Preface to the Second Edition

Shortly after the publication of *Modern High-Power Rocketry* in 2002, my wife and I moved from California to South Carolina as the result of a unique job opportunity.

I knew no one in the South, but within only a few weeks after my arrival here I was attending my first launch. It was the annual Freedom Launch, a three-day event hosted by Tripoli ICBM at the legendary field in Orangeburg, South Carolina. I was a complete stranger when I arrived there on that Friday afternoon in September, 2003. But not for very long. As a high-power rocketeer, I was quickly welcomed. I've had a great time here ever since.

In the last two years, I have attended high-power events up and down the East Coast, from the Florida Winter Nationals near West Palm Beach to LDRS23 in Geneseo, New York; in my area in Charlotte, North Carolina; in Battle Park, Virginia, and at Whitakers in North Carolina. I've gone back to the West Coast for our big launches in Central California and made the trek to the Black Rock Desert in 2004.

And at each location one thing remains constant: Belonging to NAR or Tripoli makes me part of a national family. In fact, it is an international family stretching across continents from Europe and Great Britain, to North America and beyond to Australia. As a high-power rocketeer, wherever there is a launch, I've found friends. You will, too.

This book was originally conceived not as a second edition but as an entirely new publication that would feature Level Three projects only and would cover the various aspects of obtaining Level Three certification with Tripoli or NAR. My intent was to follow up on the first book without repeating everything in it. I really had no intention of revising the first book for several years.

But that all changed in late 2003, when I realized that things were changing fast in high power and in the book. It soon became clear that the first book and the second book needed to merge into one.

This edition, which I hope serves as the most comprehensive resource on high-power rocketry to date, covers most aspects of high power.

Each chapter has been rewritten with new information, and virtually all of the photographs have been replaced with tighter, better shots that illustrate the points made more clearly than before. More than 150 new pages have been added. There are new diagrams and illustrations to help the reader better understand the fundamentals of high power. The chapters on motors and motor-building now include Animal Motor Works and Cesaroni Technology products. The electronics chapter has been expanded to cover more altimeter brands and other useful information. An entirely new chapter has been added on the construction and use of altimeter bays.

I have also included several other new sections, including chapters on launch pads, motor cleaning, and, perhaps most important, Level Three certification and the construction of a Level Three rocket. Included in the text and in the appendix are samples of Level Three applications and certification drawings and simulations. This book also contains information on taking the Level Two test with either NAR or Tripoli, and also the fundamentals of obtaining a Low Explosives Users Permit (LEUP) from the Bureau of Alcohol, Tobacco, Firearms and Explosives (ATFE).

It took more time than I thought it would to get it all done, and like most big projects, this book could not have been written without the help of many people.

Once again, the members of my home club of Tripoli Central California were of great assistance, especially club president, Scott Eakins.

I have spoken to rocketeers all over the country, and most of them agree that the best thing about high power is the support new people get from those who have been engaged in this hobby for a while. My experience as a new rocketeer nine years ago was the same. And I would like to thank those people who showed me the way in California, including Greg Davis, Brian Liggett, Richard King, Jeff Engelman, and Dick Mooradian.

I also want to thank the members of Tripoli ICBM in South Carolina who have allowed me to pore over their rockets at launches, camera in hand, for the last year. ICBM member Mike Scicchitano of Florence, South Carolina, has been particularly helpful.

Scott McLeod of Fairfield, New South Wales, Australia, graciously provided me with information and photographs pertaining to his Level Three certification flight–the first Level Three certification in Australia. (David Wilkins was the first Australian to certify. He did it here in the United States.)

Craig Christenson of Washington and Rick Dunseith of Canada provided me with similar information for their large projects, as did Richard Salinas (California) Ron Weigel (Utah), Mike Scicchitano, Andrew Tryon (Washington), John Russo (Connecticut) and Steve Gibbings (United Kingdom).

Rick Boyette of Tripoli West Palm extended every courtesy to me when I arrived to take pictures at the Florida Winter Nationals in January 2004 for Extreme Rocketry magazine, and he was equally helpful at LDRS23 in New York. Rick's scratch-built Chinese Long March is one of the many case history projects that are featured in this book.

I also want to thank the Level One and Level Two flyers who provided their case histories: Peter Carvajal, John Froeb, Terry Baucom, and Todd Haring.

One of the first rocketeers to assist me in this book was the late Stephen Roberson. I never met him; he died unexpectedly in 2003. But in our correspondence he was very helpful with Level Three information, and I have included some of his technical drawings in the appendix to this book.

Brent McNeely of *Extreme Rocketry* magazine has continued to be a great resource for me in high power. Brent has used me to cover stories in several states now, including BALLS13 in Nevada in 2004 and LDRS23 in Geneseo. Both of these events allowed me the opportunity not only to cover some of the best projects in rocketry, but also gather valuable information and photographs that eventually made their way into *Modern High-Power Rocketry 2.*

Extreme Rocketry, Sport Rocketry (thank you, Melissa Wilson and Thomas Beach) and *High Power Rocketry* are indispensable to this hobby.

There were a number of Tripoli TAP members and NAR L3CC members who took the time to e-mail me with their comments and observations on achieving Level Three certification the first time. These people include Stephen Lubliner of Arizona, Kimberly Harms of Washington, Rick Boyette, Andy

Woerner of California, Bill Cordova of New Mexico, Daniel Gates of Minnesota, Charlie Barnett of Texas, Fred Gruis of Iowa and Ed Dewey of Illinois. Other TAP and L3CC members who have helped me along the way include Tom Binford of Georgia and Rich Pitzeruse of New York.

Over the last two years, I received a lot of e-mail and other correspondence regarding *Modern High-Power Rocketry.* Most of that correspondence was favorable. But there were some critics. One early writer took issue with my usage of the terms "total impulse" and "average thrust." Another wanted more information on the Level Two exam. Someone else suggested that I include a discussion of motors other than just Aerotechs. I have tried to keep all of these comments in mind when writing the second edition.

Tim Quigg reviewed the first book for *Extreme Rocketry* magazine, and Duane Wilkey reviewed the book for *Sport Rocketry* magazine. Both reviews contained praise and constructive criticism that were helpful to me in the second book.

The overwhelming majority of photographs in this book are new. But there are a few photos that you may recognize from the first book. In most instances, the photos appear only once. But some photographs, less than 10 out of more than 800, may appear more than once. That's because some pictures illustrate more than one concept.

All of the photographs in this book were taken by me, except where noted otherwise. Many of the photographs were taken at launches, including LDRS23 in Geneseo, New York; the Freedom Launch in Orangeburg, South Carolina; DairyAire and October Skies in Riverdale, Califonia; Battle Park, Virginia; the Florida Winter Nationals near West Palm Beach (2004 and 2005); the Black Rock Desert in Nevada; and other locations. And I want to thank each and every person who appears in a photo in this book for taking the time to help me along the way. Not all of you are identified by name, but I appreciated your help!

Thanks also to Larry Smith of South Carolina, who allowed me to photograph his Hypertek inventory and Nadine Kinney of Colorado Springs, for supplying me with a photograph of Andy Tryon and his Level Three rocket before launch. And thank you, Gary Walker of Merced, California, for stepping up to the plate and taking over *The Central Valley Rocket News.*

I took more than three thousand 35mm (film) photographs for this edition, and only a fraction ended up in the book. But every photo was important to me and now serves as a permanent record, and I would like to thank the staffs at Fast Photo in Rock Hill, South Carolina, and Horn Photo in Fresno, California, for their courteous service and quality prints.

This book was designed using Adobe PageMaker 7.0, and all of the photographs that I took were obtained with a Nikon F5 or a Minolta Maxxum 3000i.

LOC/Precision, Giant Leap Rocketry, and Xavien allowed me the use of their photos or diagrams where noted.

Ray Dunakin of San Diego, veteran rocketeer and an expert in high-power on-board photography and multi-staging, graciously came into this project late in the game and provided several excellent illustrations that will be very helpful to the reader.

I also want to thank the people at Trafford Publishing in Victoria, British Columbia, especially Xavier Ames, who have provided me with their helpful suggestions and expertise for both this book and Modern High-Power Rocketry.

Dan Kirklin of Indianapolis, Indiana generously provided his time and skill reviewing and editing the final draft of this book. His professional expertise, insights, and suggestions were greatly appreciated. The fact that Dan also enjoys rocketry was of no small benefit.

Of course, the biggest help I received in writing this book came from my wife, Valerie. For the past several years she has enjoyed and encouraged my involvement in high-power rocketry, and she has never once complained about the road trips I have taken that allowed me to gather the materials for this project. She is also an excellent editor.

Finally, I would like to thank Steve Maddox and the Maddox Dairy in Riverdale, California. Without generous landowners like Steve and his family, who allow high-power launches on their land, it would be next to impossible for high-power rocketry to survive.

This book is not a theoretical work on high-power rocketry or rocket design. And it is certainly not the last or only word on high-power rocketry. There are some high-power subjects that are not covered in this book. These subjects would include experimental motors, detailed discussion of hybrid motors, the use of cameras in a high-power rocket, or new motors that are being introduced in 2005.

This book is also not written to replace any instructions you have for rocketry equipment, electronics, or motors. It is simply a nuts-and-bolts handbook for the weekend hobbyist and for those people who are members of the Tripoli Rocketry Association or the National Association of Rocketry.

This book assumes some model rocketry experience.

I hope you find it useful.

Mark Canepa
Rock Hill, South Carolina
April 2005

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Introduction

Welcome to High Power

If you haven't been to a rocket launch lately, you're in for a big surprise

Biggest Launch

The largest high-power launch in the world is LDRS (Large and Dangerous Rocket Ships). LDRS is held each summer in a different state and is attended by thousands of high-power rocketeers from around the world. The event is usually hosted by several regional Tripoli clubs, and it features rockets of all sizes. LDRS22, held in Kansas in 2002, was the subject of a three-hour Discovery Channel documentary in 2003.

When I returned to rocketry and discovered high-power in the mid-1990s, I was unable to find a single resource containing the basic information I needed to successfully build, launch and recover a high-power rocket. Sure, at my local launch site in Riverdale, California, there were plenty of friendly and knowledgeable people who were happy to share their experience and expertise. But away from the field I spent countless hours learning through trial-and-error, searching the Internet, or combing through back issues of magazines for information on motor retention, ejection charges, igniters, recovery devices, electronics, and all other aspects of high-power rocketry. There had to be a better way.

The purpose of this book is to supply the average rocketeer with an overview of high-power rocketry and to provide the novice with helpful information as he or she explores this exciting hobby. This book is not a technical treatise, nor is it a theoretical work on the physics of rocketry. It is not written for aerospace engineers or those who have obtained degrees in aeronautical engineering or related fields. This book is written for the weekend hobbyist and high-power rocketeer. It is a practical, nuts-and-bolts approach to rocketry that assumes some model rocketry experience and explores most–but not all–aspects of high power. This book is also written to assist weekend rocketeers who become members of the National Association of Rocketry or the Tripoli Rocketry Association as they make their way through the advanced certification process.

Volunteers help lift a 700-pound, 30-foot rocket built by Wedge Oldham onto the launch pad in the Black Rock Desert in Northern Nevada in September 2004. The rocket cleared 18,000 feet on three Darren Wright experimental P motors.

A Little Rocketry Background

High-power rocketry is one of the fastest growing hobbies in the United States and is rapidly spreading to many parts of the globe, including Canada, Europe, and Australia. High power attracts scores of participants to local launches held all over the country many weekends of the year. Regional and national launches now attract hundreds–even thousands–of people who attend these events to observe or participate in the wonder and science of rocketry. High power has been the subject of magazine articles in publications ranging from Popular Science to Forbes. In 2003, high-power rocketry was the subject of a three-hour Discovery Channel documentary that chronicled the largest high-power rocket launch in the world–LDRS22 in Argonia, Kansas.

Woody Hoburg's 100-pound upscale Mosquito at LDRS23 in New York.

High power has come a long way in the last 15 years. In the late 1980s, high-power rockets were relatively primitive, the selection of rocket motors was limited, and on-board electronics were virtually nonexistent. It was a pioneering time for high-power rocketry. There were no national magazines devoted to high power. There were a few regional launches, but LDRS was still in its infancy. There was no Internet, which today joins people all over the world into a single high-power community.

The early pioneers of high-power rocketry included some companies that are still with us today, such as Aerotech, LOC/Precision, Public Missiles Systems, Adept, Transolve, Magnum Rockets, and others. And from some very humble beginnings, high power has literally taken off in the last decade. Today, it is common to see high-power rockets weighing 50 pounds or more lifting off from sophisticated launch pads and achieving altitudes of 10,000 feet or higher. Such rockets may be constructed from kits supplied by commercial manufacturers, or they may be scratch-built from materials available at local hardware or building-supply stores such as Home Depot or Lowe's. Modern high-power rockets may be relatively inexpensive and easy to use, or they may be complex, electronics-equipped works of art loaded with multiple motors developing thousands of pounds of thrust.

The selection of high-power rocketry components has mushroomed since 1990. There are now at least four major manufacturers of high-power rocket motors. The selection of altimeters, timers, stagers, and other electronics is vast. And more rockets are being launched to even higher altitudes than ever before. These rockets come in all shapes and sizes: From scale models of actual military spacecraft to custom-built UFOs, flying tetrahedrons and other craft of fact or fancy. And the hobby just keeps on growing.

Model and High-Power Rocketry

High-power rocketry is distinct from model rocketry. Model rocketry is a popular hobby that has educated and entertained both children and adults for nearly 50 years. Model rockets are lightweight and constructed of non-metal materials, such as balsa wood and plastic. A model rocket can weigh no more than 53 ounces, including propellant. They can be scratch-built or purchased as kits at toy stores or hobby shops from companies such as Estes or Quest. Model-rocket motors are easy to purchase and use. They range in price from a couple of dollars each (or less) to around twenty dollars. And model rocket motors are available at hobby shops and toy stores without any special license or certification.

High-power rocketry, on the other hand, is a more recent phenomenon and involves rocket motors that cannot be purchased as readily as model-rocket motors. In high power, rocketeers must become certified users through either the National Association of Rocketry (NAR) or the Tripoli Rocketry Association.

Tripoli and NAR are the two largest high-power rocketry organizations in the world. NAR–the older of the two clubs–started out as a model-rocketry club in the 1960s and still functions as the largest model-rocketry club in the world. Tripoli has been the leading high-power club for the last 20 years. But NAR is gaining ground fast.

Top: Father and son team Scott (at right) and Tyler Brigham at a high-power launch. Left: Tripoli member Nathan Montalvo explains rocket science to young rocketeers. A launch is an excellent place for children to learn the practical aspects of rocket science.

Both Tripoli and NAR have local chapters in almost every region in the country. They are open to almost anyone, and each national organization has its own board of directors. Both clubs charge their members a nominal annual membership fee, and each organization participates in lobbying efforts nationwide to keep high-power rocketry safe and legal. Both NAR and Tripoli have rules, regulations, and safety codes that are based in part on federal laws and other legislation. Both organizations have detailed web sites that contain all of the rules of membership. The site for Tripoli is www.tripoli.org. The NAR site is www.nar.org. (In Canada, the Canadian Association of Rocketry (CAR) posts safety codes, rules, and regulations. In Great Britian, the United Kingdom Rocketry Association (UKRA) has similar rules.)

The basic high-power rocket

The fundamental components of a high-power rocket are the same as those of a model rocket. A high-power rocket has a nose cone, an airframe (also called a body tube), a motor mount, and fins. The body tube may be made of various materials, including wood, plastic or fiberglass. The fins come in a wide range of shapes and sizes and the motor mount is usually one of five common diameters–from 29mm to 98mm. Although metal is allowed in a high-power rocket, it is kept to a minimum.

The internal parts of a high-power rocket include centering rings for the motor mount and bulkheads to keep special compartments–usually called payload bays–isolated from the rest of the rocket. Payload bays carry parachutes, cameras and other electronics–most notably altimeters and timers.

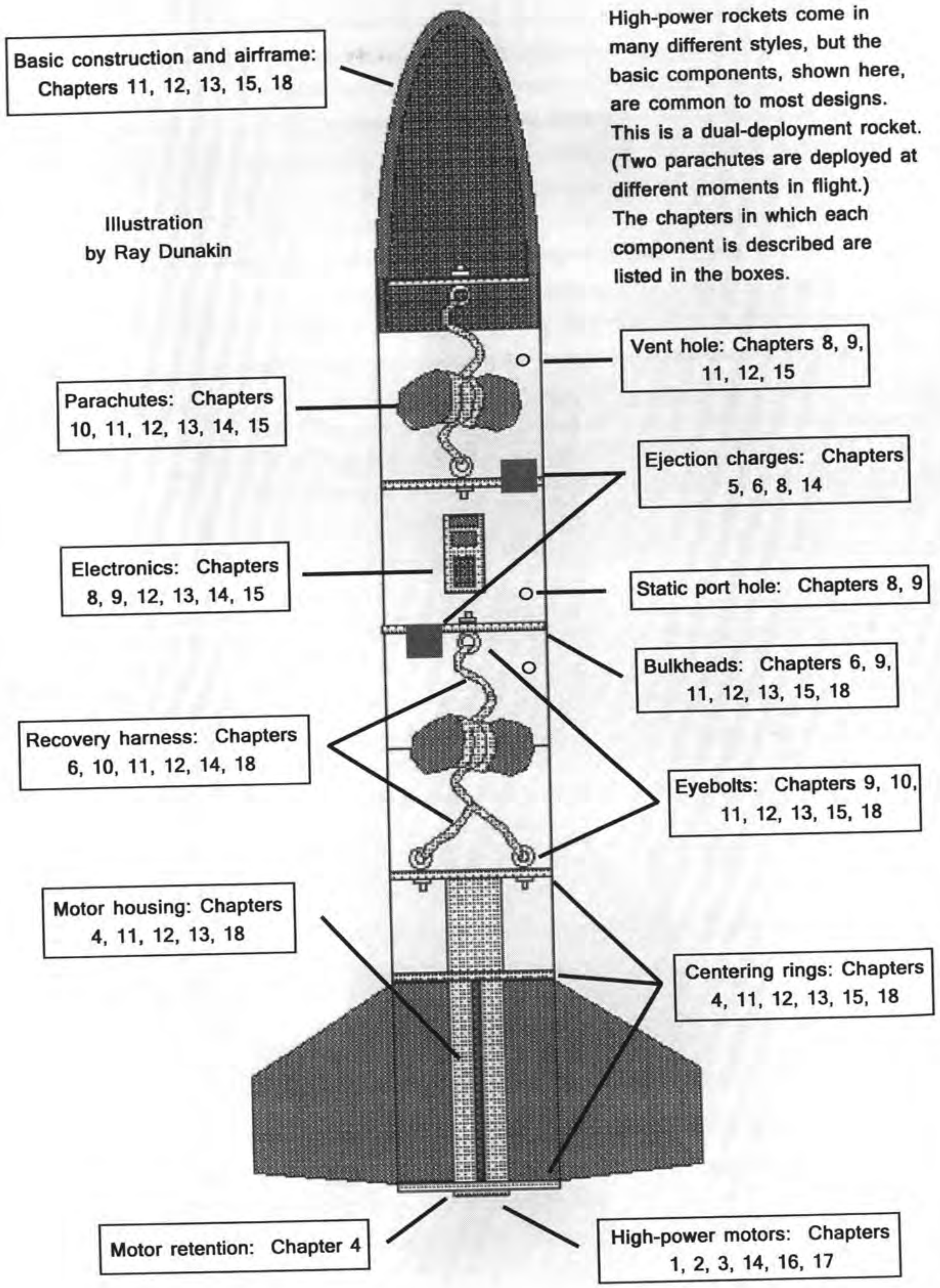
The average high-power rocket has at least one parachute. Some rockets, however, carry two: A tiny drogue parachute that is deployed at apogee (the high point in a rocket's trajectory or flight) and a larger main parachute that is deployed at a lower altitude as the rocket descends.

The launch, flight, and recovery of the average high-power rocket are also like that of a model rocket–although on a much grander scale. At ignition, a high-power rocket enters into powered flight. At motor burnout several seconds later, the

Two Clubs One Goal

Although NAR and Tripoli have separate membership lists and governing boards, both groups maintain similar rules and safety regulations designed to keep high-power rocketry safe and accessible to all. Both Tripoli and NAR have Level One through Level Three certification requirements. But both organizations will usually honor and recognize the certification level of a member from the other club. This allows NAR and Tripoli members the opportunity to legally launch their rockets at either a NAR or Tripoli event anywhere in the world.

High-Power Rocket



High-power rockets come in many different styles, but the basic components, shown here, are common to most designs. This is a dual-deployment rocket. (Two parachutes are deployed at different moments in flight.) The chapters in which each component is described are listed in the boxes.

Illustration by Ray Dunakin

rocket continues its ascent. This is the coasting stage of the flight. At apogee, the rocket turns over and begins its descent by parachute to the ground. If all goes as planned, the rocket is recovered safely and can be flown again and again with new motors each time.

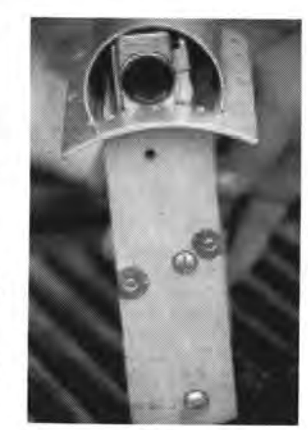
High-Power Rocketry Safety Codes

The design, construction and use of high-power rockets and high-power rocket motors are governed generally by the high-power safety codes of both Tripoli and NAR. The safety codes of both organizations are similar. A copy of each safety code is found in the appendix. The safety codes are based upon FAA regulations Part 101 and Section 1127 of the National Fire Protection Association (NFPA), also known as The Code for High-Power Rocketry. The purpose of NFPA 1127 and the rocketry safety codes is to provide for safe and reliable motors, to establish flight operations guidelines, and to protect rocketeers and the public from injury. These rules and regulations contain the pertinent definitions for high-power rocketry and describe in a general fashion the manner in which high-power rockets are to be used. These rules define high-power rockets and high-power rocket motors.

