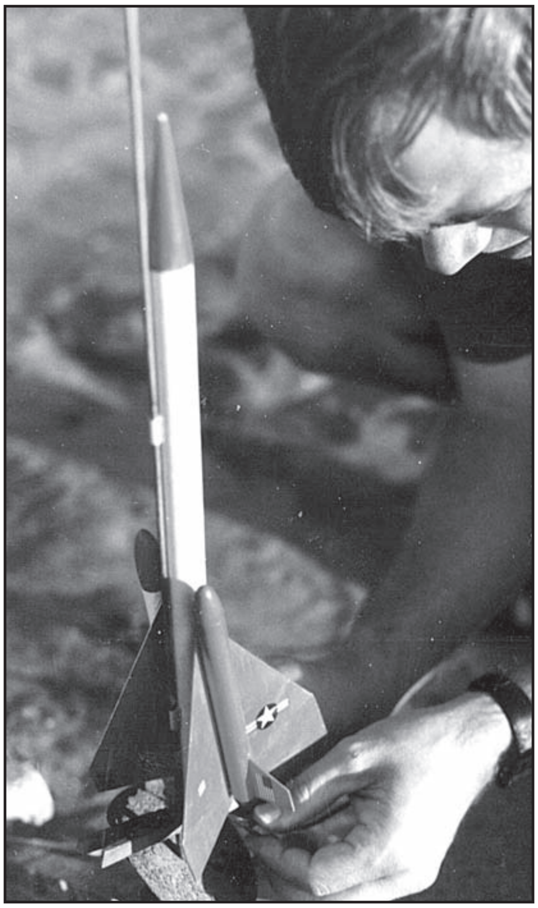
A flight is considered successful when it safely completes the five individual phases: ignition, lift-off, stable flight (including the coast phase), recovery system deployment, and safe landing. Without any one of these five phases, the flight would be termed unsuccessful.

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 classifications of model rockets (page 11). You can also find ideas in the section on the various methods of returning your model to the ground (page 13). These methods are called recovery systems. Other places to get ideas for concepts is in the payload (page 235) and styling sections of this book (page 17). But, if you've already paged through this book, you will have noticed that it 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 23), 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



P 1-2
Marc Lavigne preps a dual glider model for launch.

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. "Parts of a Model Rocket" (page 21) 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 55) describes ways to streamline your rocket to achieve very high altitudes; and "Streamer and Parachute Recovery Systems;" (page 165) describes how to determine the recovery system's size so that the model will return safely to the ground. Chapters 11 and 12 (page 193 and 219) 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 predetermine whether 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.

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 129) and "Creating Custom Parts" (page 130) 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 139), "Clustered Rocket Engines" (page 257) or "Multi-Stage Rockets" (page 241), 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

The Construction Phase

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

3. Construct model
4. Apply finish or paint model
5. Apply decals

Launch

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

P 1-3
An assortment of unique rockets designed and built by Randall Redd (photo by Marc Lavigne).

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 steps listed above comprise a cycle, where several tasks 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.

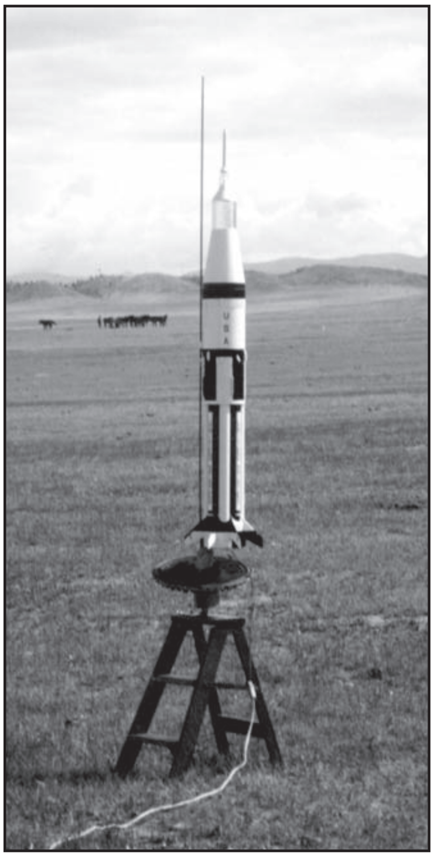
To help you understand a word or phrase which is unfamiliar, the final section of this book is a glossary of terms. It is one of the most extensive rocketry glossaries in print, with over 500 terms, covering not only rockets, but gliders too.

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 code to guide and promote safety in the hobby of model rocketry 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!



P 1-4
A large scale model of the Saturn 1B is ready for launch (photo by Tim Van Milligan).

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, its 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 than 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 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 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.