By definition, a high-power rocket motor has more than 160 newton-seconds of total impulse or an average thrust of more than 80 newtons. As discussed in more detail in Chapter 2, this usually means an H motor or larger. Rocket motors that have 160 newton-seconds or less are considered model-rocketry motors and are governed by NFPA 1122 (The Code for Model Rocketry) and similar regulations.

A high-power rocket, on the other hand, is defined by the Code as a rocket containing either a single motor that meets the total impulse/average thrust criteria above or, in the case of rockets with multiple motors, an installed total impulse of more

High-power rockets may carry many types of special electronics. Robert Utley's M-powered "Sky in My Eye," shown here, held a digital camera for aerial photos after launch at LDRS23 in New York in 2004.



than 320 newton-seconds. A rocket may also meet the definition for high-power if it weighs more than 53 ounces (1500 g). Generally, it is acceptable for high-power rockets to be made of paper, wood, fiberglass, plastic, or even composite materials with a minimum amount of metallic parts necessary for airframe integrity.

The maximum total impulse for a high-power rocket is 40,960 newton-seconds. There is no maximum weight limit for a high-power rocket provided the rocket weighs less than the rocket motor manufacturer's recommended liftoff weight for the motor(s) used for flight.

Who Can Make High-Power Motors?

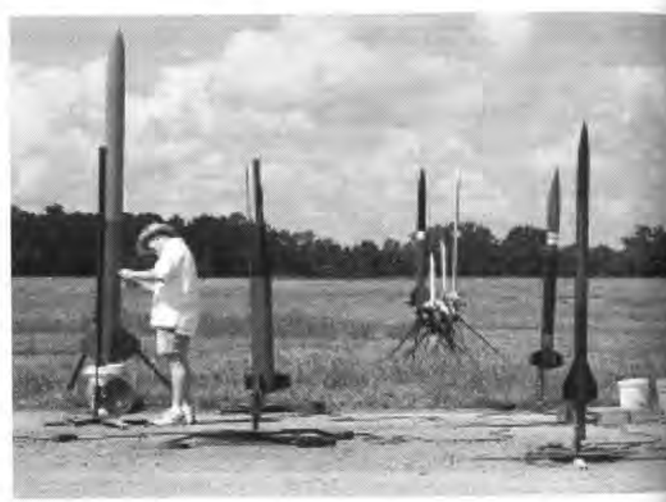
High-power rocket motors cannot be manufactured and sold to the public by just anyone. To be legal,

Join a Club

Local clubs rely on their members to maintain equipment, organize launches, and keep high-power rocketry alive. There is usually no requirement that club members contribute a minimum amount of time. People participate at the level at which they are most comfortable. Some members prefer to join and just watch, while other members spend all of their time building and launching. As with most things in life, the more you put into it, the greater the rewards.

high-power motors that are sold commercially to the public must undergo a screening process that is overseen by either Tripoli or NAR. High-power motors must meet the requirements set forth in NFPA 1125, also known as the Code for the Manufacture of Model Rocket and High Power Rocket Motors.

Once a motor has been certified, it can then be sold. Of course the manufacturer may also have to meet other requirements set by individual states before motors can be sold to the public. A current list of all of the motors certified by either Tripoli or NAR can usually be found on their respective web sites.



Local launch clubs typically provide all of the support equipment for the launch of a high-power rocket. Here, rocketeer John Clifton makes a final adjustment as an entire row of rockets is prepared for flight.

The screening process applicable to commercial suppliers of high-power rocket motors does not apply to individuals who desire to make their own motors for their own personal use. These motors are commonly referred to as experimental, or "EX," motors. EX motor design and EX launches are becoming more commonplace in the United States as more and more people learn to design, develop, and construct their own fuel for high power. EX high-power rockets follow the same basic rules for design and construction as any other high-power rocket. However, EX motor design is generally beyond the scope of this book. (See the bibliography for a partial list of EX-related magazines, articles, and books that are currently available on the subject.)

High-Power Certification

The requirements for the individual to become a certified user of high-power rocket motors and to be certified to fly high-power rockets are found in NFPA Section 1127 and the rules and regulations set forth by Tripoli or NAR. With some minor exceptions, a certified user can be any person who has reached the age of 18 and who has met the membership and certification requirements of either Tripoli or NAR. (CAR/UKRA have similar requirements.)

There are three levels of expertise in high power. These levels are known as Level One, Level Two, and Level Three. The levels are essentially the same both in NAR and in Tripoli, although there may be some minor differences in the requirements for each level between the two clubs. As a prerequisite to reaching any of these levels, a person must become a member of either Tripoli or NAR.

Level One certification is the entry level in high-power rocketry. It is attained by people who demonstrate the ability to launch and successfully recover a rocket with a total impulse in the H to I motor range (160.01-320 newton-seconds). Once Level One is obtained, the rocketeer may purchase H and I motors from dealers licensed to sell high-power motors.

Level Two certification is a two-step process. The first step requires the passing of a written examination. Next, the rocketeer must demonstrate the ability to successfully launch and recover a high-power rocket with a motor in the J, K or L range (640.01-5120 newton-seconds).

The Level Two tests given by NAR and Tripoli are not identical, but they are very similar. Both tests are multiple choice, and the questions are selected from a pool of questions published by either Tripoli or NAR. These questions are available for study online, or you can obtain copies of these questions directly from the rocketry clubs. Once the test is passed and the rocket is successfully launched and recovered, Level Two is attained.

Level Three certification is the pinnacle of modern high-power rocketry. To certify Level Three the rocketeer must successfully launch and recover a rocket equipped with a motor of at least 5120.01 newton-seconds of total impulse. This is an M motor, or greater. Level Three motors are expensive and powerful. A typical M motor can easily lift a six-inch- diameter rocket weighing 30, 40, 50 pounds or more to altitudes in excess of 10,000 feet. Once Level Three has been attained, rocketeers may legally purchase and use motors of all sizes, A through N, and beyond.

Several years ago Tripoli required a waiting period of six months between certification levels. That requirement has been abolished. Theoretically, a user can attempt certification of multiple levels on the same launch day. However, this is generally not a good idea. Most people take some time between levels to gain real experience at that level prior to moving on to the next level.

More High-Power References

Information on the different aspects of high-power rocketry is available from many sources. These sources include the web sites of NAR and Tripoli, as well as other web sites, such as Rocketry Online (www.rocketryonline.com), Max Thrust (www.maxthrust.org), or www.flyrockets.com.

Rocketry Online is probably the largest high-power web site and, along with Max Thrust, is a leading source of information for the names of rocketry manufacturers as well as the latest news in high power.

There are also several books and other publications and magazines, devoted to rocketry.

The most well-known rocketry book is G. Harry Stine's *Handbook of Model Rocketry*, a classic work first published in 1965 and an excellent starting point for all rocketeers. Stine's book covers all aspects of model rocketry and has been revised several times since it was first published. Now in its seventh edition, the *Handbook of Model Rocketry* is an excellent source of rocketry fundamentals for all rocketeers and is available both online and at retailers.

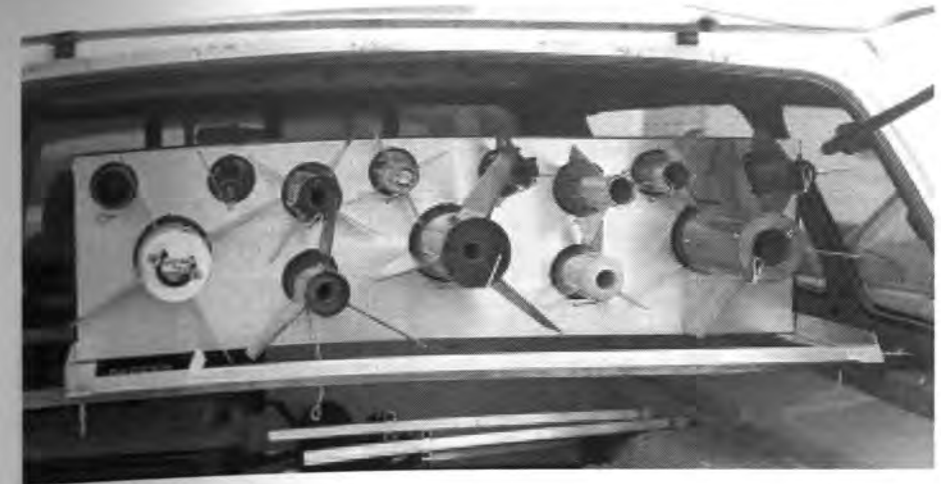
Michael Banks and Tim Van Milligan added to the rocketry library with *Advanced Model Rocketry*, released in 1998. Although this book was focused on model rockets, it also touched on high power as well.

John Wickman's work *How to Make Amateur Rockets*, first published in 1997, introduced the high-power rocketeer to important equations in rocket science and provided how-to information on building high-power rockets and making high-power rocket fuel. In 2000, Dr. Terry McCreary published his book *Experimental Composite Propellant*, which introduced rocketeers to the fundamentals of experimental motor design and testing.

More recently, Tim Quigg's book, *Level 1 Certification*, published in 2002, takes the rocketeer step-by-step through the basics of getting to the first milestone in high power. Quigg's book also provides a comparison between NAR and Tripoli and shows the novice how to get started in rocketry in his or her community. Other recent rocketry books include *The Rocket Files*, by Joseph Jimmerson and *Staging High Power Rockets* by Ray Dunakin.

In addition to these books there are at least three national magazines devoted to high power. *Sport Rocketry* is the official publication of NAR. *Sport Rocketry* is published several times a year and

Local and regional high-power launches are held year-round in most of the 50 states. Here, rocketeers and spectators look skyward as another rocket is launched at the Freedom Launch in Orangeburg, SC in 2003. Top left: A tetrahedron rocket takes flight in New York at LDRS23.



covers aspects of both model and high-power rocketry.

The first magazine devoted exclusively to high power was *High Power Rocketry*. Since the early 1990s, *High Power Rocketry* has covered local and regional high-power launches throughout the United States and is a source of numerous technical articles on rocketry written by rocketeers and experts.

Tripoli member Richard King with one of his high-power rockets.

In 2000, *Extreme Rocketry* magazine was first published. Since that time, *Extreme Rocketry* has been published nine times a year and is now one of the foremost magazines in high power. *Extreme Rocketry* stories include many of the major launches held around the country and regularly explore almost every aspect of high-power rocketry, with technical articles and product reviews.

All three rocketry magazines encourage their readers to submit articles and stories relating to their rocketry experience. These articles help rocketeers keep abreast of the latest developments and frequently suggest new ways of doing things.

Finding Your Launch Site

If you are just getting interested in high-power rocketry–or even if you are only a little curious–the best thing for you to do is to attend a high-power launch in your area.

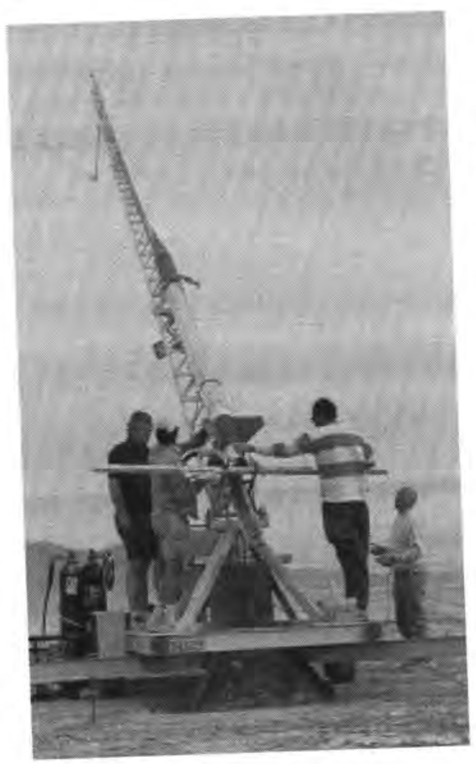
As discussed in more detail in Chapter 7, the average high-power rocket launch operates in the same manner as a pistol, or rifle range. The local club hosting the event

Get CERTIFIED

The certification process is fun and rewarding. It allows you to fly rockets of all shapes and sizes at launch fields all over the country. It is also the way in which rocketeers learn the fundamentals of high-power rocketry. Both NAR and Tripoli have a simple process for achieving Level One through Level Three certification, and there is plenty of help available for novices. The first step is to join one of the rocketry clubs and attend a launch. You will meet many people eager to help you reach your goals.

provides most of the launch equipment (primarily launch pads and electronic launch-control equipment). A Range Safety Officer opens the range to allow rocketeers to load their rockets on multiple launch pads. Once the pads have been loaded, the range is closed. Each rocket is then individually launched with at least a five-second countdown. The countdown is broadcast over a loudspeaker or local radio system so that all spectators can hear what is happening. After all of the rockets have been launched, the range opens, and the process repeats.

Locating a high-power launch site near you is made simple thanks to the web sites of Tripoli and NAR. Both sites contain listings of the many rocketry clubs located throughout the United States and overseas. For example, the official Tripoli web site, found at www.tripoli.org, contains a page that links to Tripoli clubs, also known as "prefectures" (NAR clubs are called "sections") in the world. Simply click on a state or a country on the Tripoli map, and a list of all the prefectures within that jurisdiction will be generated. From there, local launch schedules and directions can be found, as well as local contacts for the club. Almost every state in the U.S. has at least one Tripoli prefecture or NAR club. Some states, like California, Texas, New York, and Florida, have several clubs.



Experimental rocket motors are a growing aspect of high-power rocketry. EX motors are motors that are built by the individual rocketeer. They are flown at special launches from coast to coast. Above: A full-scale Nike Smoke with a P motor is prepared for launch near West Palm Beach, Florida, in February 2004. Left: An R motor hybrid is prepared for launch at Black Rock in 2004.

Most rocketry clubs hold regular launches that are open to the public. Typically, these launches are held in wide-open spaces away from towns, cities, or structures–often out in the countryside or even on isolated government land. Many clubs have monthly launches–weather permitting–and some have periodic two- or three-day events that attract

Local rocket vendors are the lifeblood of high-power rocketry. They supply rocketeers with rocket motors, rockets, parts and accessories and serve as the link between rocket manufacturers and the public. Vendors typically set up early and remain until the event is concluded.

rocketeers from an entire region–several states or more. The average high-power rocket launch is held on the weekend. Large annual regional launches, such as Springfest (Nevada), The Freedom Launch (South Carolina), Hellfire (Utah), NY Power (New York), the WinterNationals (Florida), DairyAire (Central California), Plaster Blaster (Southern California), and others are an excellent way to get the full picture of high-power rocketry. These launches usually feature rockets of all types and high-power motors of every size, A through M, or even larger. These launches also attract hundreds of flyers and spectators.

The largest high-power rocketry launch is known as LDRS (Large and Dangerous Rocket Ships). Since its creation by Tripoli members more than 23 years ago, LDRS has grown into a huge undertaking that lasts nearly a week. At a typical LDRS, thousands of flights take place over five to seven days. It is a time for high-power users to get together and exchange ideas. Vendors are on hand with the latest high-power technology, and old rocketry friends get reacquainted. LDRS is sponsored by Tripoli and is usually hosted by multiple prefectures in a given region. It is always held in the summer. LDRS moves from state to state. The last five events have been held in New York, Kansas, Texas, California and South Carolina. In 2005 the event will be held outside the United States for the first time, in Alberta, Canada.

California NAR member Brian Weese with a scale V2 rocket.

Participating in Your Local Rocket Club

Joining a local club affiliated with either NAR or Tripoli is easy, fun and rewarding. Rocket enthusiasts come from all walks of life, including plumbers, lawyers, painters, teachers, bankers, artists, police officers, and firefighters. The only common denominator is the desire to learn and the thrill of the

Junior CERTIFIED

In late 2004, NAR introduced its Junior HPR Participation Program for young people between the ages of 14 and 17. This program provides teens with the ability to fly H- and I-powered rockets. When they reach 18, the participants are ready to certify Level Two. The program has rules regarding adult supervision, but maintains the same requirements for Level One as found in the adult rules. The Junior Participation Program encourages young people to get involved in the wonder and science of rocketry. For more information, contact the National Association of Rocketry (NAR).

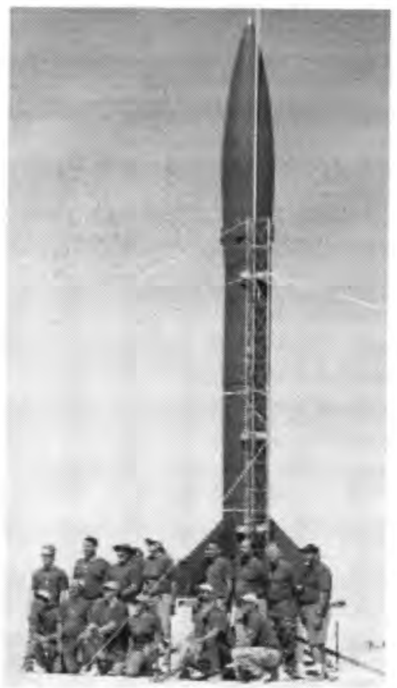
launch. It is an excellent way to meet people and make new friends with those who share a common passion for science, rocketry, and the outdoors. It is also a great way for parents to introduce their children to the wonders of science. Although high-power rocketry is limited to those over 18, almost every launch event is open to children and families. Most local and regional launches welcome children, and there are usually model- rocket pads set up so those under 18 can also participate. It is common to see high-school science students, Boy Scouts, Girl Scouts, and members of other youth organizations at high-power events.

There is no requirement that you achieve a certain certification level. Many rocketeers are content to obtain their Level One certification and fly H or I motors forever. These high-power motors provide a lot of bang for the buck and are a common sight at all high-power launches. Most people will choose not to proceed all the way to Level Three. Indeed, there are far more Level Two than Level Three flyers, and Level Two offers rocketeers the ability to do just about anything, except fly an M motor. Level Two rockets are often the most sophisticated rockets on the field.

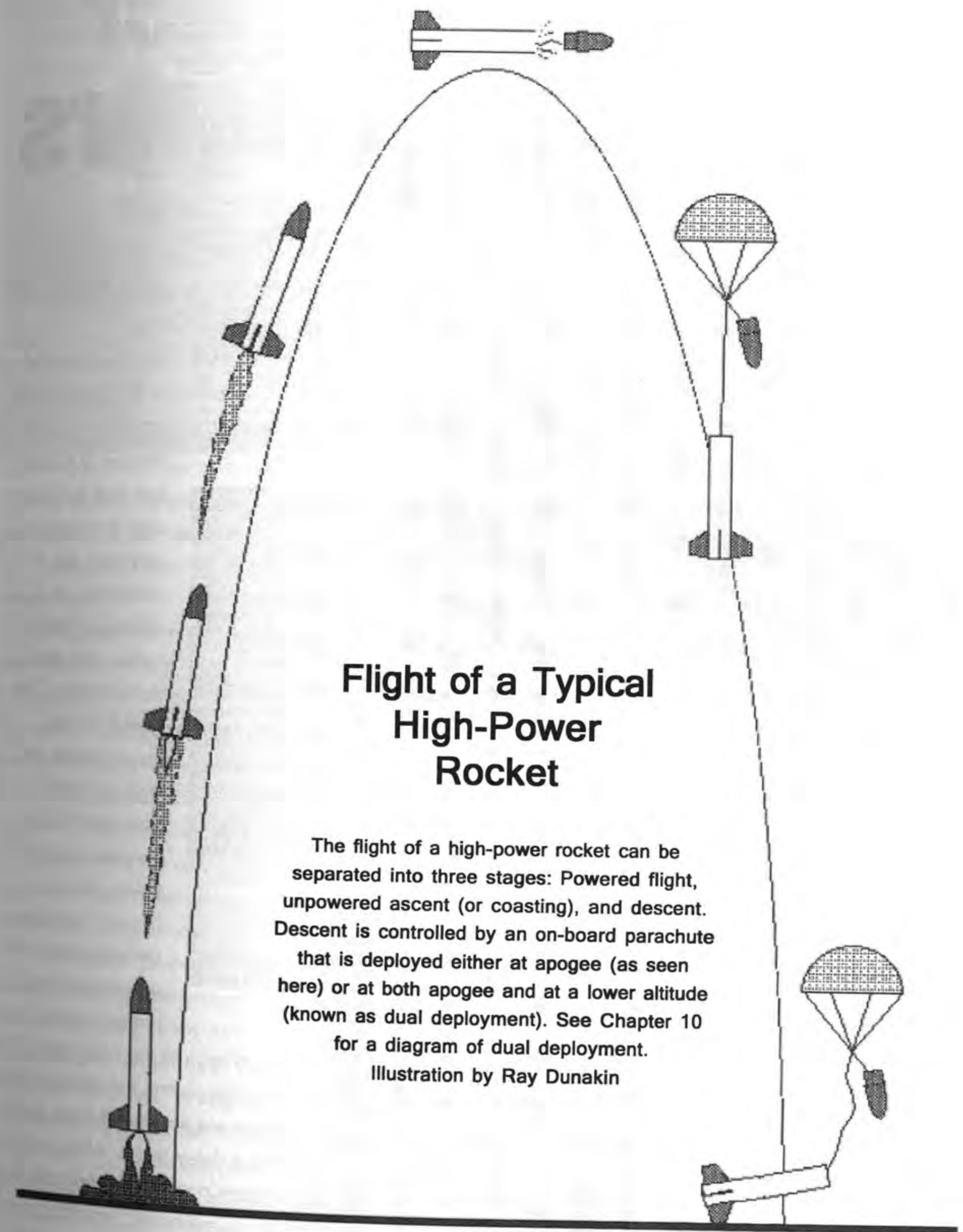
Many people find that, once they achieve their desired certification level, they get even more out of rocketry by teaching new members the ropes or by helping to ensure that their local launches stay viable and active. There are few things in rocketry more rewarding than being part of a team that puts on a large regional event that attracts hundreds of people for a high-power launch. It's a lot of work, but when you see the excitement on the faces of those who attend, it's worth the effort.

So what are you waiting for? Log onto your computer and find a launch site.

It may be the beginning of your next big adventure.