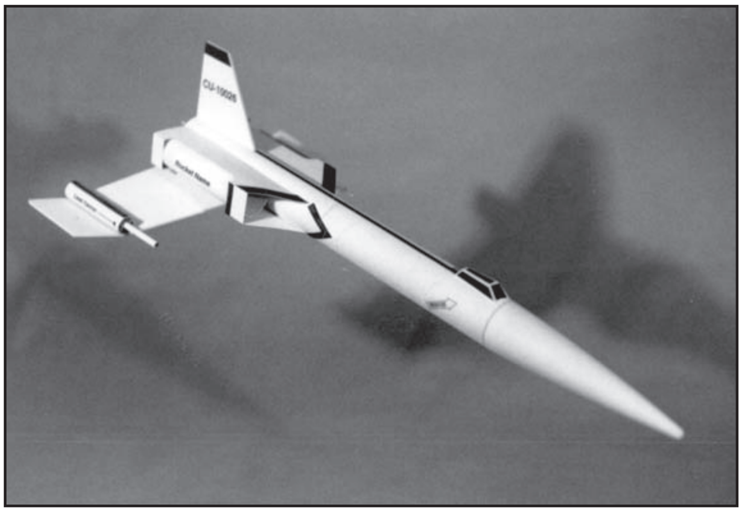
Model Classification

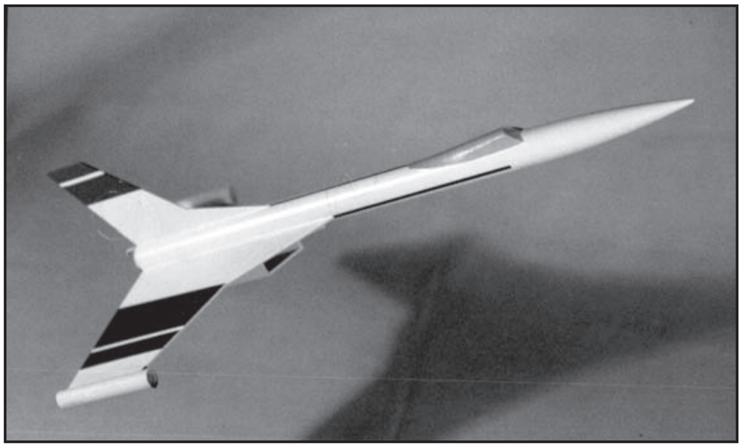
The categories listed below describe several different types of model rockets you can design and build, some of which are more complex than others. This book contains special sections describing additional design criteria that you will want to consider when dealing with those models.

P 1-5 (Photo by Patrick McCarthy)

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. Most *odd-rocs*, such as the flying-pig rocket shown on page 9, which are meant to be comical looking, are in the sport-rocket genre. The category is actually very broad and can be broken down into sub-categories based on





P 1-6 and 1-7 Two different types of futuristic or fantasy type models (photos by Steven A. Bachmeyer).

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 it 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, 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 great altitudes. See Chapter 15 if you are designing multi-stage rockets. It explains how to get the models to stage reliably 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.

Competition Model Rockets: Competition rockets are models used in games or contests. Rules for different events vary, but they 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.

4

Construction Tools

Construction will go much faster and the parts will fit together more closely if you have the proper tools for the job.

The following list describes the basic tools you'll need to build your rocket design and tells why each tool is necessary. You probably already have most of these tools, although if you are missing any, you can find them easily at hobby shops, hardware or craft stores.

P 4-1
Photo by Steven A. Bachmeyer)

Essential Construction Tools

Hobby Knife: The hobby knife has a very sharp and pointed blade. It is used for cutting cardboard, balsa wood, and body tubes. You will find it almost indispensable in the work of building model rockets. It's very sharp, so be careful in using it, as it will easily cut through flesh too. The blades can be brittle, and it's possible for the tip to snap off; so always wear safety goggles when cutting anything with a hobby knife.

Adhesives: Adhesives are used to join anything together. There are several types of adhesives, and each has a particular area where it works best. On page 71 is a list of these adhesives, and how they are used.

Ruler: The ruler makes length measurements of parts, and is used as a straightedge for marking and cutting. I recommend a steel ruler over a wooden one; it is usually more accurate, and its edge will stay straight for years. With a steel ruler you won't be slicing off parts of the ruler with your knife when using it as a straightedge, either.

Scissors: Scissors are used for cutting cloth, thin paper, thin plywood, and plastic sheet. Buy a good sharp pair, and they will last a long time.

Pencil: The pencil is the preferred marking device over pens or markers when building rockets, because the ink from a pen or marker will bleed through paint and mar the finish of a otherwise great-looking rocket.

Sandpaper: Sandpaper is used to shape or smooth a part. It is graded by its grit number. A low number means that the surface of the paper is very rough, while a high grit number means the paper has a smoother surface. Low numbers under 150 grit are used for rough shaping. Intermediate numbers, from 150 to 320, are for initial smoothing of a surface. High numbers over 400 grit are for final smoothing and polishing.

Sandpaper works better when it is clean, so be sure to shake the dust out of it often. A thorough cleaning can be done with an old toothbrush. Eventually, it will wear out as the grit flakes off the paper. It is worth the investment to get good high quality sandpaper, as it will last longer.

P 4-2 All the different paints, glues, tapes, and fillers have very specific uses during the construction of a model rocket. (Photo by Steven A. Bachmeyer)

The black, wet-or-dry paper is typically much more durable and last longer than the cheap papers.

If you want something that will last a lifetime, check out the Perma-Grit sanding tools. The tools consist of bits of super-hard tungsten carbide that are brazed to a metal base. They will last a lifetime, and they can be cleaned with a old toothbrush when they get clogged.

You can also get round Perma-Grit sanding sticks in size from 1/4" to 3/4" which come in handy for sanding the insides of just about anything.

You can use sandpaper wet or dry. Check your local hobby shop or online supplier.

Sanding Sponges: For those times when a rigid flat sander isn't quite right but trying to manage a floppy piece of sandpaper is too tedious and imprecise, you can find sponges coated with sanding material. They are great for sanding airfoils and body tubes because they conform very well to the part being sanded.

Paint brushes: Paint brushes are used for more than applying paint. You can also use them for cleaning parts and applying liquid plastic cement. For rocket work, you'll want at least a small, medium, and a wide brush. Choose a brush with good natural bristles that don't pull out easily.

Work surface: The area where you build your rocket design should be large enough to spread out your parts, and it should have a smooth, even surface. Protect the surface of your work area with a large piece of plastic sheet, such as a garbage bag. When cutting with a hobby knife, lay a piece of heavy cardboard over the plastic to prevent the knife from scoring through the plastic and into the table.

Optional Construction Tools

Razor saw: For cutting plywood, thick wood and plastic.

Sanding block: A flat block of wood to which sandpaper is attached; used to accurately shape or smooth any parts or surfaces. I prefer to use an aluminum "T" extrusion, called a sanding "T". I personally don't tape the sandpaper to the block. I just fold it over the sides and grip it tight so that it doesn't slide. Because of this, I can have several grades of sandpaper around at once, and each grit is ready to quickly spring into action when it is needed.

Wood Dowels: They come in handy for all sorts of applications, smearing glue inside of body tubes, pushing rings into tubes, and even smoothing out fillets.

I recommend having several sizes of wood dowels and some smaller pieces of music wire that act as micro dowels. I also use the music wire to unclog the tips of CyA bottles.

One tool I made myself by gluing sandpaper around a wood dowel. This tool allows me to sand on the inside of body tubes and centering rings. I try to have several dowels around with different grits of paper on them.

Music Wire or Piano Wire: Sold at most good hobby stores, this very stiff wire comes in handy holding small fins while you are painting on the surface sealer. Cut it into lengths of about 5 inches (12 cm) and poke each into the root edge of the fin. While the sealer is wet, poke it into an old cardboard box so that the fin can air dry without touching anything. The root edge gets glued to the rocket later, so the hole you make in the edge of the fin will be hidden.

Music wire can also be used as a micro-size dowel to help spread out glue on the inside of small tubes.

Razor planer: A device used to hold a sharp metal blade used to shave thin layers of wood off a larger piece of wood, dramatically decreasing the time it takes to rough-shape a piece of wood. Great for making airfoils on fins and glider wings.

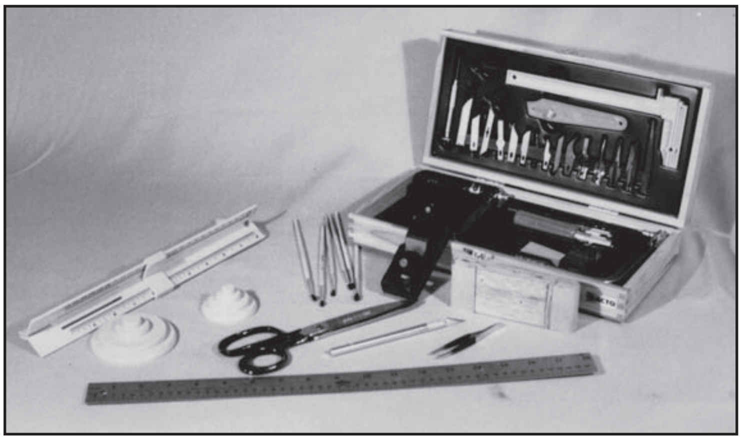
Tweezers: Used for holding small parts. The two that I use most often are the pointy ones with the teeth on the inside gripping surfaces, and the crossaction variety. The latter gets used as a small clamp for holding things while the glue dries.

Dental Picks: These stainless steel instruments can be purchased at flea markets and some hardware stores. You can use them for scraping, scoring, and spreading out paste and putties. They also are handy to dig things out of the insides of body tubes like shock cords and centering rings.

Computer and Laser Printer: The computer has become an indispensable tool for designing rockets. After the design is complete, you can print out fin templates and centering ring patterns with perfect precision.

Once the patterns are printed on a sheet of paper, you can cut them out with scissors and spray the back of the paper with a low-tack spray adhesive. Then stick them onto the balsa wood or card-stock for cutting out. Because of the low-tack adhesive, the patterns can be easily removed prior to assembling your rocket.

Dremel: The only power tool that I use (very infrequently) is a battery-powered dremel. I like the battery powered variety better than the outlet style because they run at slower speeds. Because of this, I feel I have better control over the cutting or scraping.



P 4-3 Proper tools make construction more accurate and decrease assembly time. (Photo by Steven A. Bachmeyer)

Needle Files: Small needle files usually come in a small assortment of shapes, such as square, round, half-round, triangular, flat. They all come in very handy in modeling, especially in areas that are hard to reach and require more precise removal of material. The round shapes are great for smoothing out fin fillets, and the triangular ones are excellent when you want to clean out a sharp corner edge.