Teamwork is a big part of high-power rocketry. Here, members of the Community Space Program in Washington pose with their 700-pound Honest John Missile in Northern Nevada in 2004. For more information on this rocket, and a photo in flight, see Chapter 1.



Flight of a Typical High-Power Rocket

The flight of a high-power rocket can be separated into three stages: Powered flight, unpowered ascent (or coasting), and descent. Descent is controlled by an on-board parachute that is deployed either at apogee (as seen here) or at both apogee and at a lower altitude (known as dual deployment). See Chapter 10 for a diagram of dual deployment. Illustration by Ray Dunakin

The FUEL

The primary components in solid high-power rocket propellant are usually ammonium perchlorate, also called AP, an oxidizer, and metals such as aluminum powder. A slug or section of high-power composite propellant is called a "fuel grain." These grains typically have a synthetic rubber binder to hold the materials in the grain together. A high-power rocket motor may also be a "hybrid motor," made of both solid and liquid (or gaseous) propellant, such as the Hypertek motor shown below.

1

High-Power Rocket Motors

The fundamentals of single-use and reloadable high-power rocket motors

A high-power rocket motor behaves in accordance with Sir Isaac Newton's Third Law of motion: For every action there is an equal and opposite reaction. As a practical matter, this means that a rocket moves in a direction opposite the motor's exhaust.

1-1

The purpose of this chapter is to provide a general overview of the availability, function, labeling, and use of high-power rocket motors. This chapter will also discuss several important concepts related to the selection of a high-power motor for a given rocket.

The High-Power Propellant

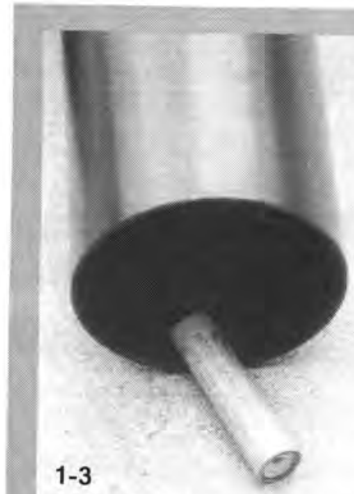
High-power motors do not use the same propellant that is used in traditional model-rocket motors. Most single-use model-rocket motors use black powder propellant. Black powder is a solid fuel that has been used through the centuries as an explosive. It is a mixture of charcoal, sulfur, and potassium nitrate. The typical model-rocket motor will have a small amount of black powder encased in tightly wound paper. There is a ceramic nozzle at one end of the motor and an ejection charge at the other end. The ejection charge and the black powder propellant are separated from each other by a delay grain. After ignition of the black powder, the propellant is consumed, eventually reaching and then igniting the delay grain in the

1-2

A collection of motor cases ranging between 38mm and 75mm rests within an eight-inch experimental motor casing. Below: An Estes model-rocket motor rests in a 98mm M motor casing.

forward end of the motor. Once the delay grain burns through, the ejection charge is ignited, and the rocket separates into at least two pieces for deployment.

A high-power rocket motor functions in the same basic manner, although composite propellant is used instead of black powder. Composite propellant is also a solid fuel. But it is more expensive than black powder and also harder to ignite. The composite fuel used in high power is not unlike the solid fuel used in the outboard boosters of the Space Shuttle.



1-3

Composite propellant is usually made of ammonium perchlorate (also called AP), aluminum powder (or other metals) and other materials. A slug or section of composite fuel is called a "fuel grain." These fuel grains usually have a synthetic rubber binder to hold the materials in the grain together.

Each fuel grain in a reloadable high-power motor is cast in a special cardboard-like sleeve. The grain is round and has a hole running from one end to the other. The shape or geometry of the hole is important, as it affects the burn rate of the propellant.

By contrast, most model-rocket motors do not have a hole running from one end of the motor to the other. They are ignited at the nozzle end, and the fuel simply burns upward (toward the forward end of the motor). This is known as an end-burning motor.

A high-power fuel grain has a different motor-core geometry. Typically, high-power uses core-burning motors, or motors that burn along the entire length of the fuel grain–from one end of the motor to the other.

Not all core-burners are the same. Some core-burning motors have a central hole in the middle of the fuel grain, while other fuel grains are slotted from the middle of the grain to the outside of the grain. See Diagram 1-1.

The end-burning motor configuration of a model rocket motor usually results in a neutral burn or neutral thrust curve–meaning the thrust of the motor remains relatively constant over the time of the motor's burn.

The thrust curve of a high-power rocket motor is more varied, depending in part on the motor core of the fuel grain. A high-power rocket motor may have a neutral, progressive, or even a regressive thrust curve. A progressive thrust curve means that the thrust of the motor increases over the time of its burn. A regressive motor, on the other hand, has decreasing thrust over the time of its burn. Commercial manufacturers of high-power fuel grains provide rocketeers with the thrust characteristics of the motors they distribute.

The Motor Case

The primary component in a reloadable motor is the motor case. The case is a pressure-resistant metallic body–usually made of aluminum–that is threaded on the inside diameter of both ends. The threads of the case accept the forward and aft closures, which are secured after the case has been loaded with propellant. The forward closure will hold a delay grain and may also contain an ejection charge. The aft end secures the motor nozzle.

Motor cases come in five common high-power motor diameters: 29mm, 38mm, 54mm, 75mm, and 98mm (Cesaroni Technology has recently introduced a 150mm case for its largest motors.) Within each one of these diameter sizes there are usually several cases available, the only difference being the length of the case. A longer case can accept more fuel grains. The threaded closures, however, will work on any case that is the same diameter as the closure, for the same manufacturer. For example, Aerotech offers several different case lengths for its 54mm line of motors. The same aft and forward closures will work on any of these cases. See photo 1-5. So a rocketeer usually will purchase a single set of closures for use on many different cases. (Unfortunately, parts are not interchangeable among the manufacturers of high-power motors.)

1-4

1-5

1-6

Top: An Aerotech single-use G motor. Above: Three 54mm Dr. Rocket motor cases. The same forward and aft closures fit each case. Left: A Cesaroni Pro38 case and reload.

Sample motor core geometry

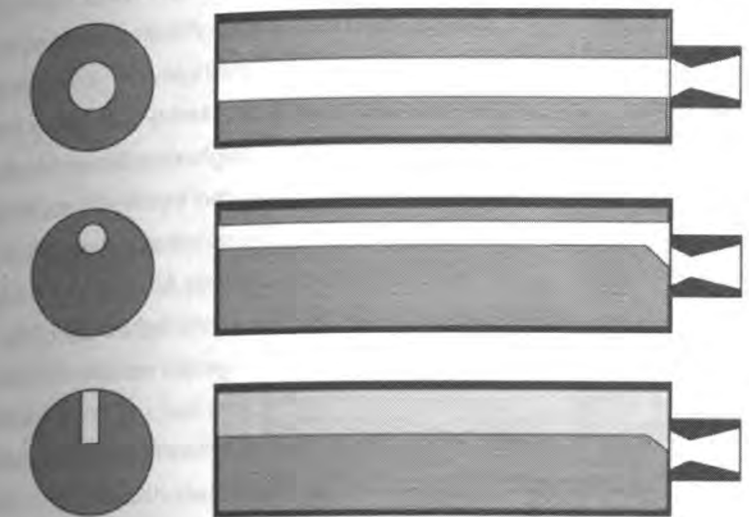


Illustration by Ray Dunakin

Diagram 1-1

Typically, the diameter of the motor case is stamped on the motor tube. See photo 1-7. The label on most high-power rocket reload kits will also set forth the diameter of the reload. This allows users to match reload kits with the correct diameter case.

1-7

An Aerotech 38mm motor case. Note that the case has the diameter and the total impulse (38/600) stamped on the side.

In reloadable motors, the motor case and the forward and aft closures are used over and over again. The case and closures are filled with parts and pieces from a motor reload kit. Although there is some variation among the manufacturers, the typical reload package will come with composite fuel, a motor liner, a nozzle and o-rings. The composite fuel grains are inserted into the motor liner, and the liner is then inserted into the case. The liner functions as an insulator. It keeps the burning propellant from overheating and damaging the motor case. The o-rings prevent the hot gases generated during the burning of the fuel from escaping through the threads of the forward or aft closures.

In the 1980s, there were few high-power motors available to the general public. And what was available tended to be limited to

The reload KIT

The average high-power solid-fuel reload kit comes with one or more composite fuel grains, a phenolic motor liner, an exhaust nozzle, a delay grain, and some o-rings. The fuel grains are inserted into the liner which is then placed in the motor case. The liner protects the case from burning propellant and the o-rings keep hot gases from escaping through the threads of the forward or aft closures. Some reload kits have reusable nozzles (AMW), while others have nozzles that can be used only once. (Aerotech and Cesaroni).

relatively low-impulse, single-use motors that were expensive and hard to come by.

Today, the rocketeer may choose from a large selection of both single-use and reloadable motors made by several well-established manufacturers. These modern high-power motors are available at local and regional launches. The lifting power and cost of these motors cover a broad spectrum. There are motor reload kits sold today in the $300 to $600 price range that can successfully lift rockets weighing more than 100 pounds many thousands of feet into the air. Most high-power rocket motors, however, cost much, much less–as little as $20 for a powerful H motor reload. So high power will fit into almost anyone's budget.


1-8

Single-Use Motors

There are two broad categories of motors in high power: Single-use and reloadable.

Single-use motors include most E, F, and G motors commonly seen at local launches and available for purchase without any special license or certification. These motors are technically not high-power motors because they have a total impulse of less than 160 newton-seconds.

But do not let the size of these smaller, single-use motors fool you. The single-use, composite propellant motors produced today are many times more powerful than the single-use Estes black powder motors manufactured for model rockets back in the 1960s. These motors are not toys. A single-use Aerotech G motor can lift a lightweight high-power rocket thousands of feet. These motors are often flown at high-power launches and are usually the first motors used by the novice who is working toward Level One certification. All motors should at all times be handled with caution, and the instructions of the motor manufacturer should always be followed.

There are a few single-use motors that do qualify as high-power motors. They are available in H, I, J, and K ranges of total impulse. These motors require the user to be certified by either Tripoli or NAR and are occasionally used for a certification flight. (However, the vast majority of certification flights are launched with reloadable motors.)


1-9

The advantage of single-use motors is that they contain all of the solid propellant and ejection charge necessary for flight and recovery. These motors typically have a built-in delay grain that will ignite a small, self-contained charge of black powder a few seconds or more after motor burnout. See photo 1-8. There is nothing to load or to build. A separate motor case is not required. The motor is simply secured in the aft end of the rocket, the igniter is installed and the rocket is ready for launch. The built-in ejection charge will release gases to separate the rocket for deployment. There is no need for on-board altimeters, timers, or other electronics. Once the rocket returns to the ground and the motor has cooled, the expended motor is removed from the rocket and discarded.

Reloadable Rocket Motors

A reloadable rocket motor is designed so that the user can load and reload a pressure-resistant metallic casing with propellant. The propellant is then consumed during flight. All that remains is debris. See photo 1-13.

There are several commercial manufacturers of high-power rocket motor casings and reload packages. Unfortunately, casings and reload kits are not interchangeable among manufacturers. This means that the casings, closures, and reload kits cannot be switched from one brand to another. An Aerotech reload kit will not fit into a Cesaroni Technology motor case. An Animal Motor Works closure will not work with an Aerotech case, and so on. That is the bad news. The good news is that

Right: Members of the Community Space Program team in Washington State launched this 700-pound, 30-foot-tall, full-scale Honest John missile at the Black Rock Desert in 2004. The rocket flew on four experimental O motors. An additional 8 G motors that were mounted high in the airframe were fired one second into the launch, to provide for a realistic roll of the rocket in flight as it ascended.


1-10

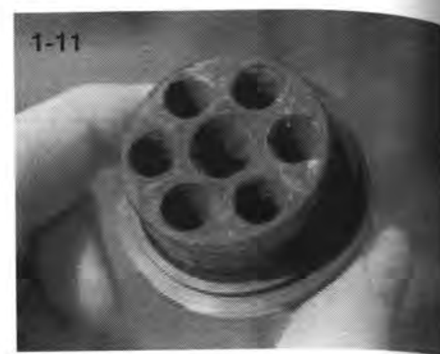
Motor Makers

There are several makers of solid-fuel high-power rocket motors. Among them: Aerotech, Animal Motor Works (AMW) and Cesaroni Technology. These three manufacturers provide reload kits and motor casings. The total impulse, average thrust, and burn times of these motors can be found on the Tripoli or NAR websites, along with the same information for approved motors made by other companies. Another company, Dr. Rocket, makes casings for Aerotech reloads only.

each of these motor makers has a wide selection of motors and reloads available for most rocketry needs.

Elements of a Motor Label

The basic elements of a rocket motor label are the same for model, single-use, and reloadable high-power rocket motors. This means that no matter what size motor you are using–whether it is an Estes C6-5, an Aerotech M1939, or an AMW M1350–you can read the label and know how that motor will perform in any given rocket.



The first element in most motor labels is a letter of the alphabet. This letter corresponds to the total impulse range of the motor. The second element in the motor label is a number. This number provides the average thrust of the motor. Many high-power motors also have a third element: The delay time for the motor's ejection charge.

Element One: Total Impulse of the Motor

Commercial motors run in alphabetical order from the letter A to the letter O. Examples include the A8-3, the H180, the K550, the M1850 and the N2000. The letter at the front of a motor label corresponds to the "total impulse" range of the motor. Total impulse can be described as a measure of the overall total energy contained in a motor (this is different from "specific impulse," which is a term that describes the characteristics of a particular type of fuel). Total impulse is measured in newton-seconds. One newton-second is the amount of force necessary to accelerate one kilogram of mass at a rate of one meter per second per second.

Motor Size	Total Impulse Range (newton-seconds)
A-G	0.1 - 160.00
H	160.01 - 320.00
I	320.01 - 640.00
J	640.01 - 280.00
K	1280.01 - 2560.00
L	2560.01 - 5120.00
M	5120.01 - 10,240.00
N	10,240.01 - 20,480.00
O	20,480.01 - 40,960.00

Diagram 1-2

In a high-power rocket motor, total impulse may be calculated by multiplying the average thrust of the motor (discussed below), in newtons, by the burn time of the motor, in seconds.

As the letters of a motor label climb higher into the alphabet, so does the total impulse of the motor. For example, high-power motors with a total impulse in the range of 160.01 to 320.00 newton-seconds are classified as H motors. Motors with a total impulse of 320.01 to 640.00 newton-seconds are classified as I motors. Motors with a total impulse of 640.01 to 1280.00 newton-seconds are classified as J motors, and so on, all the way up to an O, which covers motors with a total impulse in the range of 20,480.01 to 40,960.00 newton-seconds.

Crew and friends carry Dan Lord's 180-pound, N-powered Nike Smoke to the away pads at LDRS23 in New York in 2004.

As Diagram 1-2 shows, the total impulse doubles with each letter class. This is an important concept to bear in mind when selecting a motor for a high-power rocket. A rocket that performs well on an H or an I motor may have significant problems when switched to a J motor if the rocket was not built to handle a J motor in the first place. A rocket that is over-powered by a motor may disintegrate, or "shred," after launch. For this reason, it is fairly common for rocketeers to construct their entry-level and mid-range rockets so they can handle as many different motor classes as possible.

Aerotech

J350W

J = This letter represents a range of high-power motors that have between 640.01 and 1280.00 newton-seconds of total impulse. See Diagram 1-2 for the complete list of H through O motors.

350/370 = This number represents the average thrust of the motor in newtons. The Aerotech motor has an average thrust of 350 newtons, and the AMW motor has an average thrust of 370 newtons. For the total impulse of the motor, multiply the burn time in seconds by the average thrust in newtons to obtain an answer in newton-seconds.

W/GG = This letter denotes the propellant type (and often the color of the smoke or flame), which varies by manufacturer. The W in the Aerotech motor means "White Lightning." The GG in the AMW motor stands for "Green Gorilla."

J370GG

Animal Motor Works

Diagram 1-3

It is important to note that one motor manufacturer–Cesaroni Technology–does not start its motor label with a letter of the alphabet. Instead, Cesaroni starts its label with the motor's total impulse. (Compare Diagram 1-3 with 1-4.) For example, Cesaroni's J285 (discussed in detail in Chapter 3) actually carries the full label of 648J285-15A. The first number, 648, represents the total impulse of the motor. As shown by Diagram 1-2, this falls within the J range of motors. The total impulse is then followed by the letter J, which means the same thing as it does with other motor labels.

1-15

Element Two: Average Thrust

The second component of a motor label is a number. This number always follows the letter designation in the label–even in Cesaroni motors. This number specifies the average thrust of the rocket motor. Average thrust is a measure of how slowly or quickly the motor delivers its total energy. Average thrust is roughly that amount of thrust the rocket motor can be expected to deliver for the

Cesaroni Technology

648J285

648 = Total impulse in newton-seconds. Cesaroni motors begin their label with the total impulse. To obtain burn time, divide this number by the average thrust.

J = This letter means the same thing as in Aerotech and Animal Motor Works motors. It represents a range of all motors that have between 640.01 and 1280.00 newton-seconds of total impulse.

285 = As with the other motors, this number represents the average thrust of the motor in newtons.

Diagram 1-4

duration of its burn time. Average thrust is measured in newtons. For example, an H180 has an average thrust of 180 newtons. An L1060 has an average thrust of 1060 newtons. An M2500 has an average thrust of 2500 newtons. A G80 has an average thrust of 80 newtons, and so on.

Most motor manufacturers publish the estimated burn times for their high-power rocket motors. As alluded to earlier, if you multiply the burn time by the motor's average thrust, you will have the motor's total impulse (in newton-seconds). For example, the published burn time of an Aerotech K550 is 3.1 seconds. By multiplying the burn time (3.1 seconds) by the average thrust (550), you would arrive at a total impulse of 1705 newton-seconds.

1-16

Rocketeers help carry Woody Hoburg's 100-pound upscale Mosquito to the pads at LDRS23 in New York in 2004.

Conversely, if you have the total impulse of the rocket motor and also know its average thrust, you can approximate the burn time. In the K550 example, simply divide the motor's total impulse (1705) by the average thrust (550), and you will get 3.1 seconds.

Here's one more example. An Animal Motor Works M1350 has a total impulse of 5725 newton-seconds. To determine the burn time, simply divide the total impulse (5725) by the average thrust (1350) and you will get 4.2 seconds. And if you have the burn time (4.2) and the average thrust (1350), you multiply them together to determine the total impulse (5725).

Why are these numbers and equations important in high-power rocketry? Because they can be quickly used to determine the thrust-to-weight ratio of the loaded rocket prior to flight. This important ratio helps determine whether the rocket will have a stable flight.

Thrust-to-Weight ratio: The 5:1 Rule

The minimum thrust-to-weight ratio in a high-power rocket should be 5:1. This means that the average thrust of the motor should be at least five times the total weight of the fully loaded rocket. This rule of thumb helps ensure that the rocket will have a stable and vertical flight (assuming that it is otherwise built properly). If the thrust-to-weight ratio is less than 5:1, chances increase for an unstable flight–meaning that the rocket may veer off diagonally or even horizontally after launch. Obviously, this is dangerous for rocketeers and spectators alike–and can lead to destruction of the rocket.

Determining the thrust-to-weight ratio of any rocket requires two pieces of information: (1) the average thrust of the motor chosen for flight and (2) the loaded weight of the rocket. Since average thrust is measured in newtons and the weight of a rocket is measured in pounds, we need to convert newtons into pounds to determine the thrust-to-weight ratio. The rule of thumb here is to divide the average thrust in newtons by 4.45 to obtain the average thrust in pounds.

The following examples might seem a little complicated, but they are not. Do not get too bogged down here. Later, after you have built a rocket or two, you can return to this chapter to see how these examples work in real life.

To illustrate, assume you want to load a K550 into a rocket that will weigh 20 pounds on the launch pad (including fuel). To ensure that you have a minimum 5:1 thrust-to-weight ratio, you will need a motor that will have an average thrust of 100 pounds (20-pound rocket multiplied by 5). To determine if the K550 is up to the job, simply divide its average thrust in newtons (550) by 4.45 to obtain the average thrust in pounds. The answer is 123 pounds. Since the rocket weighs 20 pounds and the thrust-to-weight ratio (123 to 20) is more than 6:1, the motor is adequate for launch. In fact, the K550 would provide a thrust-to-weight ratio of 5:1 for a rocket weighing up to 24.6 pounds (550 divided by 4.45 divided by 5).

1-17

NAR member Brian Weese's 7.5-inch-diameter Saturn V takes to the sky on an Aerotech 54mm K550.

This does not mean that a K550 cannot lift a rocket weighing more than 24.6 pounds. In fact, it can. However, the more weight that is added over 24.6 pounds, the greater the likelihood that the inadequate thrust-to-weight ratio will lead to an unstable and dangerous flight. Conversely, a rocket weighing significantly less than 24.6 pounds–for example 10 pounds–had better be built strong enough to withstand the average thrust of the K550.

Here is another example. An N2000 is a six-grain, 98mm Level Three motor that has an average thrust of 2000 newtons. To convert that average thrust into pounds, divide 2000 by 4.45. The answer is 449 pounds. Now, divide 449 by 5 to get the maximum loaded weight of a rocket with the N2000 while still maintaining a 5:1 ratio. The answer is 89 (449 divided by 4.45). An 89-pound rocket can thus be safely lifted by an N2000 (assuming all other thing are equal). Of course, an N2000 can lift rockets weighing much more than 89 pounds. However, the more weight that is added over 89 pounds, the greater the chance for an unstable rocket.

1-18

It should be noted that the Code for High Power Rocketry does not mandate a 5:1 thrust-to-weight ratio in every rocket flight. Section 4.9 of NFPA 1127 provides that the maximum liftoff weight shall not exceed one-third of the average thrust of the high-power motor used for launch. This is a 3:1 ratio. Using a 3:1 ratio, the same N2000 motor should be able to lift a rocket weighing nearly 150 pounds (449 divided by 3). However, it is better to err on the side of caution. By aiming for a higher thrust-to-weight ratio, you help ensure that the rocket will have a safe flight.