Tapes, Glues and Adhesives

*Wood Glue***:** It is much stronger and dries faster than ordinary white or school glue. Once dried, it does not soften when exposed to moisture like white glue. Sometimes this glue is call aliphatic resin. It is used for any paper-to-paper, paper-to-wood, or wood-to-wood bond. It works by penetrating into the fibers of the paper and wood and creating tiny fingers that grasp the fibers. This requires that the glue come into direct contact with the fibers of the material, so remove any paint, filler, or other substances from the surfaces being joined. This glue does not work on plastics. Wood glue shrinks slightly when it dries, and this may affect the appearance of your rocket if you use it for fin fillets. To improve the appearance of wood glue shrinkage, apply a second fillet of ordinary white glue on top of the dried wood glue. Although not as strong, the school glue does not shrink when it dries.

Super glue (Instant glue): Technically known as *Cyanoacrylate*, this type of glue is very versatile and can be used on a variety of materials. It creates a very strong surface bond, so it works best when the materials being jointed have smooth surfaces. It will bond most materials and is probably the best adhesive to use when bonding plastic to wood. As the name implies, this glue hardens very quickly and sometimes almost violently, bubbling up instead of turning hard. This happens when the glue is applied too thick, or when it is accelerated too fast. The accelerator is sold as a non-aerosol pump atomizer, and is sometimes called *kicker*. It makes the adhesive harden nearly instantaneously. Use caution with this glue, as it instantly bonds to skin. Wear safety goggles to protect your eyes from accidental splatters.

Instant glue comes in a variety of viscosities, from water-thin to syrupy thick. The thin kind works well on close-fitting parts, while the thick fills any gaps between loose-fitting parts. Some instant glues are compatible with expanded styrene foam, but before you try gluing styrene foam, make sure the bottle says it can be used for this purpose. Also, don't use any kicker on foam, because it will melt the foam. The foam-safe variety of cyanacrylate is sometimes known as odorless glue because it does not give off an

T 4-1

Fin Alignment Guide

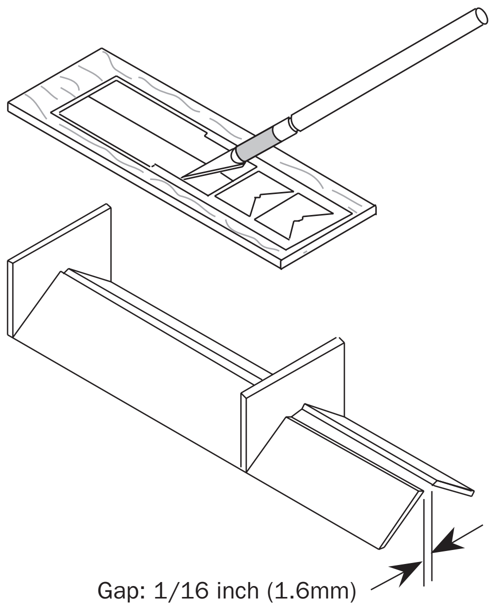
(for 1/16" thick fins)

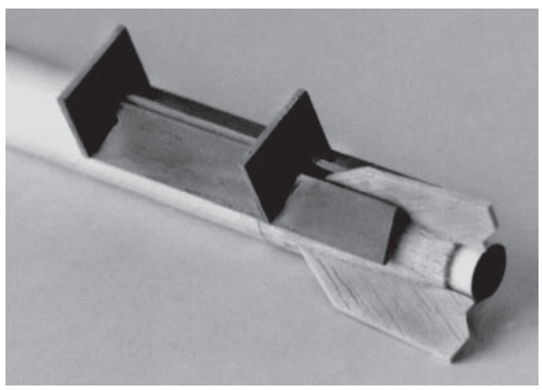
1. Photocopy this page, and cut out the fin alignment guide parts from the copy. Glue them to a 1/16" piece of balsa wood (3M Spray Mount™ works fine). Using a sharp hobby knife and a metal ruler, cut out the four pieces.

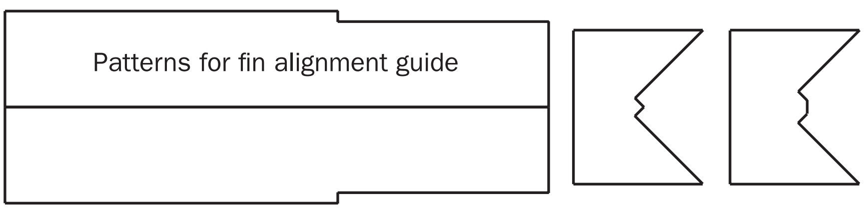
2. Glue the pieces of the fin alignment guide together with wood glue as shown in the illustration. Before the glue sets, check to make sure the width of the slot is snug by placing a 1/16" piece of balsa wood into it. Set it aside to completely dry.

3. Use the fin alignment guide as shown in the illustration to keep the fin parallel to the tube. It can be held in place while the glue on the fin dries by wrapping a rubber band around the tool.

4. You can also use the edge of the tool to draw lines on the tube for fin placement.







odor when it hardens.

Plastic Model Cement: This type of glue is used only on styrene plastics. It works by melting the surfaces of the parts being bonded, and fusing them together. It will not work on plastic to paper, or plastic to wood bonds. Plastic model cement comes in two varieties, a water thin and a clear paste. Apply the thin variety with a paint brush; it works best when the parts being joined have no gaps between them. The clear paste is sold in a small tube.

Contact Cements: This is another surface bonding agent, as it does not penetrate the fibers of paper or wood. You can use it to bond paper-to-plastic, but the bond will be very weak. The best time to use this type of adhesive is when you're laminating paper sheets together, or bonding thin balsa skins onto foam wing cores. It is usually sold in an aerosol can. Rubber cement is a weak form of contact cement, but it can be used in rocketry when making paper transition sections.