The importance of considering the thrust-to-weight ratio was illustrated a few years ago at LDRS20 in the Southern California desert. One of the most impressive rockets at the launch was a beautiful one-third scale V2 rocket that stood more than 15 feet tall with a diameter of more than 21 inches. The rocket weighed in at about 285 pounds and was powered by a cluster of five high-power motors. The central motor was a 98mm Aerotech M1939. The M motor was surrounded by four 54mm Aerotech K560s. This rocket was carrying some serious thrust. At ignition, the entire crowd at LDRS was on its feet. And that was a good thing. The mighty V2 lifted slowly on the M1939 and on three of the four K560s (one of the K560s did not light). Almost immediately, the rocket began to arc over. The beautiful missile rose a few hundred feet in an angled flight path, passed over the flight line, and proceeded to crash in the parking area. Fortunately, the only thing damaged was the rocket.

What happened? Inspection of the destroyed rocket after flight

Thrust CURVE

Many high-power motor reload kits come with instructions that include the thrust curve characteristics of the motor. If you are using a motor for the very first time, take a look at the thrust curve diagram. Most motors have an initial thrust that is higher--sometimes much higher--than the average thrust of the motor as labeled. For some motors, the average thrust may, in fact, be a bit higher or lower than the label indicates. The thrust curve may reveal that the motor has a much higher *initial* thrust-to-weight ratio than 5:1, at least right off the bat. Still, err on the side of caution. The 5:1 ratio is a good rule of thumb and will help ensure that you have plenty of thrust for your rocket.

revealed that one of the motors did not light, thereby reducing the overall average thrust of the massive rocket and perhaps contributing to an asymmetrical flight path.

But there may have been another culprit, too: an inadequate thrust-to-weight ratio. The M1939 is a powerful motor. But the math indicates that to maintain a 5:1 ratio an M1939 should not be used in a rocket that weighs more than 87 pounds (average thrust of 1939 divided by 4.45 = 435; divide 435 by 5 = 87). And to maintain a 5:1 ratio the K560s should not be used in a rocket that weighs more than 25 pounds (average thrust of 560 divided by 4.45 = 125; divide 125 by 5 = 25). Even if all five motors were added together, the lift weight for a 5:1 ratio would be 187 pounds–far less than this rocket's actual lift weight of 285 pounds.

Things look much better with a 3:1 ratio (the ratio found in the Code). The weight of the rocket could be up to 309 pounds. But this left much less margin for error–and when one of the motors failed to light, the rocket was in serious trouble.

The bottom line: Never launch any high-power rocket without at least considering the thrust-to-weight ratio of your rocket with the motor you have chosen for flight.

Element Three: Delay Times and Ejection Charges in Motor Labels

Most single-use motors have a built-in ejection charge of black powder that is preset by the manufacturer to ignite several seconds after motor burnout. This time interval is known as the "delay time" and is generally the third element of a motor label. The delay time is preceded by a dash in the label. For example, in a G40-7 the delay time is seven seconds. See photo 1-20. In an H210-10 the delay time is ten seconds, and so on. The delay grains in single-use and high-power reloadable motors are always located in the forward end of the rocket motor, opposite the end with the nozzle (aft).

1-19

Robb and Christine Haskins and friends prepare their M-powered "Erikris Kyle" rocket at the Freedom Launch in South Carolina.

Reloadable motors work on the same theory, but most high-power reloads have no delay time specified on the motor label. Instead, rocketeers purchase delay grains with intervals of 6, 10, 14 seconds or more, depending on the characteristics of their rocket and deployment system. Thus, when a rocketeer purchases a K550, for example, there is no delay time in seconds printed on the package label. Since it is a reloadable motor, the purchaser can pick and choose the ejection-charge time interval he or she wants for his or her flight. The chosen delay grain is loaded into the forward closure of the motor when it is assembled.

Delay times in Cesaroni motors are adjustable. Cesaroni motors have delay grains which allow the rocketeer to actually alter the delay time of the ejection charge with the use of a special tool. The delay time on the label usually represents the maximum delay that can be set with that particular motor. For example, in the 765J330-16A the maximum delay is 16 seconds. But this time can be reduced with the use of the tool. See Chapters 3 and 6.

1-20

Once a rocketeer moves into the larger motors, such as L motors and beyond, there is often no motor-based ejection charge at all, because these rockets will typically be equipped with on-board altimeters that control the firing of ejection charges that are not attached to the motor. (There is no motor-based charge on Animal Motors Works reloads or hybrid motors–electronics must be used.) For more discussion on altimeters and ejection charges, see Chapters 6, 8, and 10.

There are many reasons why rocketeers choose different delay times. These reasons will be discussed more thoroughly in the chapters on ejection charges and deployment and recovery. But for now, keep in mind that the best time for a delay charge to cause separation and deployment is at, or near, apogee. This is when the rocket is moving slowly and, as a result, the recovery system will be pulled out of the rocket smoothly without undue shock or stress. If the delay time is too short or too long the rocket may be traveling too fast either up or on the way back down. This can lead to damage to the rocket's airframe caused by the recovery harness or even to a failure of recovery, which can destroy the rocket.

Additional Motor Label Information

Some high-power rocket motors have an additional label that describes the type of propellant used in a particular motor. For example, Aerotech motors have four basic types of propellant: White Lightning, Blue Thunder, Black Jack, and Redline. To keep track of these fuels, Aerotech attaches a letter designation to some of their motors immediately following the average thrust, such as the K550W (for White Lightning) or the K1275R (for Redline). White Lightning propellant produces a bright orange flame and dense white smoke.

A Blue Thunder motor, identified by the letter T, produces a blue or violet flame and has very little

Motor FAILURE

Motor failure in high-power rocketry is uncommon, but it does occur, sometimes due to a defective part or casing. But more often than not, failures can be traced to simple operator error. The most common cause is loading the motor incorrectly, or leaving out parts. Every part in a reload kit is important. So be sure you load the motor in an uncluttered environment and double check to see that you have used all the parts. An o-ring left out of the 54mm motor below caused the fuel to burn right through the casing.

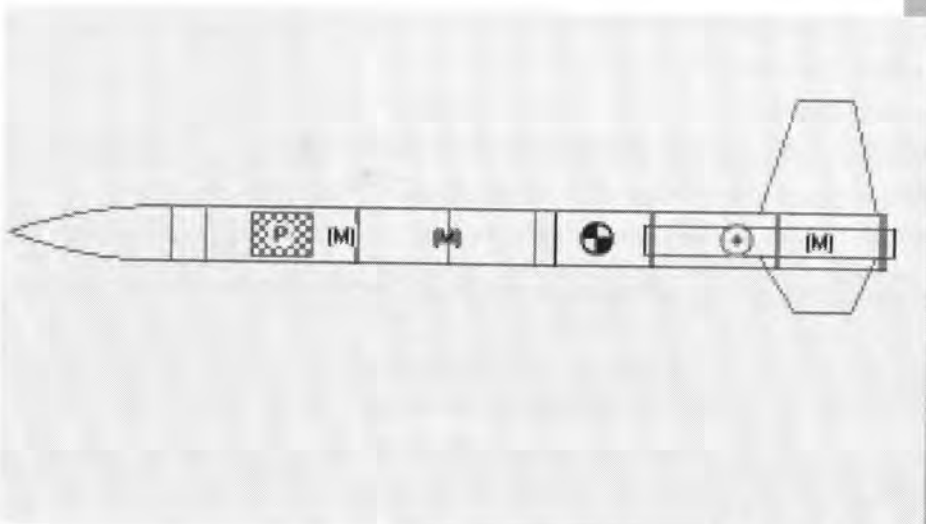


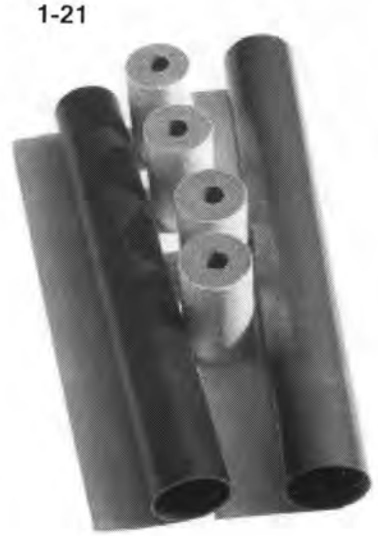
Diagram 1-5

Computer programs such as RockSim, used at left, allow the rocket builder to design a rocket on screen to determine (among other things) the stability of the rocket before construction. Below: An Animal Motors Works casing with the fuel grains and the motor liner.

smoke. Both of these motors are easy to ignite, have relatively short burn times, and are useful in getting heavy rockets quickly off the launch pad.

A Black Jack motor, identified by the letter J in the motor label, has a longer average burn time and produces lower average thrust. A Black Jack also produces thick, black smoke on ignition.

1-21



Finally, Redline motors are identified by the letter R in the label. These motors produce a bright red flame on ignition.

Animal Motor Works uses a different set of letters to identify their reloads. Some of their common propellant types include White Wolf (WW), Green Gorilla (GG), and Blue Baboon (BB). An example would be the 75mm M2500GG reload. These high-power reloads have different color flames and varying motor performance. Animal Motor Works also has new reload types on the way. For a complete and updated description of the characteristics of Aerotech or Animal Motor Works motors, log on to their web sites, listed in the appendix.

Rocket Stability: The Center of Pressure and the Center of Gravity

The selection of one particular motor over another may affect the relationship between two of the most important elements of high-power rocketry: the center of pressure and the center of gravity.

The center of pressure is the point at which aerodynamic lift of a rocket is centered. The location of the center of pressure is determined by the design of the rocket. Among the more common characteristics that might change the location of the center of pressure include the length of the airframe and the size and number of fins on the rocket.

The center of gravity is the point at which a rocket balances when it is completely prepared for flight, including the motor. Among the more common elements that affect the location of the center of gravity include the weight of the motor, the number and weight of the fins, nose cone weight, and the length of the rocket.

The relationship between the center of pressure and the center of gravity helps determine whether the high-power rocket will have a stable flight. Stable flight in this sense means a safe, vertical trajectory from liftoff. The rule of thumb here is as follows: The center of gravity in a high-power rocket should be at least one body-tube diameter forward of the center of pressure. For example, if a rocket is 7.5 inches in diameter, the center of gravity should be at least 7.5 inches forward of the center of pressure. If a rocket is 11.5 inches in diameter, the center of gravity should be at least 11.5 inches forward of the center of pressure, and so on. Failure to adhere to this rule of thumb can lead to the launch of an unstable rocket that may veer off in any direction, and be destroyed.

1-22

The exhaust nozzle in this rocket's motor came apart at ignition. As a result, there was no pressure inside the case and the fuel simply burned without any liftoff.

The starting point in determining the stability of any rocket is to determine the locations of both the center of gravity and the center of pressure on the rocket body.

There are a number of methods used to determine the center of gravity. One of the easiest is to tie string around the rocket and move the string along the length of the rocket until it is perfectly balanced. Once the point is determined, place a mark or put a piece of tape on the rocket body indicating the location of the center of gravity. Be sure the rocket is fully loaded with the motor and parachute, etc., when calculating the center of gravity.

If you do not have the motor yet, use lead weights and place them

The CG and the CP

Checking the relationship between the center of pressure and the center of gravity is not just a good idea, it is required by the Code for High-Power Rocketry. The center of gravity must be at least one body-tube diameter in front of the center of pressure. NFPA 1127 provides that, if requested by the Range Safety Officer (RSO), the rocket user must provide the RSO with the location of the centers of pressure and gravity. If the stability of the rocket cannot be determined, the RSO can deny launch of the rocket.

in the motor tube to simulate the approximate weight of the loaded motor prior to actual launch.

The center of pressure requires some complicated mathematical computations. Fortunately, there are a number of low-cost computer programs available to assist the rocket builder. For example, programs such as Winroc and RockSim allow the rocketeer to simply type in the rocket's dimensions, and with the press of a keyboard button the location is determined. For rocketeers who want to perform the calculations the old-fashioned way, there are several good sources of information available. These include Bruce Lee's "Center of Pressure Calculations Made Easy" (*High Power Rocketry,* June 1995) and "Calculating the Center of Pressure in a Model Rocket" by Jim Barrowman, a copy of which appeared in the March 1998 issue of *High Power Rocketry.* Once the center of pressure is located, make another mark on the airframe of the rocket.

Once the center of gravity and the center of pressure have been located on the rocket, make sure the center of gravity is at least one body tube diameter in front of the center of pressure. If the center of gravity is too close to the center of pressure or is behind the center of pressure, then the rocket is unstable. Usually, the easiest way to correct this problem is to move the center of gravity forward in the rocket (as opposed to moving the center of pressure aft). This is commonly accomplished by adding weight to the nose cone and then rechecking the center of gravity. Adding weight to the nose cone should move the center of gravity forward.

Calculating the center of pressure and the center of gravity is especially important in large rockets, like this Level Three certification rocket built by Craig Christenson of Washington. Photo courtesy of Craig Christenson

It is also possible to move the center of pressure aft. For example, adding larger fins on the aft end of the rocket typically moves the center of pressure aft. However, this usually entails significant design changes in the rocket. This is why it is common for rocketeers who are scratch-building their own rockets to use computer programs to determine the center of pressure on a given design even before the rocket is constructed.

It is common for rocketeers to launch kit-built rockets with larger motors than the manufacturer originally intended. Adding a larger and heavier motor to the aft end of the rocket will tend to move the center of gravity aft. At high-power launches you might see an occasional launch where a rocket is clearly unstable for a moment and then appears to correct

The size of the fins, the number of fins, the length of the rocket, and the weight of the motor are a few of the factors that affect the center of pressure and the center of gravity.

itself before shooting off in a straight line. This indicates that the rocket may not have been stable before flight because the motor was too heavy and the center of gravity was too far aft, but as the propellant burned, the center of gravity moved forward, and the rocket stabilized. The danger here is that once the rocket becomes stable, it may have been pointing in a dangerous direction (i.e. not vertical). So always give consideration to the center of pressure and the center of gravity when selecting a high-power motor for your rocket.

Most commercially produced high-power rocket kits are properly built by the manufacturer to be stable for flight with the motors that are recommended with the rocket.

However, it is still a good practice to check the center of pressure and the center of gravity on all high-power rockets prior to flight. This is especially true of scratch-built rockets.

Tripoli member Duane Uhl with his LOC Expeditor.

Purchasing High-Power Rocket Motors

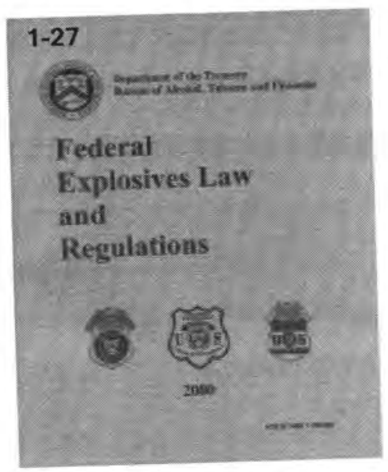
Empty high-power motor casings and closures can be purchased by anyone without any special license or certification. They can be purchased at hobby stores, from rocket vendors or through the mail from manufacturers or other users. Many single-use motors can also be purchased without any special certification–provided the motor has less than 160 newton-seconds of total impulse or an average thrust of less than 80 newtons.

High-power reload kits, on the other hand, are not available at hobby stores or retail outlets. Instead, these kits are made available for sale at local launches by dealers licensed to sell them. A high-power reload kit–which contains the actual fuel grains and other compo-

LEUP HELP

The permit process for a Low Explosives Users Permit (LEUP) begins with a form submitted to the ATFE and may end with a personal interview. Both Tripoli and NAR provide online help for people applying for their LEUP. The process is not difficult, but it does take several weeks to complete. The cost for a basic LEUP is currently $100 and can be renewed in three years by the user. For more information, log on to the ATFE site at www.atf.gov and visit the web sites for NAR and Tripoli.

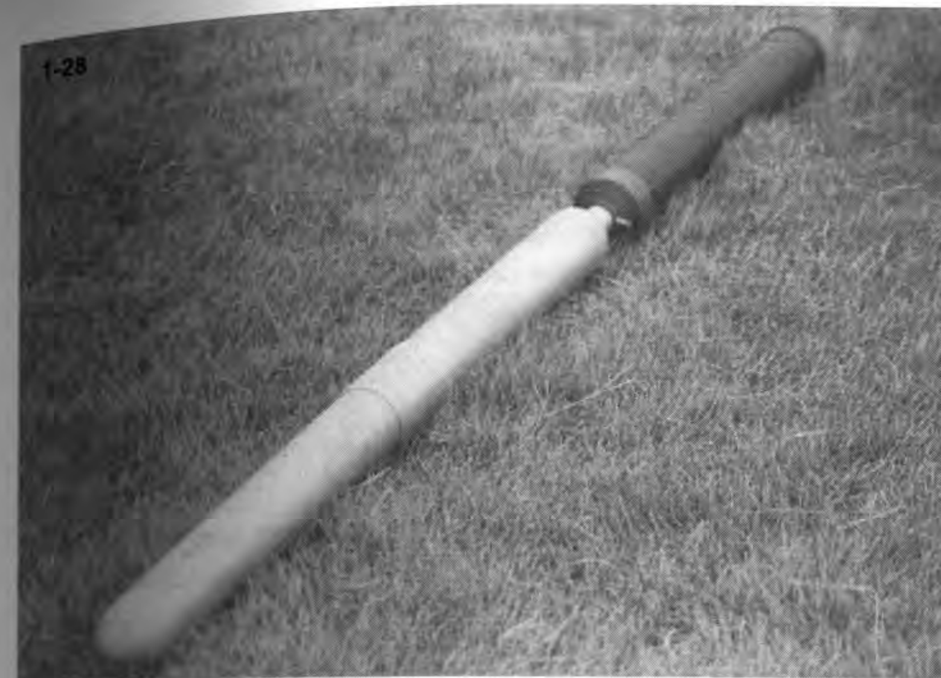
nents–cannot be purchased until the rocketeer meets the certification requirements set by either Tripoli or NAR. The only practical exception to this rule allows a rocketeer to purchase the reload he or she will need for a certification attempt. Once a person is certified by either NAR or Tripoli, he or she may purchase reload kits within their certification level.



In addition to the certification requirement, many jurisdictions (and many rocket vendors) now require the rocketeer to obtain a Low Explosives Users Permit (LEUP) from the Bureau of Alcohol, Tobacco, Firearms, and Explosives (ATFE), prior to the purchase of a high-power rocket motor. The minimum age for such a permit is 21. The LEUP costs about $100 and is usually good for up to three years and may then be renewed. Once obtained, the permit allows individuals to purchase and use any certified high-power motors within the person's certification range.

Generally, the ATFE issues two types of permit. The most common permit is for people who want to purchase and fly high-power motors on the day of purchase at the launch site.

The second type of permit is for people who wish to purchase and then store high-power rocket motors for flight on another day. The permit requirements for storage of high-power rocket motors reflect not only common-sense personal safety



Hybrid motors are generally exempt from the requirements set by the ATFE. This is because hybrids use separated propellant ingredients in two different forms. A hybrid motor consists of a solid fuel component and a liquid oxidizer, usually nitrous oxide (in the tank).

considerations but also safety concerns for the general public.

For example, NFPA Section 4.19.1 (2002) provides that high-power motors shall be stored at least 25 feet from smoking, open flames, and other sources of heat. Section 4.19 further provides that motors kept indoors must be stored in a special magazine. The magazine is to be painted red and the top of the magazine shall bear the following words in white letters at least three inches high: EXPLOSIVES–KEEP FIRE AWAY. See photo 1-26. Section 4.19 allows indoor magazines to be located in a detached garage or outbuilding, but not in a residence (although the ATFE has discretion to allow the magazine to be kept in an attached garage).

Three casings and a set of closures (with an injector bell) for a Sky Ripper 38mm hybrid system. Photo courtesy of Sky Ripper.

Section 4.19 does not describe the construction materials for the magazine. That information may be found in the Code of Federal Regulations, which is available online and at many public and legal libraries. The ATFE also publishes an orange booklet entitled *Federal Explosives Law and Regulations* that contains the pertinent information. See photo 1-27. The applicable section of the code is 27 CFR 55.

The code lists five different types of explosive magazine. The magazine used by the average high-power rocketeer would be a Type 3 magazine, also known as a "day box." The day box is a portable magazine. It must be fire-resistant, weather-resistant, and theft resistant. The maximum net propellant weight that may be stored in a Type 3 magazine is 50 pounds.

A Type 3 magazine is required to be constructed from steel no thinner than 12-gauge and lined with one-half-inch thick plywood. The magazine must have at least one lock. Additional specific information regarding the construction of a Type 3 magazine is found at 27 CFR 55.209.

The current ATFE rules to obtain an LEUP require a fingerprint check, photo identification, and some very basic background questions. In addition, if you are applying for a storage permit, you will be expected to have the storage magazine inspected at the request of the ATFE and the local fire marshal. The rules relating to permits obtained from the ATFE for high-power rocketry are still evolving. In addition, both NAR and Tripoli have launched court actions against the ATFE that may impact the requirements of the permit. So always check online with either NAR or Tripoli for the latest information on the subject of the LEUP and storage magazines. When in doubt, contact your local Tripoli prefecture or NAR chapter and the local office of the ATFE.

And here is another thing to keep in mind: Get started early. Although the application process is easy, it may take several weeks, if not longer, for the ATFE to fully process the paperwork, conduct an interview, and grant you the permit. If you are applying for a storage permit, the time period may be even longer.

A Word on Hybrid Motors

A hybrid rocket motor employs separated propellant types that are combined at launch. Typically, the hybrid consists of a solid fuel grain and nitrous oxide.

For example, the Hypertek line of hybrid motors (available through Cesaroni Technology) combines a thermoplastic solid fuel grain with nitrous oxide. The basic motor consists of three parts: the oxidizer tank (for the on-board nitrous oxide), an injector bell (See photo 1-31), and the fuel grain. The fuel grain and the nitrous are kept isolated from each other until just prior to ignition. Ignition occurs after the on-board tank is filled and vented. See photo 1-32. At that time, the launch controller will cause an electrical spark to arc in the presence of oxygen. This will light the motor.

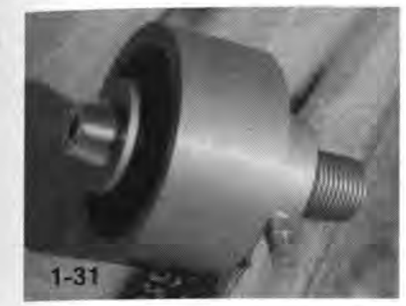

1-30

Setting up a rocket for launch on a hybrid takes a little more time, but with practice it goes smoothly. Here, rocketeers at a Virginia launch prepare a rocket for flight on a hybrid motor.

Hybrid motors do not have built-in ejection charges. So electronics are a must for deployment and recovery. Nor do hybrids leave much of a smoke trail, so it is important to keep a close eye on the rocket or to equip the rocket with a transmitter or beeper, or both Hybrids do make a unique sound, unlike any noise emitted by a solid-fuel motor, which is a real crowd-pleaser at any high-power launch.

The primary advantage of hybrid motors is that they are less costly to use on a flight-by-flight basis. A hybrid motor usually costs a fraction of the price of a solid-fuel motor with similar performance characteristics. Since the fuel and the oxidizer in a hybrid motor are isolated from each other until just before ignition, there are no ATFE issues regarding storage or use. Hybrids are not covered by the rules and regulations that pertain to most solid high-power fuels. In other words, the user does not need to have an LEUP and most of the materials can be freely shipped via the mail.

The disadvantage of hybrid motors is the need for extensive and expensive ground-support equipment. This usually includes a separate launch-control box, a nitrous oxide tank and an oxygen tank (for the spark), and special valves, solenoids and pressure lines at the pad. The initial investment in the ground-support equipment can be several hundred dollars. However, the equipment should last a long time, and rocketry clubs frequently pool their resources to purchase a ground-support system that can be used by all of their members. In addition, nitrous oxide and oxygen are available at low cost from most industrial gas supply companies or welding shops.


1-31


1-32

A nitrous oxide tank vents seconds before launch of this high-power hybrid rocket in Battle Park, Virginia. Top: An injector bell for a hybrid rocket motor.

Basic rocket construction is the same for a hybrid as for a solid-fuel rocket, with one notable exception. The motor tube for the hybrid is longer, since the hybrid motor consists of both a fuel grain and an oxidizer tank. So if you are planning on flying hybrids, make the necessary modifications to your rocket during construction.

For a recent article and intorduction to hybrid motors, see Kevin Trojanowski's story in the March 2005 issue of Extreme Rocketry magazine.

Additional safety issues

There are many common sense safety rules dealing with high-power rocket motors that have been codified in the safety codes of the NAR and Tripoli, as well as NFPA 1127. These include rules forbidding the launch of any high-power rocket horizontally or at an aircraft, as well as the general prohibition of consumption of alcohol or drugs while participating in a high-power rocketry activity. NFPA 1127 Section 6.1 prohibits the use of a high-power rocket or rocket motor as a weapon or against any target. High-power rockets shall not carry any flammable or explosive payloads or any vertebrate animals.

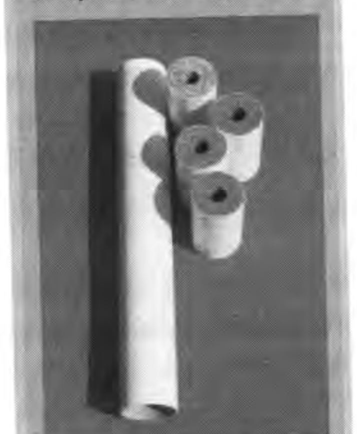
High-power rockets and high-power fuel should at all times be handled with care and in accordance with the manufacturer's instructions. High-power rocket motors should not be handled or left within reach of children or exposed to any open flame or heat sources.

For a more complete list of prohibited acts, pick up a copy of the Tripoli or NAR safety rules and the Code for High Power Rocketry. See also the appendix.

For a list of high-power rocket-motor thrust characteristics and other useful motor information–including the availability and location of simulation programs–log on to www.thrustcurve.org, an excellent rocketry web site prepared by California Tripoli flyer John Coker.

The Motor

There are more than 70 reloadable motors that are approved by either Tripoli or NAR (or both) for Level One through Level Three certification. These include motors built by Aerotech, Cesaroni, Ellis, Loki Research, Hypertek, and Sky Ripper, among others. Many of these motors are in the H and I range and either 29mm or 38mm in diameter. A complete list of motors available for certification can be found on the web sites of NAR or Tripoli. The list is also published twice a year in Sport Rocketry.



2

Level One Certification

Getting certified and building your first Level One reloadable motor

Level One is the entry-level certification range for high-power rocketry.

To obtain Level One certification with either Tripoli or NAR, a rocketeer must successfully launch and recover a rocket equipped with a high-power motor in the range of 160.01 to 640 newton-seconds of total impulse. This would mean a motor in the H or I class.

Tripoli member Scott Canepa prepares for his Level One certification flight.

Although it is possible to certify Level One with a single-use motor in this class range, the majority of people certify with reloadable motors. Since the selection of single-use high-power motors is limited, it makes sense for users to become acquainted with the reload process by using a reload in their first high-power launch.

The purpose of this chapter is to provide step-by-step guidance in loading a reloadable Level One high-power rocket motor.

The Certification Requirements

First of all, it is possible to fly a rocket with high-power performance without a certification rating. Persons without any certification may still fly single-use and reloadable motors up through G motors. At most high-power launches there are many F and G motor flights. This motor range is popular with rocketeers of all certification levels since F and G motors are inexpensive (less than $20) and

A person must be at least 18 to become certified with NAR or Tripoli. Still, high-power launches are frequently attended by parents and their children. Launches are an excellent place to teach children about both science and responsibility--and to have fun at the same time.

can lift a lightweight rocket thousands of feet. However, to enjoy the motor selection and benefits of motors with more performance, you must become certified to fly at Tripoli or NAR launches.

A Level One certification attempt begins with the paperwork. The user joins either Tripoli or NAR (or both) and fills out the appropriate form for certification. The user brings that form to a local launch site. After a successful launch, the form is completed by witnesses to the flight and then mailed to the applicable rocketry organization. (The forms used by Tripoli and NAR are not interchangeable.)

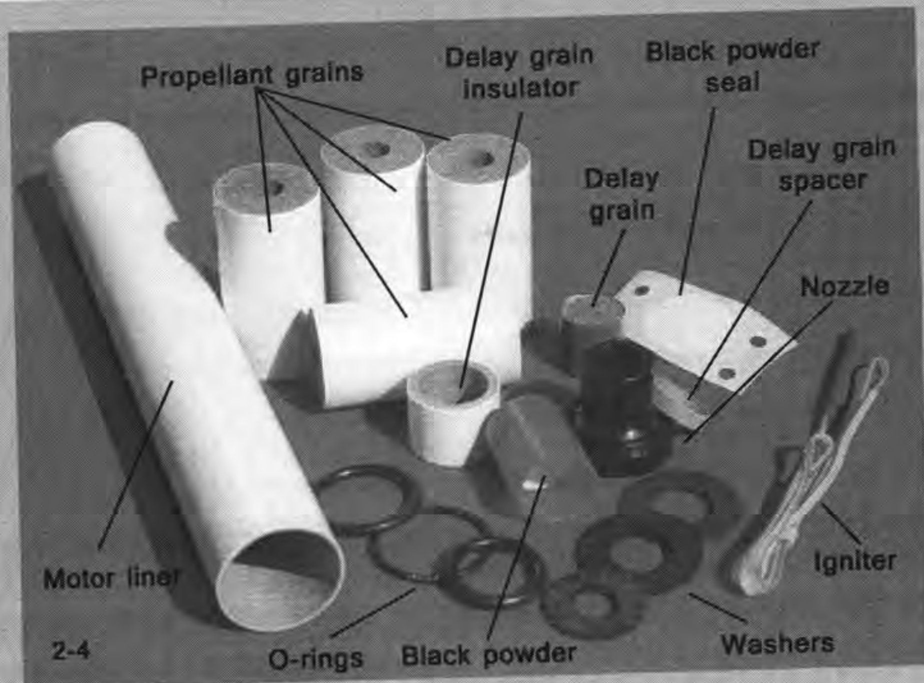
Members of the Pascale family enjoy a winter launch in Central California.

There is no written test for Level One certification. But the user must be a member of NAR or Tripoli (or related foreign organization). The Code for High Power Rocketry also requires the candidate be at least 18 years old. The rocket must be successfully launched and recovered–intact–for the rocketeer to become certified. This means that if the rocket is lost or seriously damaged there will be no certification. "Serious damage" typically means that the rocket cannot be immediately loaded with another motor and flown again. There is no rule that limits the number of certification attempts by a rocketeer. If you fail the first time, try again.

The Aerotech H180W

Currently, more than 20 different motors may be used to certify Level One. These motors are in the H and I range of total impulse and are typically either 29mm or 38mm in diameter. (For a current list of Level One motors that are certified for use by Tripoli or the NAR, check their web sites.)

Aerotech manufactures the most reloads available in the H and I range. In this chapter, we will reload the Aerotech H180W. This

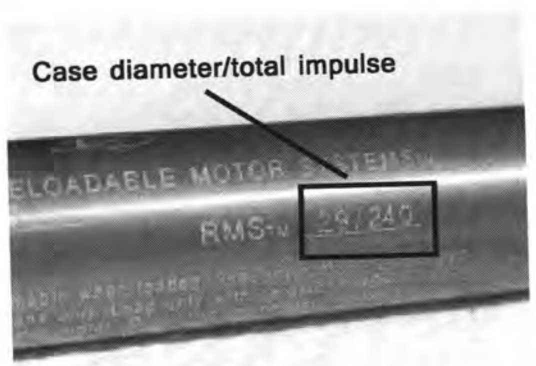


2-4

This is the four-grain Aerotech H180W reload kit. The H180 is a 29mm motor with 240 newton-seconds of total impulse. This reload fits into an Aerotech or Dr. Rocket 29/180 motor casing. Below: The Dr. Rocket reloadable case has a stamp that indicates the case diameter and the total impulse range.

motor has an average thrust of 180 newtons and a total impulse of about 240 newton-seconds. The burn time is approximately 1.2 seconds.

The equations discussed in Chapter One provide a thrust-to-weight ratio for this motor. By dividing the average thrust of 180 newtons by 4.45 we arrive at 40.4 pounds. To determine a 5:1 thrust-to-weight ratio, we then divide 40.4 by 5, which equals 8 pounds. The weight of 8 pounds is the maximum safe lift weight when using the H180W to stay within the 5:1 ratio.



2-5

As the W on the Aerotech motor label indicates, the H180W is a White Lightning motor. It will produce a bright orange flame and dense white smoke. It is a great motor to get started with, and the reload costs less than $20. The reload kit comes with all of the necessary fuel and internal components for launch. However, the reload kit does not come with the case and closures.

As explained in Chapter One, a reload kit is not the entire motor. The kit must be combined with a reloadable motor case and both forward and aft closures to complete the motor. In this example, we are using a Dr. Rocket reloadable motor case. This is a 29mm case with forward and aft closures that thread onto the aluminum body. As seen in photo 2-5, the case has the numbers 29/240 stamped on the side. The first number is the diameter of the case. The second number is the approximate total impulse of the motor when loaded. This method of identifying the case can be found on most Dr. Rocket and Aerotech high-power casings.

Loading the Motor

Photo 2-4 shows the reload kit. The kit comes complete with fuel grains, washers, o-rings and all the necessary items to fill the case from closure to closure. The wire at the right edge of the photos is an igniter for the motor. Some–but not all–reload

kits come with igniters. In any event, igniters are readily available for all reloadable high-power motors and are discussed in more detail in Chapter 5.


2-6


2-7

2-8

First: Read the Instructions

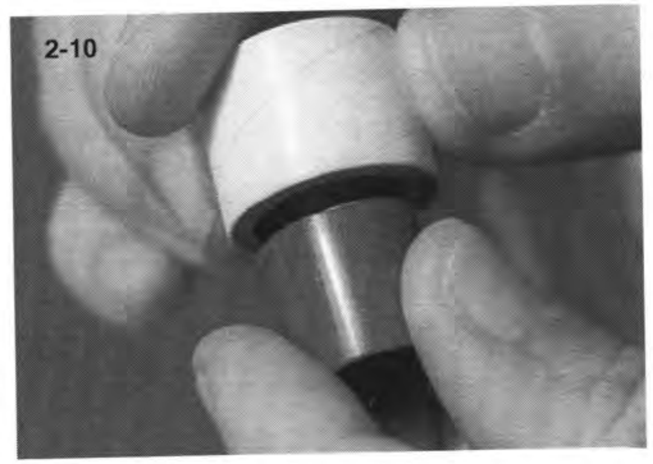
The most important thing to do prior to assembly is to thoroughly read the instructions that come with the reload kit. If you have any doubts or questions as to how the motor should be put together, contact the manufacturer, or a dealer, or someone in the local rocket club who has experience with these types of motors. Also, be sure to compare the parts list with the parts that came with the kit. Every part in a high-power reload is important. Therefore, never attempt to use a reload if anything is missing. And never launch a reload if you have extra parts after the motor has been assembled. This is dangerous and can lead to injury or destruction of the motor case and the rocket.

A couple of years ago at our local launch in California, an experienced Level One flyer used an H180W in a nice Public Missiles Systems kit that was perfect for this motor. The rocket weighed well under 5 pounds and was expected to reach an altitude of at least 2,000 to 3,000 feet. Unfortunately, it never got that far. At ignition, the rocket started to rise, and then it burst into flame, careening into the ground, where it was destroyed. The culprit? A close inspection of the rocket and the floorboard of the rocketeer's truck uncovered an o-ring that had inadvertently been left out of the motor. As a result, the hot gases from the burning fuel grains simply

The Delay

The delay grain in this Aerotech motor can be either short, medium, or long. These terms translate into 6, 10, or 14 seconds, respectively. As explained in more detail in Chapter 6, it is important to pick a delay grain that will lead to deployment at, or near, apogee. This will help ensure a smooth deployment. Failure to do so can lead to an early or late deployment, which is the primary cause of a zipper in the airframe, below.


2-9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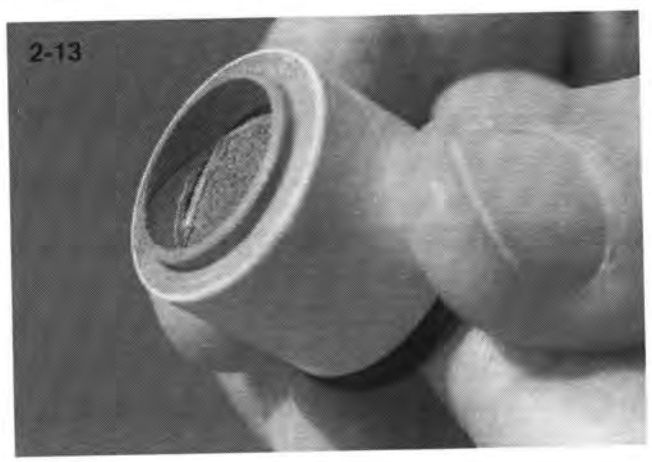
2-12


2-13


2-14


2-15


2-16

melted through the forward end of the case, setting the rocket on fire and destroying the motor. The moral of the story: Be careful at the field when loading any high-power motor. Take your time. Try to load the motor in a quiet place, preferably on a clean tabletop. And be sure that you have used every single part in the kit.

Once the parts list is confirmed, apply a light coat of grease to the threads of the aft and forward closures. This will aid in disassembly after flight. Then, apply a light coat of grease to the o-rings in the kit. Do not apply too much. Apply just enough to give the rings a shiny appearance. See photo 2-8. Set the o-rings aside, but keep them clean.


2-17

Assembly of the Delay Grain

The delay grain in the H180W separates the burning fuel grains in the case from the black powder in the forward closure. When the motor is ignited on the pad, the delay grain begins to slowly burn from the bottom of the grain to the top. After several seconds, the grain will burn all the way through and the black powder will ignite. The resulting expansion of gases leads to deployment of the rocket's recovery system.

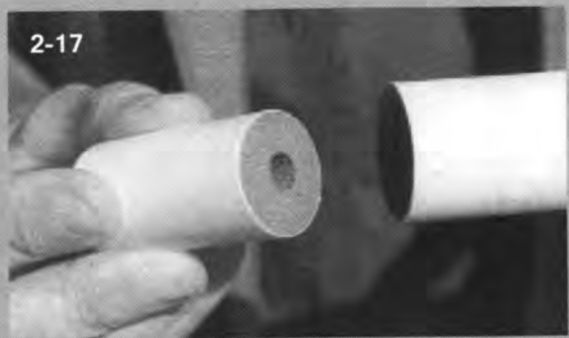
Pick up the delay-grain insulator and, as illustrated in photo 2-9, chamfer both inner edges with a fingernail or other sharp object. (Chamfer means to cut or grind in a sloping manner, so as to form a notch or bevel.)

Next, place the delay grain, the delay-grain spacer, and the delay-grain o-ring into the insulator, as shown in photos 2-10 through 2-13. Be careful not to damage the outside paper on the delay column when you squeeze or fit the column into the insulator. This can lead to the ejection charge firing prematurely. Set this assembly aside for the moment.

The reload kit comes with a 13/16" soft, flat, neoprene washer. As shown in photo 2-14, pick up the washer and place it all the way into the forward threaded closure of the motor case. The forward closure is the end with the recessed well where the black powder will eventually be poured for the ejection charge. Now, place a thin film of grease on the inner circumference of the closure, but not on the neoprene washer. With the neoprene washer in place and the inner circumference greased, take the delay grain assembly and slide it (o-ring first) gently all the way into the closure. See photos 2-15 and 2-16. Set this entire assembly aside. It is time to install the propellant grains in the motor liner.

The fuel grains and the motor liner

The Aerotech H180W reload kit comes with four 29mm fuel grains and a motor liner. Place each grain into the motor liner. See photo 2-17. The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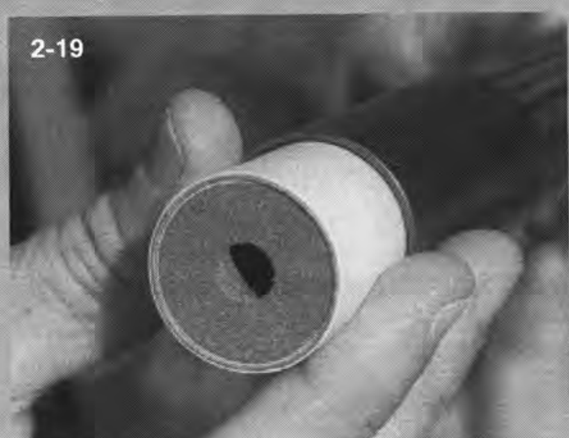
2-18


2-19


2-20

grains should fit easily into the liner, but they will be snug.

Occasionally, the grains cannot be placed into the liner without applying a lot of force. This may occur because the grains have become slightly swollen after manufacture. This is not a big problem. Simply peel away a thin layer or two of the paper or cardboard wrap that encases the swollen grain, and it will usually fit better into the liner.

Do not use a motor liner that has been damaged in any way. The motor liner and o-rings in the reload kit protect the metallic reload casing from hot gases as the fuel burns during flight. Failure of the o-rings or liner may allow these gases to reach–and melt–the case. If the liner is cracked or broken, find another one.

Once the four fuel grains are inside the liner, apply a light coat of grease to the outside of the liner, taking care not to get any grease on the fuel grains. See photo 2-18. The grease on the liner will aid in disassembly and cleanup of the motor after flight. Now, push the liner containing the fuel grains slowly into the motor case until both ends of the liner are equally recessed inside the ends of the case. See generally photos 2-19 and 2-20.

Installing the Forward Closure on the Case

The H180W reload kit comes with two one-inch fiber washers. These are the forward and aft insulators.

As illustrated in photo 2-21, take one of these insulators and place it into the forward end of the motor case until it is seated against the motor liner. Then, place the greased 3/32" o-ring into the case so it is seated against the forward insulator. See photo 2-22. Be sure that the o-ring has a small amount of grease on it and is free of any debris, such as dirt or hair. Any debris on the o-ring–even a grain of dirt–may allow the hot gases generated during the burning of the motor to escape.

The importance of the o-ring (and all o-rings) being absolutely free of contaminants cannot be overstated. The o-ring in the forward closure helps prevent the hot gases of the burning motor from reaching the ejection charge early. If these gases reach the black powder in the charge, there will be an early and violent deployment of the recovery system. Even worse, if the o-ring fails (or if it is not installed) you will see a blow-by—the burning gases from the propellant will exit not only through the aft nozzle (as they should), but also through the tiny hole in the forward closure, causing the metal around the hole to melt. The result is a failed motor and a burning rocket.

Now, pick up the forward threaded closure (the closure with the delay-grain assembly inside) and gently thread the closure onto the motor case where the forward insulator and o-ring were just installed. Be sure to keep the motor case in a horizontal position, parallel to the ground, as this step is completed. See photos 2-23 and 2-24.

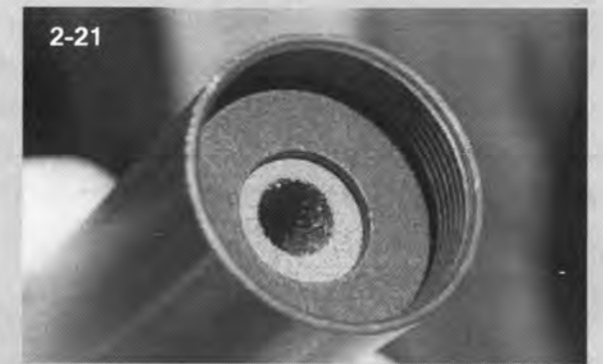
The Aft Closure and the Nozzle


2-25

Now direct your attention to the other, open end of the case. This is the aft end of the rocket, where the motor nozzle will be placed. The nozzle is shown in photo 2-25.

Place the last insulator into the aft end so it seats against the liner. See photo 2-26. The reload kit comes with a black motor nozzle. Occasionally these motor nozzles have a bit of plastic residue, or "flash," in the throat, or center of the nozzle. If so, use a hobby knife or other sharp instrument to gently scrape the flash out of the nozzle's center. The nozzle should be clear and free of any debris.