Epoxy: Epoxy is a two-part adhesive that is mixed together before it is applied. It is a chemical cure, which does not rely on evaporation of solvents to complete the hardening process. It works well in the same places as instant glue but gives a much stronger bond, although it takes longer to harden. You can buy it in thick or thin viscosities, as well as various cure times from 5 minutes to 24 hours. In general, the longer the cure time, the stronger the bond. You can slightly accelerate the cure time by warming the epoxy with a hair dryer (no open flame heating devices) after application. Heat will cause the epoxy to thin out and become runny before it hardens. Be sure to anticipate this, because the epoxy could run off the model.

Tape: Tape is used to temporarily hold two parts together. Two types of tapes are used in the construction phase of the design process: masking tape and cellophane (clear plastic) tape. Masking tape is used extensively during general-purpose construction, while the cellophane tape has a more specific purpose. It is used during the painting process to create sharp lines between two colors. Masking tape does not work as well for this process because the paint will seep under the edges of the tape, leaving a jagged edge between paint colors.

Sealers, Paint, Primer and Solvents

Filler paste: Filler paste is used to fill wide gaps between parts and to make fillets along the joint where the fins attach to the body tube. It is sold in tubes and small jars. Many of the newer pastes are water soluble; they can be thinned with water if they start to dry out, and have no unpleasant odors. Select a paste that is sandable, because you always need to sand a filled surface to make it smooth and ready for the paint primer. An alternative is carpenter's spackle, found at hardware stores.

Wood sealers: Wood sealer is used to fill the voids in the grain of balsa wood. Apply in liquid form with a paint brush, and sand smooth when dry. Most times, several applications of sealer are used to completely fill the wood to give it an even surface. A good wood sealer is Elmer's Fill-n-Finish paste, which can be purchased at a hardware store. It can be thinned with water, and has no unpleasant odor.

Paint and primer: Paint the rocket when the construction phase is completed. Apply primer first, as it is formulated to bond to most surfaces. Choose a primer that is sandable. You may have to remove the primer by sanding to fix flaws. Apply paint over the primer after it has completely dried. For the best finish, choose an aerosol paint, or use an airbrush.

Solvents: Solvents are used to clean up after the painting is finished. Soak paint brushes in the solvent for a few minutes to rid them of excess paint. Most solvents will work with only a certain type of paint, so always read the labels carefully. All solvents should be used with care, since they can cause chemical burns if they come in contact with your skin, and always wear safety goggles to protect your eyes. Always use solvents in a well-ventilated area, and follow the cautions printed on the label of the container.

5

Basic Raw Materials

Materials— My model rockets will be made of lightweight materials such as paper, wood, rubber, and plastic suitable for the power used and performance of my model rocket. I will not use any metal for the nose cone, body, or fins of a model rocket.

This is the very first paragraph in the safety code used by all model rocketeers. The founding members of the National Association of Rocketry knew that the materials used in rocketry could affect the overall safety of the hobby. Before this safety code was written, people thought it was normal to launch metal projectiles from their back yards. This rule was implemented to keep you safe.

When selecting the materials, try to use lightweight materials with good strength characteristics. You want your rockets to be strong enough to survive the forces that occur during launch and landing, so they can be used again and again. Keeping the mass of models low allows them to fly to high altitudes and accomplish other great feats. Plus, low mass means less potential for damage to people and property around your launch ranges.

Below are some of the many materials that are available to the model rocket designer, and their chief characteristics.

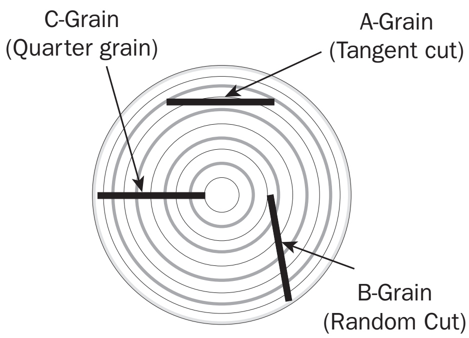
P 5-1
This rocket was made from a plastic model kit of a USAF Mace. These rockets are called plastic model conversions. (Photo by Marc Lavigne)

Balsa Wood

Balsa wood is the "miracle material" of the hobby world. It has the best strength-to-weight ratio of readily available material. Not only is it known for its high strength and low density, it can be easily shaped, sanded, glued, and painted. It is also non-toxic and biodegradable, and it absorbs shocks and vibrations well. Balsa wood is imported into North America from plantations in South America. Don't worry about destroying the rain forests by using this wood, it grows incredibly fast: an average of 60 to 90 feet in 6 to 10 years, with a diameter of about 45 inches. The rain forests aren't being destroyed to harvest balsa wood, so use it with a clear conscience.

Because of its versatility and strength, balsa wood can be used extensively to construct your rockets. Typical uses include nose cones, wings, fuselages, and fins.

Fig 5-1



Cross section of a tree log to illustrate how balsa is categorized

Balsa can be purchased in almost any hobby shop, and it comes in strips, sheets, planks and blocks. Strip sizes can range from 0.79 mm (1/32 inch) X 0.79 mm (1/32 inch) to 2.5 cm X 2.5 cm (1 inch X 1 inch); sheets are available in thickness up to 6.35 mm (1/4 inch), and widths of typically 7.6 cm (3 inch) or 10.1 cm (4 inch). Anything larger would be considered a plank or a block of balsa.

You can use strips for making surface details and general reinforcing of the model, such as fin fillets or reinforcing the leading edges of glider wings. Use sheet balsa for making fins and wings. Large blocks can be made into nose cones, transition sections, nose blocks, or anything that is carved or shaped.

Typically, balsa is identified in two ways. The first is by the density of the wood. The denser the wood, the stronger and harder it is. Densities can range from 80 to 320 kg/m^3 (5 to 20 pounds per cubic foot), with 160 to 192 kg/m^3 (10 to 12 lb/ft^3) considered medium weight. Extremely lightweight balsa with a density under 96.1 kg/m^3 (6 lb/ft^3) is considered "contest grade" and is used on competition models where mass must be kept to a minimum and where durability is not a top priority.

The second way to classify balsa is by its grain pattern, which is determined by how it was cut from the log of the tree (Fig 5-1). Grain direction determines the rigidity or flexibility of a balsa sheet more than density does. For example, if the sheet is cut from the log so that the tree's annular rings run across the thickness of the sheet (A-grain), the sheet will be fairly flexible edge to edge. If, on the other hand, it is cut with the annular rings running through the thickness of the sheet (C-grain), quarter grain, it will be very rigid edge to edge. When grain direction is less clearly defined (B-grain), the sheet will have properties intermediate between A and C grain. B-grain is the most common and is suitable for most jobs.

Whenever you come across pure A-grain or C-grain sheets, learn where to use them to take best advantage of their special characteristics:

A-GRAIN sheet balsa has long fibers that show up as long grain lines. It is very flexible across the sheet and bends around curves easily. It also warps easily and is sometimes called *tangent cut*.

DO: Use sheet for covering rounded fuselages and wing leading edges. Use planking for fuselages, forming tubes, strong flexible spars, hand-launched glider fuselages. Use for fins for small, ultra-light competition model rockets.

DON'T: Use for sheet balsa wings or tail surfaces, flat fuselage sides, ribs, or formers.

To make A-grain balsa wood more pliable and easier to bend without breaking, soak it overnight in a bucket of water with a small amount of ammonia (or bleach) added. It should be bent or shaped while wet, and then held in the correct shape until it is completely dry.

B-GRAIN sheet has some of the qualities of both A and type C. Grain lines are shorter than type A, and it feels stiffer across the sheet. It is a general purpose sheet and can be used for many jobs. It is sometimes called *random cut*.

DO: Use for flat sheet fins on most rockets, for flat fuselage sides, trailing edges, wing ribs, formers, planing gradual curves, and wind leading edge sheeting.

DON'T: Use where type A or type C will do a significantly better job.

C-GRAIN sheet balsa has a beautiful mottled appearance. Some people say it looks like fish scales. It is very stiff across the sheet, and if bent it splits easily. When used properly it helps build the lightest, strongest models. This is the most warp-resistant type, but it is difficult to sand. It is sometimes called *quarter grain*.

DO: Use for sheet balsa fins on larger model rockets. Can also be used for sheet balsa wings on larger gliders, tail surfaces, flat fuselage sides, wing ribs, formers, and trailing edges. Best type for wings on larger boost gliders and hand-launched gliders.

DON'T: Use for curved planking, rounded fuselages, rounded tubes, hand-launched glider fuselages, or wing spars.

Plywood

Plywood is made by gluing thin sheets of hardwood (called veneer) together so the grain direction of each layer is perpendicular to the adjacent layers. This material is only available in sheets, which vary in useful sizes from 0.4 mm (1/64") to 6.35 mm (1/4"). It is used in places where the part needs maximum stiffness. This material is heavy, and it should be used sparingly. Another drawback of plywood is that it is hard to cut with typical modeling tools, except for 0.4 mm (1/64") ply, which is easily cut using scissors.

Spruce

Spruce is a wood native to North America and is available in a variety of sizes. The most useful forms of spruce for rocketeers are strips or dowels. If you need a stiff part like the main spar on a large built-up wing or the fuselage boom on a glider, spruce is an excellent choice. You can also use it to reinforce weaker structural members of the rocket.

Basswood

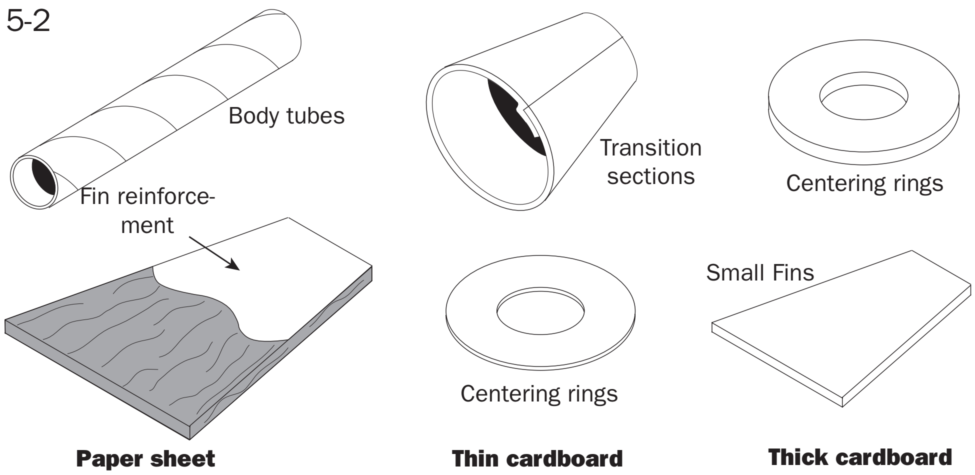
Basswood is a medium-density wood that can substitute for balsa wood. Its chief characteristic is that it has a tight wood grain, and because of this it takes very little filler to achieve a smooth finish. This makes it excellent for models that need a smooth surface, such as fins on a scale model. You can find basswood at hobby stores that carry balsa wood.