Pick up the nozzle and place it into the case so it is seated against the insulator. As shown in photo 2-27, place the last remaining o-ring into the case so that it is seated in the groove between the motor casing and the exhaust nozzle. Pick up the aft closure and gently thread it into place on the case. See photo 2-28. As indicated in the Aerotech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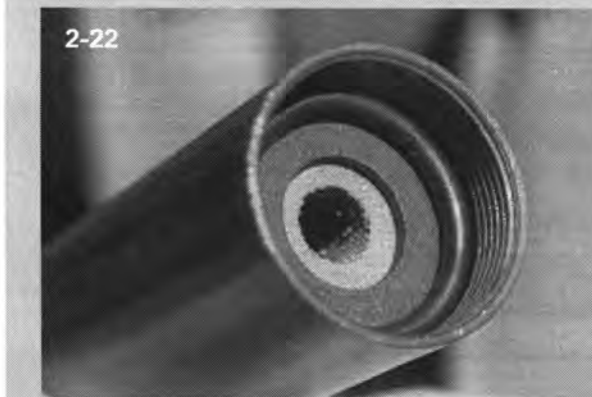

2-22

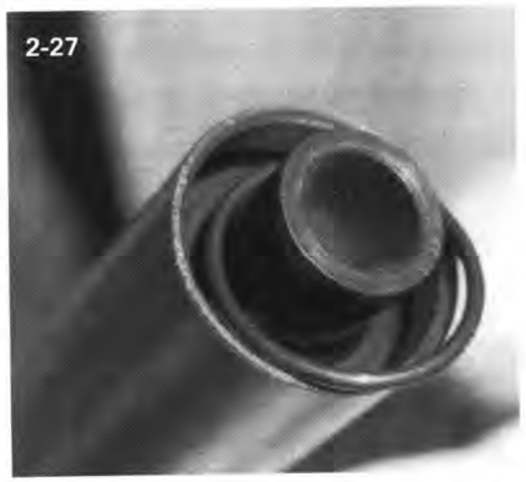

2-23


2-24

instructions for the H180W, there may be some resistance to threading the closure during the last 1/32" to 1/64". This resistance occurs as the closure tightens against the o-ring. The o-ring is being compressed and is expanding outward to seal against the threads of the closure. This prevents any gases from escaping through the threads. Aerotech points out that this is normal and there may even be a slight gap between the closure and the motor case after it is fully tightened. Do not use tools to try to further tighten the closure and eliminate this gap–you may damage the o-ring.

That's it. The H180W is now loaded. All that remains is placement of the ejection charge in the well of the forward closure and insertion of the igniter at the pad.


2-26


2-27

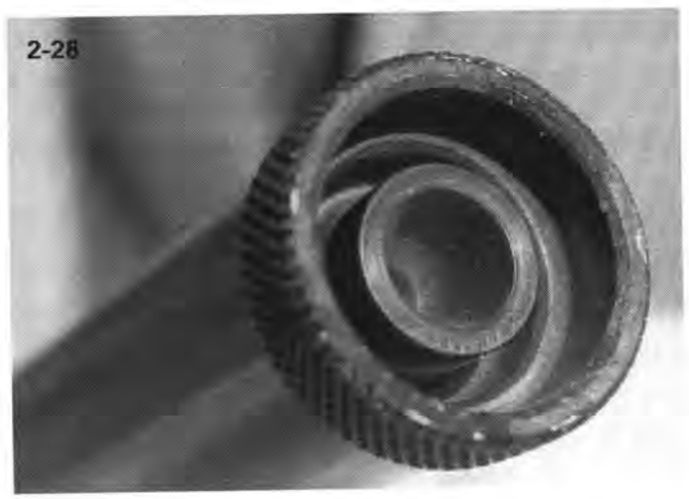
Placing the Ejection Charge in the Motor

Ejection charges may be controlled by on-board electronics, or they may be motor-based. If you are using a motor-based charge, it is time to place the black powder into the well. If no ejection charge is used, the well should be filled with grease.

Aerotech reload kits often come with a small charge of black powder. In the H180W kit, this powder is contained in a red plastic cap. After the black powder is removed, this cap is also used to secure the igniter to the exhaust nozzle prior to launch, discussed below.

Black powder is also available for purchase in one-pound cans in many states at gun stores. A one-pound can of black powder should last for dozens of flights. The most common type of black powder used in high-power is 4FFFF. According to the ATFE's 2000 edition of the *Federal Explosives Law and Regulations Guide*, also known as the Orange Book, black powder is an explosive material for purposes of federal explosives laws and regulations. The book states: "However, the law exempts from regulation commercially manufactured black powder in quantities not exceeding 50 pounds . . . intended to be used solely for sporting, recreational, or cultural purposes in antique firearms. . . ."

When in doubt, check with your local ATFE office to determine the legality of storing black powder for rocketry use.


2-28

Prior to placement of the powder in the forward well, be sure that both ends of the motor have been fully tightened. Peel away the cover on the red plastic cap to reveal the black powder inside. As illustrated in photo 2-29, pour the black-powder contents of the cap into the recessed well of the forward closure. The Aerotech instructions recommend filling the well ¾ full, unless the rocket is four inches in diameter or larger. In that case, fill the well completely.

As explained in more detail in chapters 6, 8 and 10, the larger the internal dia-meter of the rocket body (or the section that will be exposed to the ejection charge), the greater the amount of black powder necessary to separate the rocket.

Once the appropriate amount of powder has been placed into the well, seal the well with the adhesive sticker that comes with the kit. See photo 2-30. The seal must firmly adhere to the closure and not allow any of the tiny powder grains to leak out. If the seal is not perfect, take a piece of masking tape and add it to the adhesive sticker.

The purpose of the ejection charge is to force the rocket body apart to allow for deployment of the rocket's recovery harness and parachute. If the amount of black powder is insufficient, or if some of the powder leaks out prior to launch, the charge may become useless, and there will be no deployment. If that occurs, the rocket will almost certainly be destroyed. So always be certain that the ejection charge seal is absolutely secure.

The timing of the ejection charge is discussed in chapters 6, 8 and 10.

Installation of the High-Power Igniter

The final step in the assembly of this Level One motor is to install the igniter at the pad. The igniter is the last piece that goes into the motor. The typical igniter is a high-resistance two-lead wire with a flammable head at the forward end. This flammable head is slowly pushed into the nozzle and core of the motor as far as the igniter will travel. The free igniter wires are stripped about one inch per wire from the ends and then wrapped around alligator clips that are located at the pad. These clips are connected to a wire that runs all the way back to the master-launch control box. When a button is pushed on the control box, an electrical current travels from the power source (usually a battery), through the switch in the control box, to the launch pad via the wire and the alligator clips, and through the igniter wire. The igniter wire then heats up and lights the flammable head, which lights the motor, and launches the rocket.


2-29


2-30

Prior to insertion of the igniter into the aft end of the H180W, strip off at least one inch of insulation from each of the igniter leads. Attach these stripped ends to the alligator clips at the pad–one wire per clip. Wrap the stripped wire around the alligator clip for a firm electrical connection. Then, and only when the rocket is vertical on the pad, insert the igniter into the H180W as far as it will go.

The Aerotech reload kit comes with a red plastic cap.

Post Flight

Motor casings will remain hot for some time after flight. Wait at least one hour before you attempt to handle the motor again. But do not wait too long. Aerotech recommends that your casing be cleaned within 24 hours. The longer you wait, the harder it may become to remove the residues left from the propellant and other internal parts of the reload. This is a good rule for all motors. For more information on motor cleaning, see Chapter 17.

This cap is used to secure the igniter in place. Take the cap and slice a vent hole in it. Then place the cap over the igniter wire and the motor nozzle. The fit should be snug–even tight. See photos 2-31 and 2-32. If the red cap is not available, a piece of masking tape will also suffice to hold the igniter in place. But *do not plug the nozzle.*

If you are using electronics to control deployment of the rocket, arm the electronics first, before inserting the igniter. This way, if the rocket should be mistakenly launched (which can occur only after the igniter is in and hooked up to the alligator clips at the pad), the rocket will be able to deploy as planned.

Igniter failure can occur if the ends of the igniter wires or alligator clips are touching each other or any metal object, such as the blast deflector. So be sure that the alligator clips are hanging free from any metal around the pad. Igniters also have a tendency to become dislodged in a slight breeze. So use some masking tape or any other handy method to ensure that the igniter stays in the rocket after you leave the pad.

Conclusion

The H180W is an excellent motor for Level One certification. Cesaroni Technology and Loki also make excellent high-power motors used for certification, including the H143, H144, and the H153, each with a total impulse in the appropriate range for a Level One attempt.

To determine which motor would be best for your certification flight, check with the manufacturer of your rocket (if it is a kit) or log on to the web sites of the motor manufacturers for complete specifications and availability.

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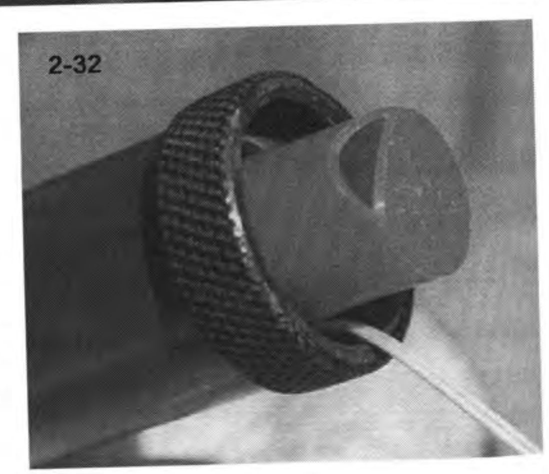
2-32



Top: The Aerotech igniter has been placed in the motor core through the nozzle. Bottom: The plastic cap supplied in the reload package is used to secure the igniter in place. Note the air vent that has been sliced in the cap.

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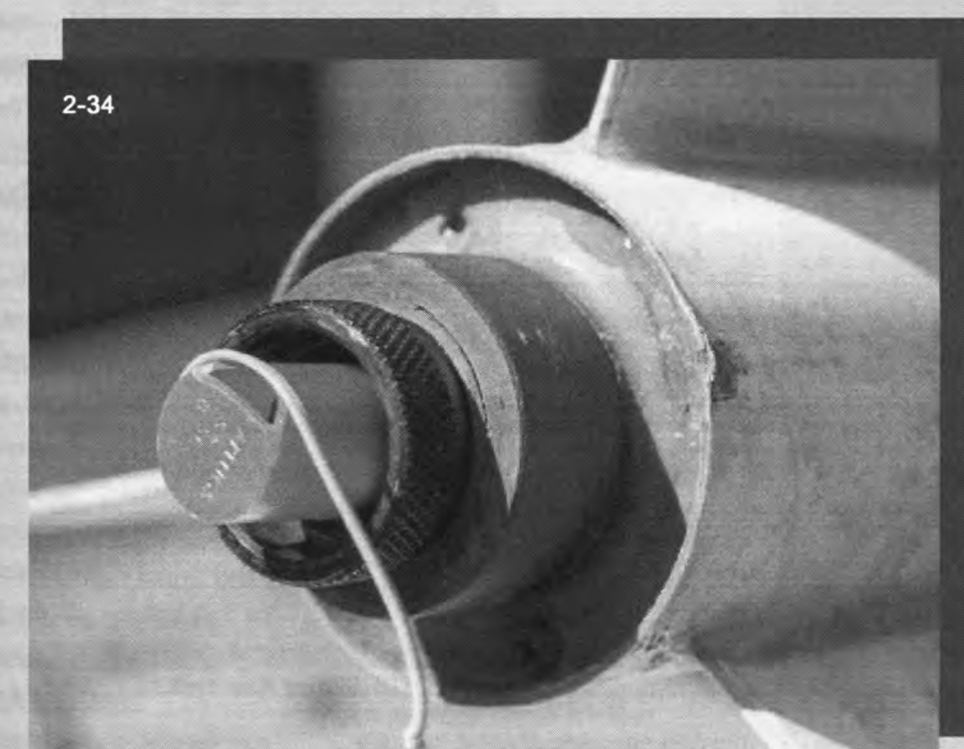
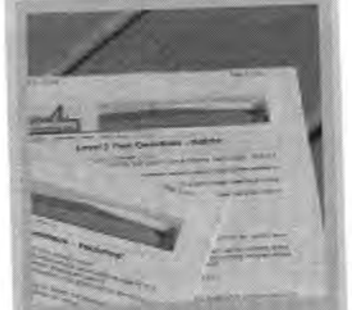


3

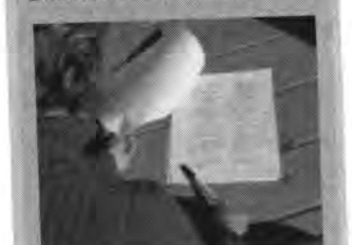
Level Two Certification

Making your way through the written test and your first Level Two flight



The Test

The NAR Level Two practice test contains questions chosen from several categories. These categories include rocket stability and construction, applicable regulations, storage requirements, range and safety practices, and motor labels. The Tripoli practice test is similar in nature, but is broken into two broad sections: Safety questions and technical questions. Both practice exams come with the questions and the answers. Both exams can be downloaded from the Internet on the Tripoli and NAR web sites.



Level Two is the next step in the high-power certification process.

There are three basic requirements for Level Two certification. First, the rocketeer must have previously obtained Level One certification. Second, the rocketeer must pass a written multiple-choice exam administered by either NAR or Tripoli. Third, the candidate must launch and successfully recover a rocket equipped with a motor in the range of 640.01 to 5120 newton-seconds of total impulse. These are J, K, and L rocket motors.

The purpose of this chapter is to first review the application and knowledge requirements of the Level Two examinations and then to assemble three Level Two reloadable motors from different manufacturers: Cesaroni Technology, Aerotech, and Animal Motor Works.

New York NAR member Rich Pitzeruse, left, and South Carolina flyer Mike Scicchitano with their K-powered rockets at LDRS23 in New York.

The Level Two Application and Exam

Both Tripoli and NAR administer their own certification examinations. The tests are similar but are not identical.

Both exams evaluate the rocketeer's general knowledge of laws and regulations pertaining to high power as well as the fundamentals of launch safety and rocket construction.

Level Two rockets are some of the most complex at any launch. Here, a Level Two rocket with a seven-motor cluster with more than 5,000 newton-seconds of total impulse is prepared for flight at LDRS21 in Southern California in 2001. (The launch trailer was built by the late Stephen Roberson.)

The NAR examination consists of 33 multiple-choice questions. These questions are chosen from a pool of 100 questions that are available through NAR for study prior to the test. The average rocketeer will obtain a copy of the questions, review the answers thoroughly, and then sit for the test. The passing grade for the NAR test is 88%. This means the rocketeer can miss only four questions. Passing the written test is a prerequisite to the Level Two certification flight.

The Tripoli test questions are also available online through Tripoli's main web site. The Tripoli exam is 50 multiple-choice questions. The passing grade is 90%. This means that the rocketeer can miss no more than 5 questions.

The actual examination is usually administered at the launch field by a local representative of either Tripoli or NAR.

Tripoli member Steve Sawyer of California and his wife, JoAnn, at LDRS23 in Geneseo, New York.

After passing the test, the user is ready to attempt Level Two flight. Both Tripoli and NAR have forms and procedures in place for Level Two certification flights. Tripoli's current procedure is simple: A one-page form is filled out, and the launch is witnessed by a club prefect, by a Tripoli Advisory Panel (TAP) member, or by a member of Tripoli's board or directors. As a practical matter, the witness is usually the club prefect, since a prefect is present at most, if not all, Tripoli high-power launches. Once the rocket is safely recovered, the paperwork is signed by the prefect and sent by the rocketeer to Tripoli headquarters for certification.

The NAR procedure is similar, but the paperwork is more detailed. NAR uses the same one-page form for both Level One and Level Two attempts. There are several boxes on the form

3-4

Tripoli member Wayne Anthony prepares his rocket for flight at a launch site in Battle Park, Virginia. The rocket was equipped with a Level Two range motor–an L motor.

that must be checked prior to flight. These boxes confirm that the motor being used is certified, affirm that an accompanying certification checklist has been complied with, and note other information related to the rocket and flight.

The launch of the rocket and its safe recovery must be witnessed by two NAR members in good standing. At least one of those witnesses must be certified at the same level as the certification attempt. This means that two Level One members cannot be the official witnesses to a Level Two certification. (By contrast, only one Level Two or Level Three witness is needed for a NAR Level One attempt.)

3-5

The witness(es) must sign the certification affidavit on the lower section of the certification application. The certification application and the certification checklist are both available online from NAR.

Motor selection for a Level Two attempt is vast. There are dozens of motors in the J, K, and L range available from several major manufacturers. These include both solid fuel and hybrid motors.

In this chapter, we will illustrate the assembly of three solid fuel Level Two motors from three different manufacturers. The first motor is a five-grain 38mm Cesaroni Technology J285. The second motor is a six-grain 38mm Aerotech J350. The final motor is a five-grain 54mm Animal Motor Works K570. (The assembly instructions in this book are not meant to replace the instructions provided by the motor manufacturers.)

Cesaroni Pro38 648J285-15A

Cesaroni Technology produces a wide range of high-power reloadable motors. Not only are these motors reliable and gaining in popularity, but they are also the easiest to assemble of all the high-power reloads.

For our first Level Two example we are using the Pro38 five-grain J285. This motor's official designation is 648J285-15A.

As explained in Chapter 1, the number 648 in the motor label corresponds to the total impulse of the motor in newton-seconds. Cesaroni is the only manufacturer that lists the total impulse number on its label first. The number 285–which follows the J in the label–represents the average thrust of the motor. Thus, this reload has an average thrust of 285 newtons and a total impulse of 648 newton-seconds. If we divide the total impulse (648) by the average thrust (285), we can arrive at the approximate burn time of the motor, which in this case is 2.27 seconds.

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How much weight can the Cesaroni J285 safely lift? Again, as discussed in Chapter 1, to obtain a 5:1 thrust-to-weight ratio, start by dividing the average thrust of 285 newton-seconds by 4.45 to obtain a pounds-seconds figure. The result is 64. Now divide 64 by 5. The answer is 12.8 pounds. This means that the J285 will have a 5:1 thrust-to-weight ratio in a rocket that weighs 12.8 pounds. Does this mean that the J285 cannot lift a heavier rocket? No. The J285 can lift a heavier rocket, but if you want to maintain a safe thrust-to-weight ratio of at least 5:1, then 12.8 pounds is the limit.

The J285 is an excellent motor for Level Two certification, and the reload kit currently retails for about $45. In addition to the reload, the rocketeer must have the case for the J285. The case houses the reload and with proper care and handling can be reused for many flights. The rocketeer must also have access to the Cesaroni delay- grain adjustment tool, illustrated in photo 3-7.

The Cesaroni Reload Kit

As with all high-power reloads, prior to reloading this motor, be sure to read any and all instructions that come with the kit. If there are any instructions that you do not understand, contact the manufacturer or speak with someone at a local rocket club who is familiar with loading this motor. Needless to say, do not load this motor in the presence of any open flame, cigarette, or other heat source. Prior to assembly, be sure that all of the parts are present and

The Motors

There are more than 40 different motors in the J, K, and L range that may be used for Level Two certification in either Tripoli or NAR. These include motors in the 38mm, 54mm, 75mm, and even 98mm diameter range. The motor makers include Animal Motor Works, Cesaroni, Aerotech, Loki Research, RATT Works, Sky Ripper (shown below), and Hypertek, to name a few. Any approved solid fuel or hybrid motor may be used to certify. Homemade or experimental (EX) motors may not be used in a certification attempt.


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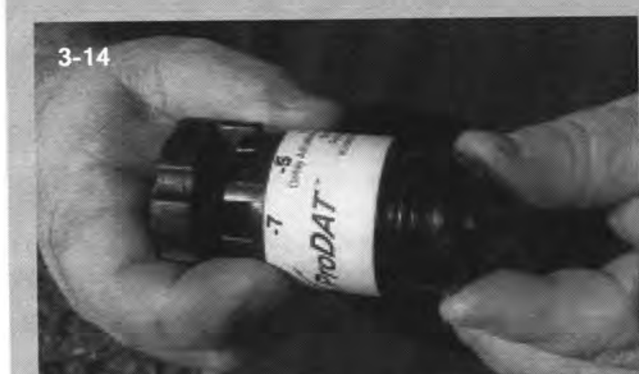

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that the reload is in good condition, without any signs of damage.

There are very few parts to the J285. The reload kit comes with an igniter, a built-in ejection charge, and the reload assembly. The reload assembly is a sealed unit that contains the five 38mm fuel grains and the nozzle. It is entirely self-contained. There are no individual washers or o-rings to handle, no distinct fuel grains to load, and no parts that have to be greased before assembly. As shown below, once the delay charge is determined, the entire motor assembles in only a few minutes.

Preparing the Delay Charge

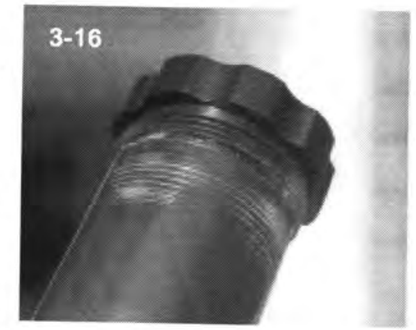
The first step in assembly of the motor is to set the delay charge. The motor label indicates that the reload has a preset ejection charge that will fire 15 seconds after motor burnout (648J285-**15**A). This time period may be shortened. In fact, for most rockets that will use the J285, 15 seconds is a very long time for motor ejection. If the delay time is not adjusted downward, there is a good chance that the rocket will reach apogee and return to the ground before the charge fires. For this reason, never forget to consider what time would be best for your rocket, and adjust the delay charge accordingly. See Chapter 6

The delay/ejection module is located at the forward end of the reload liner. See photo 3-8. Using a simple twisting motion, gently remove the module from the liner, as shown in photos 3-9 and 3-10. Put the liner assembly aside for the moment while you work on the delay/ejection module.

The module has a built-in o-ring on its outside diameter. See photo 3-11. You will also note that at one end of the module there is a white label or seal. Underneath the label is a small charge of black powder. See photo 3-12. If you are using electronic recovery in your rocket and do not wish to utilize the motor-based charge, you may remove this label and transfer the powder to the ejection-charge holder in the rocket.

As illustrated in photo 3-13, the opposite end of the module exposes the delay grain. The 15-second delay in this motor may be reduced by 3, 5, 7, or 9 seconds with the delay-grain adjustment tool. The adjustment tool consists of two parts: A drill guide and a drill holder.

In this example, we have decided to set the delay time at 8 seconds for the rocket we will launch. Therefore, we must reduce the 15-second delay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grain by 7 seconds (15 - 7 = 8). Select the delay adjustment desired, rotate the drill holder to the labeled notch in the guide (-7) and then seat the drill-holder tab into the drill-guide notch.

Holding the drill guide and the drill holder in one hand, insert the delay module into the drill guide cavity until the drill bit comes in contact with the delay grain. See photo 3-14. Now, gently rotate the drill holder clockwise while applying light pressure. Drill into the delay material until the guide bottoms out against the delay grain. Cesaroni recommends rotating the drill guide several more revolutions to ensure that the delay material is cleared from the hole created by the drill.

Remove the delay module from the drill guide. As illustrated in photo 3-15, you will see a small hole in the center of the delay grain that was created by the drill. The delay grain is now finished and ready for re-insertion into the motor liner.

The J285 comes with 1.3 grams of black powder in the delay module. This powder is contained just below the white label/seal in the delay module. If you wish to increase the amount of powder, do not remove the white label. Instead, Cesaroni recommends placing any extra charge on top of the white label and then covering that powder with tape to seal the cavity.

To reinstall the ejection module, using a simple twisting motion, gently push the module back into the forward end of the motor liner as far as the module will travel. Be sure that the o-ring on the module goes fully into the liner. A small gap of about 1/8-inch between the forward end of the liner and the shoulder of the delay module is normal.

The Fuel Grains and the Motor Liner Assembly

It is time to insert the liner assembly (which also contains the fuel grains) into the motor case. You will note that the liner has a threaded end. See photo 3-16. This is the aft end of the liner, and these threads correspond to the threads in the aft end of the metal motor case. See photo 3-17. Push the forward end of the liner (the end with the delay module) into the case until the threads of the liner engage the motor case. Then, firmly but slowly, thread the liner into the case. See photo 3-18. Tighten the assembly by hand. The instructions for this motor state that the assembly is designed to have a small gap between the liner and the motor case. However, this gap should not be more than 1/16 inch. If the gap is too large, Cesaroni recommends that the assembly be removed and re-checked for proper fit and assembly.

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With very few parts, the Pro-series motors go together in only a few minutes and clean up quickly after launch. Otherwise, the motor is handled in the same manner as any other high-power motor. Do not forget the case!

That's it. The Pro38 J285 is loaded and ready to go. As you can see, once you are familiar with the instructions and have some experience, the actual time it takes to load this motor and prepare it for flight is only a few minutes. The reload kit is supplied with an igniter and a cap to hold the igniter in place on the pad. See photo 3-20. As explained in chapters 2 and 5, the igniter should not be installed until the rocket is vertical on the pad and any on-board electronics are already armed.

Aerotech J350W

The Aerotech J350W is another 38mm motor that is excellent for Level Two certification. This White Lightning Aerotech motor packs a wallop off the pad, with an average thrust of 350 newtons and a burn time of just over 2 seconds. The motor has a total impulse of more than 700 newton-seconds. For our example, we are using a Dr. Rocket 38/720 reload casing.

At a price of around $40 to $45, the J350 is comparable in cost to the Pro38 J285. However, the Aerotech motor has more parts and is a little more difficult to assemble. But it's still easy to use.

As illustrated in photo 3-23, the reload kit comes with about 20 pieces, including six fuel grains and an Aerotech igniter. Once the parts list is confirmed, read the entire Aerotech instruction sheet carefully. It is important to take your time with the instruction sheet even if you have built other Aerotech motors before. There are some minor differences in the construction and assembly of Aerotech reloads, so do not assume that, because you are familiar with one motor, you are familiar with them all.

3-22

California Tripoli member Bruce Rohn with his Public Missiles Systems Patriot missile.

Be sure the parts fit together before assembly. On the J350, the six fuel grains should slip easily into the motor tube liner. If the grains are wrapped in plastic, remove the plastic. As explained in Chapter 2, occasionally the fuel grains will swell after manufacture. This may make insertion of the grains into the liner difficult. If this occurs, gently peel off a thin layer or so of the fuel grain's outer paper lining. Do not peel away too much—just enough for the grain to fit into the tube.

Prior to assembly, take a hobby knife and gently debur the inner circumference of the motor liner. See photo 3-24. Then, inspect the exhaust nozzle. Be sure the nozzle core is free of any plastic flash that remains from the factory. See photo 3-25. If the central core of the nozzle is not clear and round, take the hobby knife and remove any remaining flash from the core.

Then, grease the four o-rings in the kit and the threads of the forward and aft motor closures. Remember, try not to use too much grease on the o-rings–just enough to give the o-rings a shiny appearance. And as discussed in Chapter 2, avoid getting any dirt or debris on the o-rings or the closures. Finally, chamfer the inside edges of both ends of the delay-grain insulator, using only your fingernail.

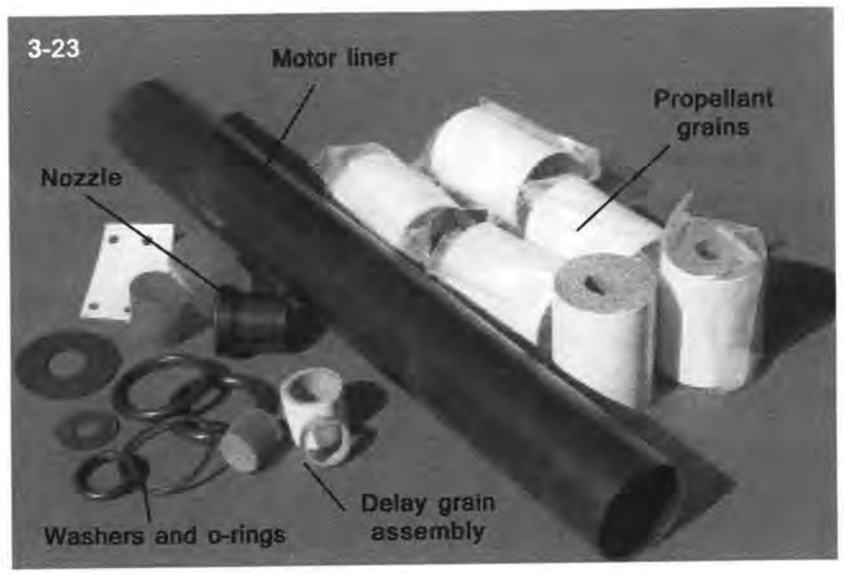
Forward Closure Assembly and the Delay Grain

Actual assembly of the motor begins with the forward closure. The forward closure houses the delay grain and the black-powder charge that will be used for motor ejection.

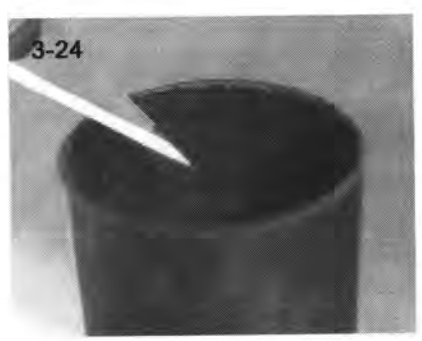
Place the thick, 13/16-inch delay o-ring onto the very end of the delay element, as illustrated in photo 3-26. Be sure that your hands are free of any grease or dirt when handling the delay grain. Grease or debris on the delay grain can lead to failure of the ejection charge and destruction of the rocket. With the o-ring in place on one end of the delay grain, take this assembly and gently push it into the white cardboard delay-grain insulator, as shown in photo 3-27. Note that the o-ring does not go into the insulator; rather, it abuts one end of the insulator.

Now pick up the tiny cardboard aft delay spacer and push it gently into the delay insulator on the end of the insulator opposite the o-ring. Set this assembly down for a moment.

The J350W reload kit comes with one soft, pliable neoprene washer. This is the forward delay spacer. Although it is called a "spacer," you will see that it is as thin as a washer. Pick up the forward closure of the motor. This is the closure with the well in which the black powder will eventually be poured. Carefully drop or place the spacer into the bottom of the forward closure, as shown in photo 3-28. Be sure that the spacer is fully seated against the bottom of the closure. Now, pick up the delay-grain assembly and place it into the forward closure–o-ring end first. You will note that the cardboard delay insulator may protrude slightly above the closure. See photo 3-29. The forward closure assembly is done for now. Set it aside.



3-23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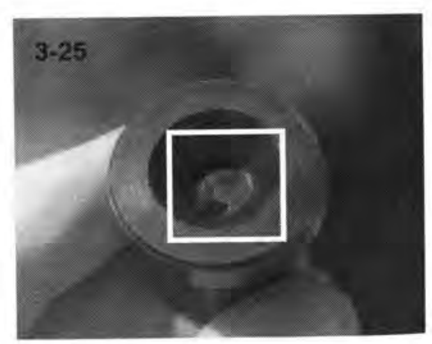
3-25

Installing the Seal Ring

The J350W is one of about a half dozen Aerotech motors to use a black aluminum seal ring. Be sure that you have this ring with your case. The seal ring comes as a part of the case assembly, along with the forward and aft closures. The seal ring is reusable. It is not supplied in the reload kit. Its purpose is to prevent the hot gases of ignition from escaping between the forward insulator and the top of the liner. Do not attempt to use a J350W without the aluminum seal ring. As you look at the seal ring on end, you will notice that it has a thin groove going all

the way around the circumference. Pick up the thinnest o-ring in the reload kit (1/16" by 5/16"), and place it into the groove on the metal seal ring. Now, place this assembly onto one end of the motor-liner tube, o-ring side first. In other words, the o-ring should be inside the liner tube.

If the metal seal and o-ring do not fit into the liner, pick up the hobby knife, and again gently debur the end of the liner tube. The fit should be very snug. (See the photos in the sidebar discussion on the next page.)

Loading the Propellant Grains

There are six 38mm propellant grains in this motor. Slide each grain into the open end of the motor-tube liner. With the grains installed, lightly grease the outside of the motor liner. This grease will aid in disassembly of the motor after flight and in cleanup of the motor case.

Place the greased motor liner into the Dr. Rocket 38/720 motor casing. At this point in the assembly, there should be two o-rings left on the table. Take the thinner of these two o-rings, and place it into the motor casing so it is seated against the aluminum seal ring. See photo 3-30.

Now, with the motor case held in a horizontal position, take the forward closure assembly, and gently thread it onto the end of the casing containing the aluminum seal ring. See photos 3-31 and 3-32. Tighten the closure by hand only.

The Aft Closure and Nozzle

Place the remaining fiber washer into the aft end of the motor case so it abuts the motor liner, as illustrated in photo 3-33. Now take the last o-ring, and place it into the same end of the case so it rests against the fiber washer. See photo 3-34.

The reload kit comes with one black exhaust nozzle. Place the nozzle into the open end of the motor case so that it sits directly within the o-ring and against the fiber washer. The fit of the nozzle in the o-ring should be snug. See photo 3-35.

Pick up the aft metal closure, and slowly thread it onto the open end of the case. See photo 3-36. It is not necessary to use any kind of tool when


3-26


3-27


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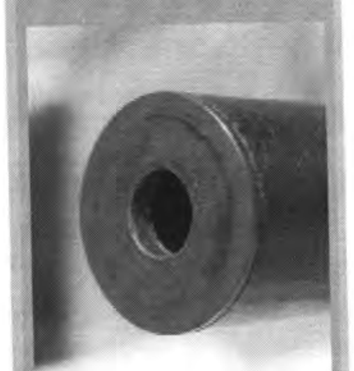
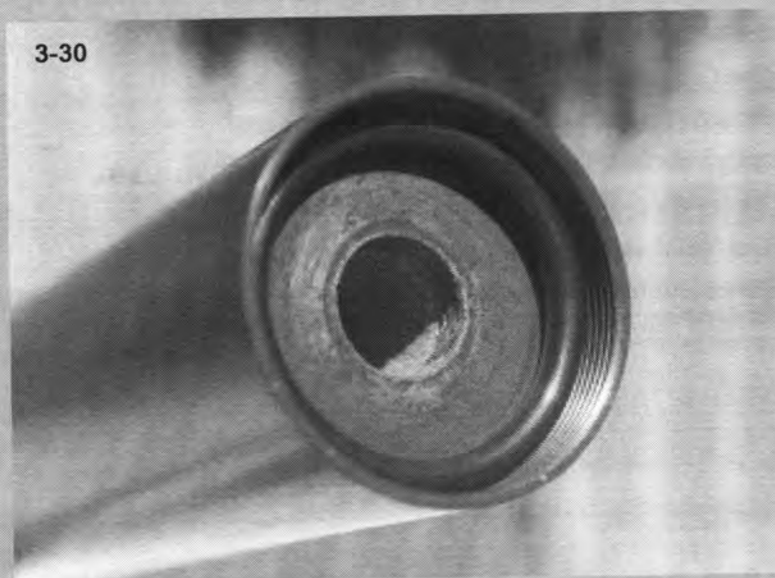
3-29

Seal DISC

The J350 is one of several Aerotech motors that uses a forward aluminum seal disc. The disc replaces the forward insulator. The disc has a groove for an o-ring (see photo above) and together the disc and o-ring prevent the flow of hot gases between the top of the liner and the seal disc. The disc comes with the casing. It does not come in a reload package. The seal disc is reusable--so be sure to save it after cleanup of your J350.





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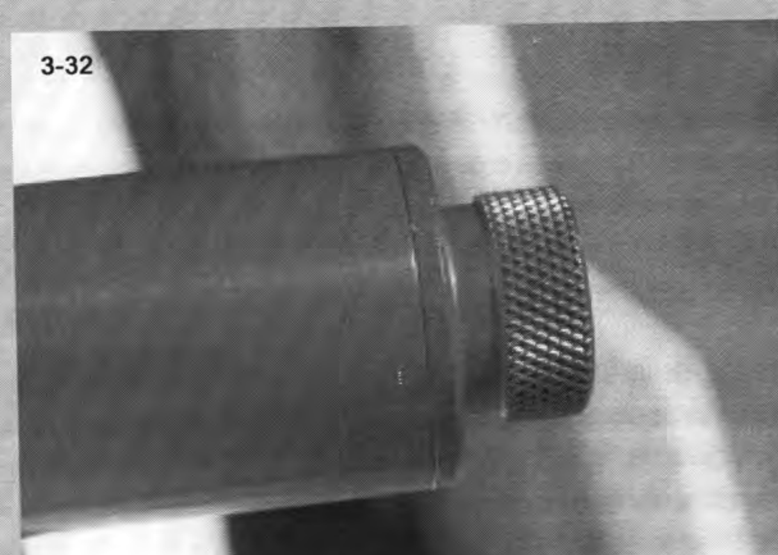
3-31



3-32

threading on the closure. Tighten the closure by hand.

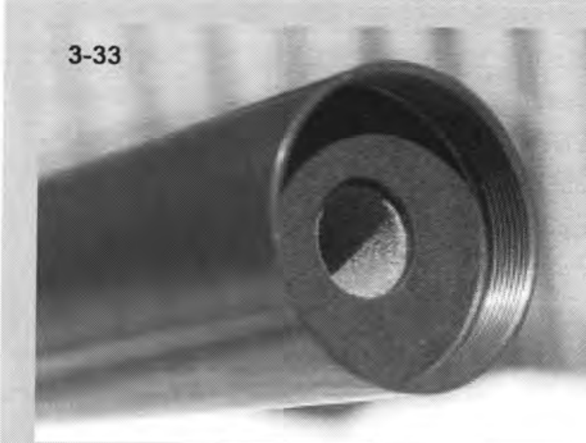
As indicated in the Aerotech instructions, it is not unusual to encounter significant resistance as the closure is threaded onto the case. If a slight gap remains between the shoulder of the closure and the case, that is OK. It is also not unusual to hear the grains rattle a bit with the motor sealed and loaded.

Loading the Ejection Charge

The final step in assembly is loading the ejection charge. The J350W has a two-second burn time. After the motor is ignited, the six fuel grains will be completely consumed in about two seconds. At ignition, the delay grain placed in the forward closure will also ignite, but it will burn at a much slower rate in accordance with the time set by the reload package (short, medium, or long). When the delay grain burns to the end, it will ignite the charge of black powder that is placed in the well of the forward closure.

The process to load the well is the same as shown for the well in Chapter 2. To load the well, stand the motor on its end with the well facing up. You will note that in the center of the well is a tiny hole. Fill the well with black powder to about ¾ full for rockets up to four inches in diameter, and all the way full for rockets larger than four inches in diameter. The black powder should be 4FFFF. Some of the powder will leak through the tiny hole in the center of the closure.

The reload kit will come with an adhesive sticker to seal the well. Place it over the well so that the black powder is completely sealed. Any leaks of black powder will diminish the ejection charge and could cause failure of ejection and the destruction of the rocket. So be sure that the well is properly sealed. If the sticker is not enough, use masking tape to seal the well. After the seal has been applied, with the aft end of the motor pointed toward the ground, gently shake the motor to ensure that some of the powder trickles into the hole in the ejection charge well.



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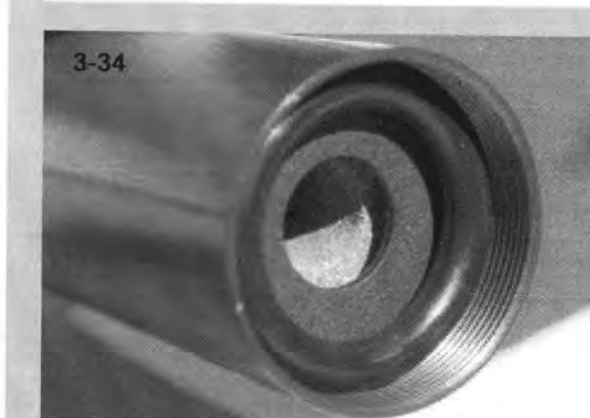

3-34

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3-36

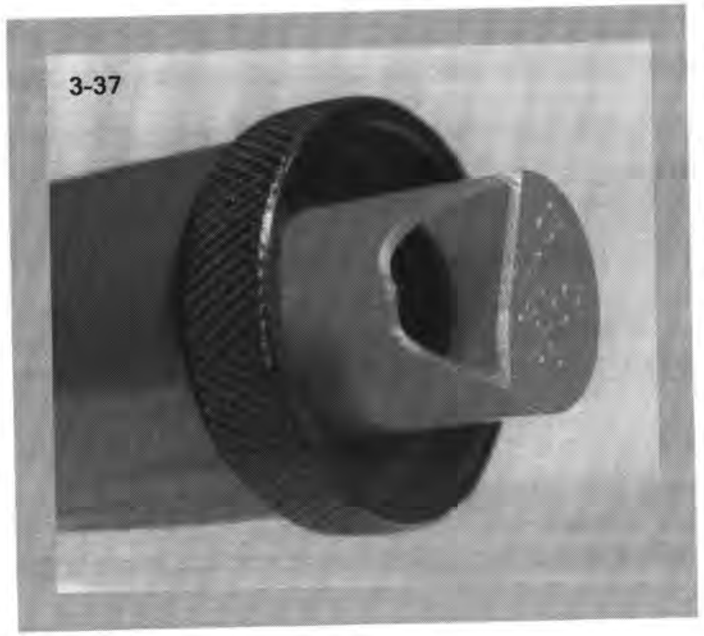
The J350W is now loaded and ready to go. Although is has more parts than the Cesaroni motor, the Aerotech reload does not take long to assemble. With a little practice, the motor can be put together in less than 10 minutes on the field.

Placing the Igniter in the Motor

Do not install an igniter in a high-power motor until the rocket is vertical and secure on the pad. The motor is loaded into the aft end of the rocket and should be secured to the rocket by means of positive motor retention.

The J350W can be ignited with most commercial igniters, and the kit usually comes with an Aerotech igniter. In any event, the kit will come with a red plastic cap that is used to secure the igniter in place while awaiting launch. Take a hobby knife, and slice a small vent in the cap. Then insert the igniter into the aft end of the motor, through the nozzle, all the way up the inner core, until the igniter cannot be advanced any farther.

3-37



Now, place the red plastic cap over the nozzle, securing the igniter wire in place. See photo 3-37 (without the igniter in place). If the cap is missing, a piece of masking tape will suffice. For more information on how to install igniters, see Chapter 5.

Animal Motor Works K570-WW

Animal Motor Works makes a wide range of excellent high-power motors in the 54mm, 75mm, and 98mm diameter range. For Level Two certification flights, the AMW K570 is a good choice. This motor has an average thrust of 570 newtons and a published burn time of just over three seconds. With nearly 1700 newton-seconds of total impulse, this high-power reload is comparable in price and performance to Aerotech's 54mm K550. Our reload kit ran about $100. This is more expensive than our first two examples–but keep in mind that the K570 is not a 38mm motor; it is a 54mm reload. As such, it has much more performance than the previous two reloads.

For example, the K570 can safely lift a much heavier rocket than the J285 and the J350 and still maintain a thrust-to-weight ratio of at least 5:1. If we divide the K570's average thrust of 570 by 4.45 we reach a pounds total of 128. Now divide 128 by 5. The answer is 25.6 pounds. This means that a K570 can safely lift a rocket weighing 25 pounds while still maintaining a 5:1 thrust-to-weight ratio.

There are some fundamental differences in the AMW motor and the reloadable motors produced by Cesaroni or Aerotech.

First, the AMW reloads do not use any type of motor-based ejection charge. On-board electronics must be used for deployment of the recovery system. Second, the aft closure on the AMW motor does not act as a thrust ring. The closure does not protrude beyond the edges of the case. So AMW uses a built-in snap ring on the reload case that functions as a thrust ring. Third, the reload case in the AMW motor is not threaded. The forward bulkhead and aft nozzle are secured with snap rings, which are easy to remove and install with an ordinary pair of snap-ring pliers.