Paper

Paper is truly a wonderful building material for model rockets. It is lightweight and strong, accepts almost any type of glue, can be easily painted, and is both biodegradable and recyclable. It is one of the safest materials to use in the construction of a rocket, because if it hits something, it crumples in on itself without shattering. This is the best way to get rid of the kinetic energy of rocket with the least amount of damage.

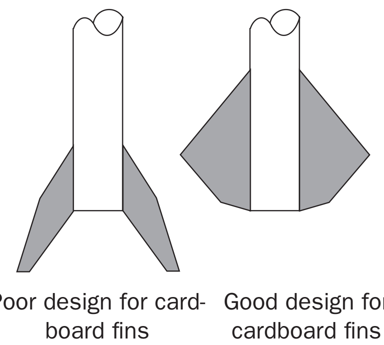
The variety of paper types as defined by its construction and material components is immense (Fig 5-2). For example, think of all the different types of paper products; tissue paper, wax paper, newsprint, crepe

Fig 5-2



Uses for paper in model rocketry

Fig 5-3



Cardboard isn't as strong as balsa wood, so care should be used to design fins that are less susceptible to damage.

paper, cotton rag paper, bond paper, light cardstock, heavy cardstock, corrugated cardboard, Bristol Board, and molded paper products are just a few of those available. Also papers come in a wide variety of weights, colors, textures, and finish coatings. For component materials, paper can be made from a wide variety of organic materials including wood pulp, cotton fibers, and the latest craze, hemp fibers.

Paper is available in an almost infinite number of thicknesses, so you can use it in a variety of locations. Roll thin paper to make tubes, and apply it over other materials to make a smooth skin. Use medium-thick paper to make centering rings, or roll it to make transition sections. Use cardboard to make centering rings or fins for small rockets.

A nice feature of paper fins is that they do not chip apart from hard landings. If a paper fin is bent, it can easily be repaired by wicking water-thin CyA glue on the crease to increase its stiffness and strength. Since the grain of paper isn't as strong as the grain of wood for the same weight, you typically use wood fins for larger rockets. Also, don't use a swept back configuration for paper fins, as they are more susceptible to damage (Fig 5-3).

The natural fiber paper products retain many of the wood-like qualities. They can be cut, glued, sanded, painted, and shaped with the same type of woodworking tools. Another wood-like quality is that most papers have a grain direction. To see this for yourself, take a piece of newspaper and tear it. You'll see that if you tear it one way, you get a fairly straight line, but if you tear it in the other direction, it is very jagged. This means it's stronger in one direction than the other, and you can use this to your advantage.

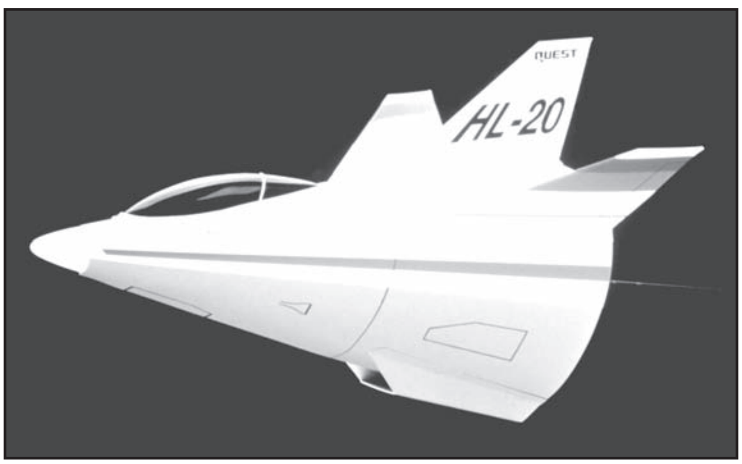
The grain direction of paper will make a difference in the sharpness of a fold. If you fold perpendicular to the grain direction, the crease isn't as sharp, and it may try to straighten itself out.

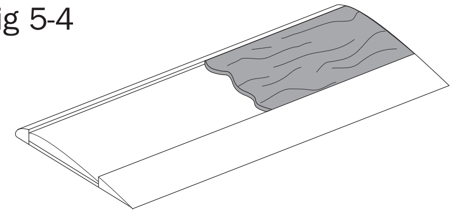
If the natural fiber-based paper products are not enough, there are even synthetic varieties that have other characteristics. Think of Tyvek®, a polyester based paper which doesn't tear at all; spun-woven nylon (available from Dave Brown Products, www.dbproducts.com) which makes a great hinge material because the fibers stay springy, and even Nomex® paper, which doesn't burn.

There are also paper combinations with other materials like Foam Core products. These are really strong and can be used to make fins and even glider wings.

Molding paper is another construction technique. It can be used to make complex and compound curves out of paper. You've probably seen molded paper in the form of egg cartons at the supermarket, and very large plant pots are made in this method. They are formed by making a thick water slurry of paper fibers and pouring it into a two part mold. The mold halves are brought together under a lot of pressure, which squeezes the water out of the fibers. Typically, one side of the mold has a mesh surface which allows the water to escape.

P 5-2 The HL-20 rocket kit uses paper to create a complex looking design. (Photo courtesy of Quest Aerospace)





Balsa wood over the top of plastic foam is very strong

This makes one side fairly smooth, and gives the other side a rough texture. The part is then removed from the mold and allowed to dry. Big parts with thin wall thicknesses can be made this way.

In rocketry, molding paper hasn't really caught on due to the intensive set-up required to make molds. A simpler way may be to use a papier-mâché set-up.

Probably the best characteristic of paper that makes it a great choice for rocket builders is that it is cheap. Most times, it is even free! So if you are limited by your rocketry budget, it is the best material to use for construction.

Plastic

Plastic, a very versatile material, is relatively strong and light. It has been used extensively in model rocketry because it can be molded into a variety of shapes, for example nose cones, transition sections, fins, etc. Modelers building rockets from scratch usually buy plastic in sheets called sheet styrene. Styrene can be easily glued, cut, shaped, and painted.

Thin, flexible plastic is often used to make parachutes. You probably already have this plastic at home in the form of trash bags and dry cleaner's bags.

Polystyrene is also available in a rigid foam called expanded polystyrene, often mistakenly called Styrofoam®. It is used to fill large empty volumes or voids which need to be strong, but without feeling squishy. This material is easy to cut and shape. A thin metal wire heated to a high temperature can cut through the foam like a knife through butter. Use this technique to cut accurate shapes such as wing airfoils. Since expanded polystyrene foam is not very strong, you must use it with other materials such as balsa, plywood, or fiberglass. Usually the foam is sandwiched between two thin skins of the secondary material to make a strong, lightweight part (Fig 5-4).

You might find some expanded polystyrene around your house. Of its many uses, the most common are as packaging of delicate equipment and as a heating insulation. Don't use the "packing peanuts," but the solid blocks of foam are fine.

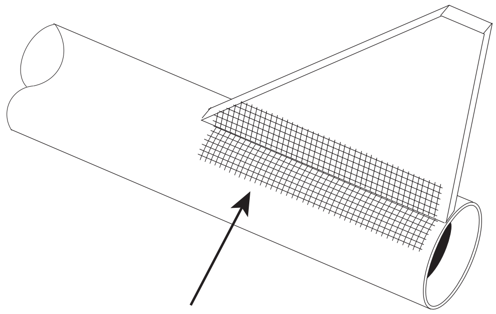
Take care when gluing anything to foam, as many adhesives will dissolve it. Don't use any styrene cements or polyester-based resins. Epoxy-type resins work very well. If you are unsure about a glue, test the compatibility of the adhesive on a scrap piece of foam first.

The same type of problem also exists with most paints. The solvents in the paint will dissolve the foam. In this case, you'll have to use one of the newer water-based paints. They are now available in spray cans, although they are a bit more expensive. But if they are applied in thin coats, they can be painted over foam—and the results are usually acceptable.

Fiberglass

P 5-3
Ultra low-mass rockets can be made using fiberglass. These rockets require extra forms and construction jigs to hold the fiberglass while the epoxy hardens. (Photo by Tim Van Milligan)

Fig 5-5



Fiberglass cloth with epoxy can be used to reinforce fin joints

Fiberglass, as its name implies, is made from very thin strings of glass that are usually woven together to make a lightweight cloth. Although fiberglass is a relatively old product, it is considered an exotic material in model rocketry because it is not often used and requires special methods of application. Fiberglass is available from hobby stores that sell radio control airplanes.

Fiberglass is always used with some type of resin; it can be epoxy, polyester resin, or even instant glue. When the resin hardens, it holds the individual fibers together, creating a strong material (Fig 5-5). Sometimes fiberglass is sold in thin sheets with the resin already hardened. This type is used to make exceptionally strong fins and centering rings.

In rocketry, fiberglass is more commonly used to reinforce fins and sometimes is wrapped around body tubes for higher strength. Many competition rockets are made entirely out of fiberglass. When fiberglass is used properly, very lightweight rockets can be constructed. Special forms or fixtures must be created to wrap the fiberglass around until the resin hardens. These forms are then carefully removed, yielding a stiff pre-shaped part. Construction of these highly specialized parts is not covered in this book, because the need for these parts is very rare.

Casting Resins

Another more exotic rocketry material is polyurethane casting resin. It is a two-part liquid that is poured into a mold. It is somewhat similar to epoxy, but hardens much faster—30 seconds to a few hours, depending on the chemical formulation. The drawback is that it is relatively weak, and therefore isn't used as a structural part. Typically, the resin is poured into a mold to make plastic-like parts. Examples are nose cones, simulated nozzles, and other protuberances attached to the model. Unless the part is repetitive, it is typically easier to make these parts with other methods described in this book. But if you want to learn more about using casting resins, contact Apogee Components for Technical Publication #12, which describes how to make molds for these resins.

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