Finally, the nozzle on the K570 is reusable. It is a graphite nozzle, and it comes with the motor case. It is not supplied in the reload package.

The Motor Case and Reload Kit

The motor case for the K570 is purchased separately from the reloadable motor package. The case will come with a forward bulkhead, two snap rings, and a steel nozzle washer that are all reusable. The case will also come with a reusable graphite nozzle.

The reload kit for the K570 comes complete with five 54mm fuel grains, two o-rings, and a phenolic motor liner. That's it. There's not much to double-check, and there's not much to misplace or lose. Still, as with all reloadable motors, be sure to compare the parts list that comes with the AMW K570 instructions to all the parts you receive in the reload. Also, review the instructions carefully before you assemble the motor. If you have any questions or concerns, check with your local dealer or directly with Animal Motor Works.

Installation of the Graphite Nozzle

Pick up the graphite nozzle. Be sure it is clean of any debris or dirt that may have remained after the last time it was used. Inspect it for any obvious signs of damage or cracks. Now take one of the two identical o-rings in the kit and place a light coat of grease on the o-ring. Place the greased o-ring into the groove on the graphite nozzle, as shown in photos 3-38 and 3-39.

Place a small amount of grease on the forward and aft end of the motor case. The aft end of the case is the end with the built-in snap ring around the outside. As mentioned above, this snap ring will serve as the thrust ring for the motor when it is installed in the rocket.

With the o-ring greased and the aft end of the case greased, pick up the nozzle assembly and, using a firm twisting motion, place the nozzle into the case, as shown in photo 3-40.

Push the nozzle into the case far enough so as to make visible the groove for the internal snap ring. See photo 3-41. With the nozzle installed, place the steel nozzle washer into the case so it abuts the nozzle, as illustrated in photo 3-42. Be sure the steel washer does not cover the snap-ring groove.

It is time to place the first snap ring. Using the

3-38

3-39

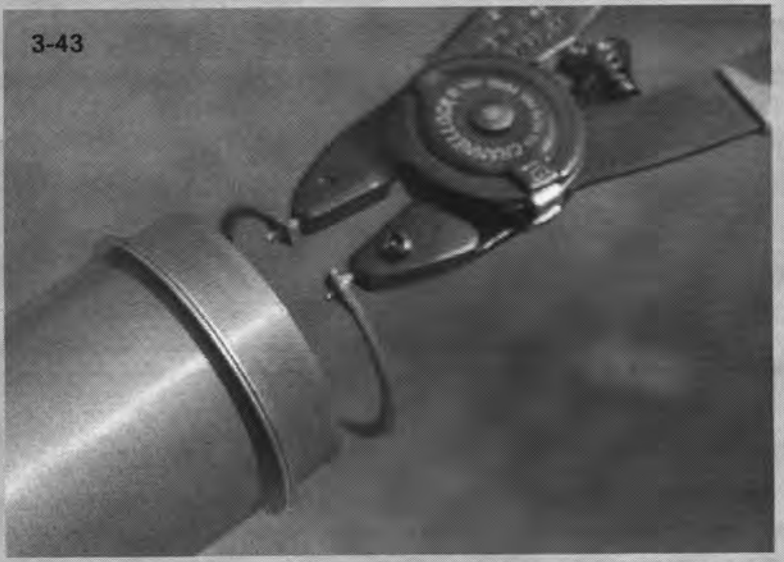
3-40

3-41

Snap RINGS

Animal Motor Works does not use threaded end caps or a threaded case to secure the fuel grains and motor liner in the case. Instead, AMW uses snap rings to hold everything in place. Inside either end of the case there is a groove, as shown in the photo at right. The groove will hold a snap ring. The snap ring keeps in place the forward bulkhead (above) or the aft nozzle (below). The snap ring is easy to install with snap-ring pliers, available at any hardware store or home-improvement store. The snap ring is reusable. It does not come in an AMW reload kit.

3-42



3-43

3-44

snap-ring pliers, carefully install the aft snap ring, as shown in photos 3-43 and 3-44.

The instructions from Animal Motor Works recommend using safety glasses when you install the snap ring with snap-ring pliers. This advice should always be followed. Snap rings can, during installation, spring out of place and can shoot upwards or in any direction. So always wear safety eyewear when placing or removing the rings. Once the snap ring is installed in the nozzle end of the case, set the case assembly aside for a moment.

Placing the Reload Grains

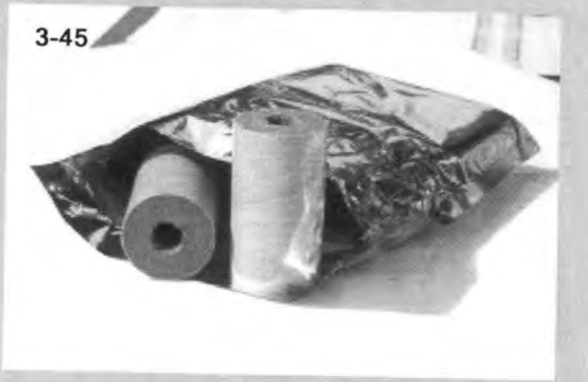
The K570 comes with five 54mm reload grains. The grains are packaged separately in a static protection bag. See photo 3-45. Open the bag and remove the grains. Place the grains, one at a time, into the phenolic motor liner. See photos 3-46 and 3-47. Once all five grains are installed, apply a light amount of grease to the outside of the liner. This coat of grease will help in disassembly and cleanup of the motor after flight. Now, pick up the motor-case assembly. Hold the case horizontal. Gently slide the motor liner (with the grains installed) into the open end of the motor case until it is fully seated against the nozzle assembly. See photo 3-48. Set this assembly aside for a moment.

Installing the Forward Bulkhead

The forward bulkhead has a groove in the middle for the remaining o-ring. Once again, lightly coat the o-ring with grease, and then install it onto the bulkhead. See photo 3-49. Take this assembly and once again using a twisting motion, install the bulkhead assembly into the forward end of the motor case until it is fully seated against the motor liner. See photo 3-50. When placed correctly, the bulkhead should reveal the snap ring groove on that end of the case, as illustrated in photo 3-51.

Once the bulkhead is in place, install the final snap ring, as shown in photo 3-52. Again, when using the snap-ring pliers, wear eye protection.

As these photos reveal, the forward bulkhead has a threaded hole on the outer end. This hole will accept a closed eyebolt. This threaded hole is used



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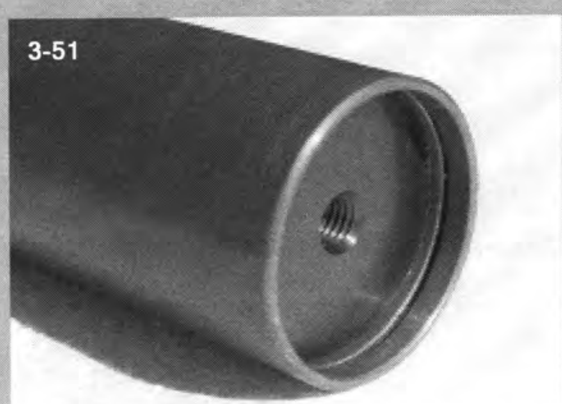
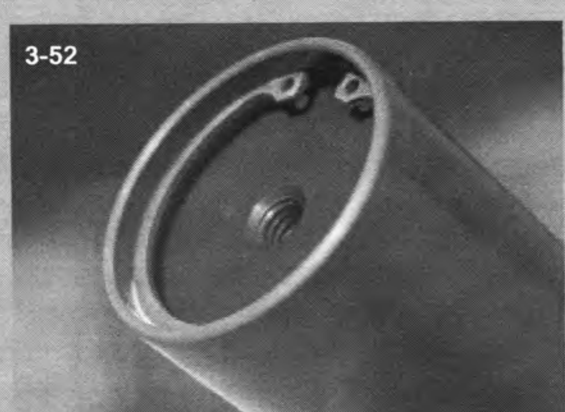
3-48


3-49


3-50


3-51


3-52

to install a bolt for removal of the forward bulkhead after flight. As illustrated in photo 3-53, it may also be used to attach an eyebolt for the recovery harness. This is particularly helpful in minimum-diameter rockets, where space inside the airframe is at a premium.

The igniter is placed in the K570 by inserting the pyrogen or electric match end first and running it all the way up the motor. As shown in photo 3-54, a piece of masking tape may be used to secure the igniter in place. Do not block the nozzle opening.

Flight of the K570 and Cleanup

That's it. The AMW K570 is now ready for installation in the rocket. With experience, this motor is easy to load, and the actual reload time takes only a few minutes. The K570 provides a nice white smoke trail as it climbs into the sky and produces enough performance for any Level Two rocket project.

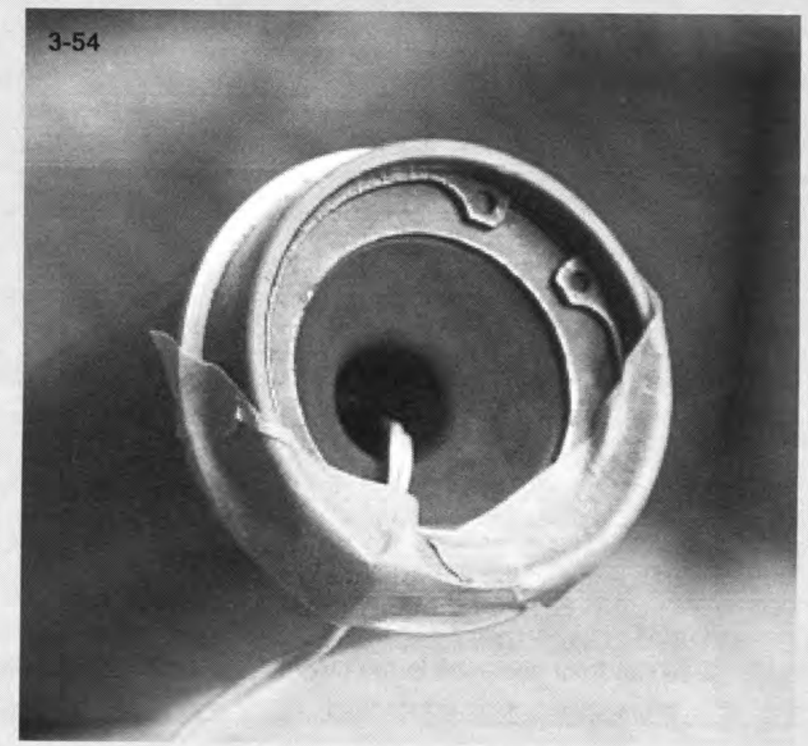
As for cleanup, AMW recommends cleaning the motor case within 24 hours after firing–a good rule for all high-power motor reloads. Be careful when removing the reusable graphite nozzle. Avoid dropping the nozzle on any hard surface as the graphite can become chipped. As explained in Chapter 17, Animal Motor Works suggests soaking the nozzle in water to aid in cleanup. When the nozzle is removed from the water, be sure to remove any debris from the throat of the nozzle. Discard the o-rings. They are not reuseable.

Conclusion

The Cesaroni Technology 684J285-15A, the Aerotech J350W, and the Animal Motor Works K570-WW (and similar motors) are excellent motors to use for Level Two certification. Additional Level Two motor makers include Ellis, Loki, Hypertek (hybrid), Kosdon, RATT Works (hybrid) and Sky Ripper (hybrid), among others.

For a complete list of approved motors, check the web sites of either Tripoli or NAR.


3-53


3-54

Why BOTHER

Motor retention is an important step in the construction of any high-power rocket. Yet it is often overlooked. Many kits do not come with a motor retention system. Some high-power rocket kits do not even mention motor retention. So why bother? Because: 1. At most high-power launches, a rocket without a reliable means of motor retention will not be allowed to launch. 2. Your rocket can be destroyed during flight without one. This chapter shows you how to construct a good system.

4

Motor Retention

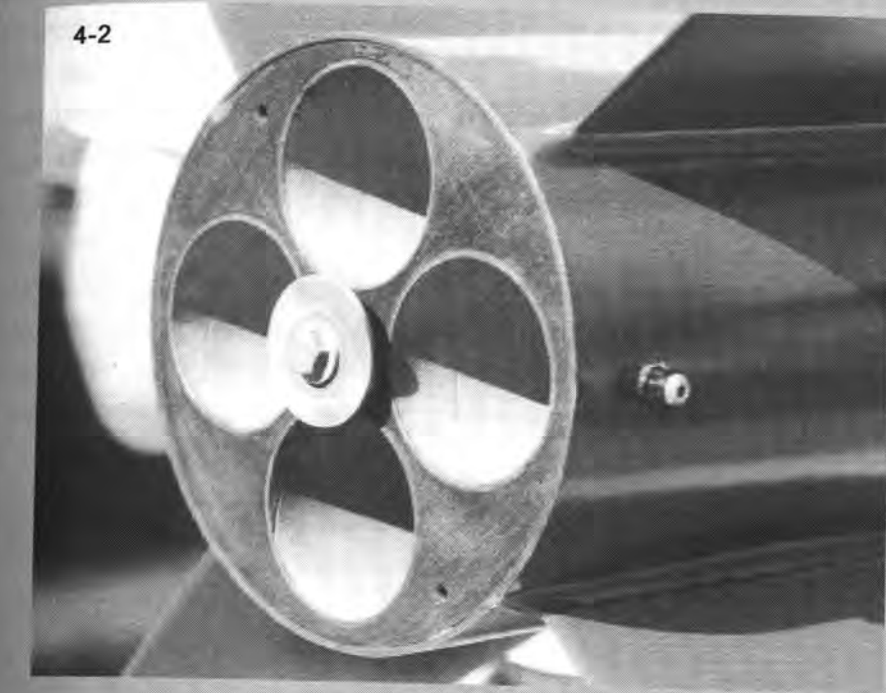
How to keep your high-power rocket motor where it belongs

At LDRS23 in New York in 2004, one large rocket had quite a memorable flight. This 11-foot-tall monster of a rocket weighed more than 100 pounds and was powered by a massive N motor. At ignition, the rocket roared into the blue sky, trailing smoke for several thousand feet before turning over at apogee and deploying (mistakenly) its main parachute. There was a sudden shout from someone in the crowd: "Something's falling!" Indeed, something was falling. It was the N motor. Somehow, the N motor casing had slipped out of the rocket and was plummeting to the ground.

4-1

Tumbling end over end for more than a thousand feet, the casing struck the soft ground several hundred yards from the launch pad, bounced high into the air, and then settled in the grass. Fortunately, the expensive N casing was found. Not all of them are.

The purpose of this chapter is to provide examples of some of the basic methods of motor retention used in high-power rocketry. This chapter will also examine the related topic of motor adapters, which allow different diameter rocket motors to be used in the same rocket. Motor adapters allow rocketeers more flexibility for motors on launch day.


4-2

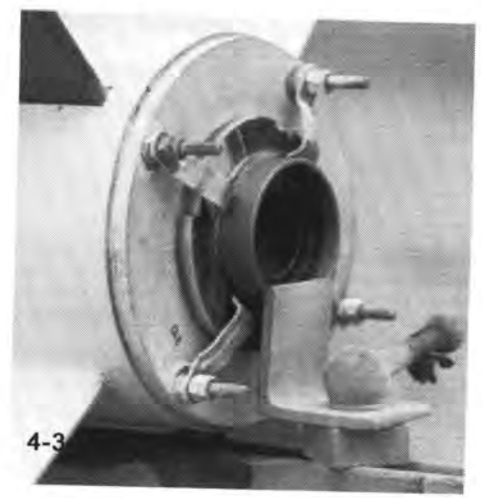
Motor retention in high-power rocketry can come in many different forms and can be as simple as a single bolt and washer, left, or a complex system of nuts and bolts, below.

The Need for Motor Retention

In high-power rocketry, the rocket motor must remain in the airframe between the moment of ignition and the conclusion of recovery. This is so for at least two reasons. First, reloadable casings are expensive. If the casing is dislodged during flight, the motor will fall out and never be seen again; that portion of the rocketeer's investment in the hobby will also disappear. Second, motor retention ensures the safe return of the entire rocket.

If a high-power rocket is using motor-based ejection charges (black-powder charges located in the forward closure of the motor) insufficient motor retention will result in the motor being ejected out the aft end of the rocket when the ejection charge is fired. Not only will the motor be lost, but the rocket may not separate due to insufficient forward pressure in the airframe. The rocket's recovery harness will not deploy, and the rocket will return to the ground as what is commonly called a lawn dart because it strikes the ground nose first at high speed.

Fortunately, quality motor-retention systems are simple to create and easy to install–even in rockets that have already been built. Motor retention systems may be purchased in prepackaged kits from rocketry outlets or scratch-built with components available at most hardware and home-improvement stores.


4-3

Using Masking Tape

Most high-power rocketeers began their experience in rocketry with model-rocket kits. In model rocketry, motor retention is simple and effective. The typical model rocket motor mount has a built-in, flexible metal clip that is attached to the motor-mount tube. This clip can be moved out of the way when the motor is inserted into the rocket. After the motor is secured, the metal clip springs back into place and protrudes slightly over the aft end of the motor. This holds the motor in place and prevents the motor from being kicked out of the rocket when the motor's ejection charge is fired. At the forward end of the motor mount is a thrust ring, which prevents the motor from shooting straight through the rocket.

The mechanics of motor retention found in model rocketry are the same for high-power rocketry.

Many people begin their experience in high-power rocketry launching rockets equipped with single-use motors in the E, F and G range. Since these motors have a total impulse of less than 160 newton-seconds, they are technically not considered high-power, but they provide the rocketeer with lots of high-power excitement, especially when used in lightweight rockets or when combined in clusters. Typically, a single-use motor contains a built-in ejection charge in the forward end of the motor that is preset to ignite at a specific moment after motor burnout. This time interval is usually set at the factory between six and sixteen seconds. As noted in Chapter 1, the time of the charge is usually stamped directly on the motor.

4-4

4-5

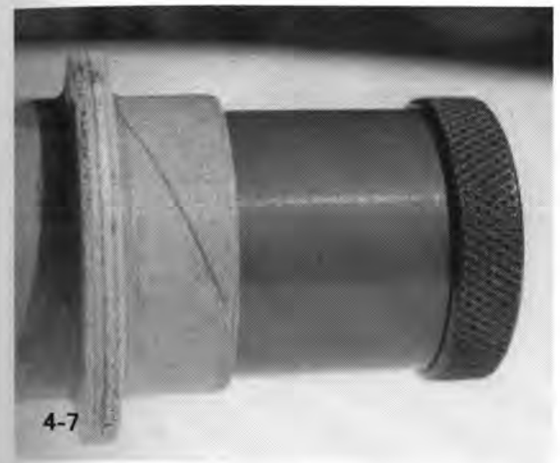
4-6

Masking tape is sufficient for motor retention with most low-impulse single-use motors. Be sure the fit is more than snug. It should be tight enough to make removal difficult, but not impossible.

Most single-use motors are secured in the rocket motor mount with masking tape. As illustrated in photos 4-4 through 4-6, masking tape is wrapped around the body of the motor and the motor is then squeezed or friction fit into the rocket's motor tube. The masking tape in these rockets serves the same purpose as the motor retention clip and forward thrust ring in model rockets. The tape also serves as a thrust ring because it prevents the motor from shooting up through the motor tube and out of the rocket body. The masking tape ensures that the motor will remain with the rocket throughout the flight–preventing the ejection charge from forcing it out.

There is more than one way to effectively secure a single-use motor in the motor tube with tape. Some people place large amounts of tape around the aft end of the motor so it is impossible for the motor to move forward during the thrust phase of the launch. However, this method may still allow the motor to be ejected backward when the black powder charge is fired. Other people wrap tape around the middle of the motor and then carefully force the motor into the motor mount. This is the better way.

In either event, if you are using masking tape, start with a little tape at a time. Wrap the middle of the motor once and place it into the motor tube. If the motor is too loose, place another wrap around the middle. The goal is to make the fit snug to tight. If the motor is loose, it may fall out or be ejected out from rocket. So err on the side of using too much tape. If the motor is stuck in the motor tube after flight, take a broom handle or similar pole and carefully knock it out of the rocket from the forward end of the tube.



4-7

4-8

The aft closure on many reloadable motors acts as a thrust ring, preventing the motor from moving through the airframe upon ignition.

The use of tape as a means of motor retention is good for small rockets with single-use motors and will usually suffice if there is no other means of motor retention built into the rocket. However, once a rocketeer graduates to high-power reloadable motors, there are better alternatives.

Moving up to Positive Motor Retention

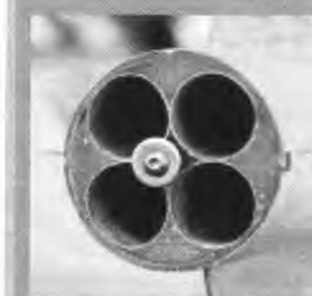
On many reloadable motors, the aft (or nozzle) end of the motor case is larger than the motor tube. The lip on the motor casing acts as a thrust ring and prevents the motor from launching through the rocket on ignition. See photos 4-7 and 4-8. However, there is nothing to prevent the motor from being kicked out the aft end of the rocket at the moment of motor ejection. To solve this problem, most people will install some means of positive motor retention.

Positive motor retention describes a system of retention that is built into the rocket. Unlike masking tape, this type of retention is used over and over again. It forcibly retains the reload casing in the rocket for the duration of the launch, flight, and recovery.

As illustrated by the photos at

The DESIGN

The basic construction concepts may vary, but most motor retention systems are easy to install in the average high-power rocket. This is especially true if the retention system is installed while the rocket is being built. In most systems, the aft end of the rocket is equipped with some type of clamp or flat washer that can be secured onto the motor casing's aft closure. The clamp, secured with a screw, or bolt, holds the motor snugly in the motor mount tube for the duration of flight.



the end of this chapter, positive motor retention can be accomplished in many ways. It is interesting at any local, regional, or national launch to walk along the flight line observing the many ways people devise motor retention systems. This is an excellent way to learn new methods and ask questions of more experienced rocketeers.

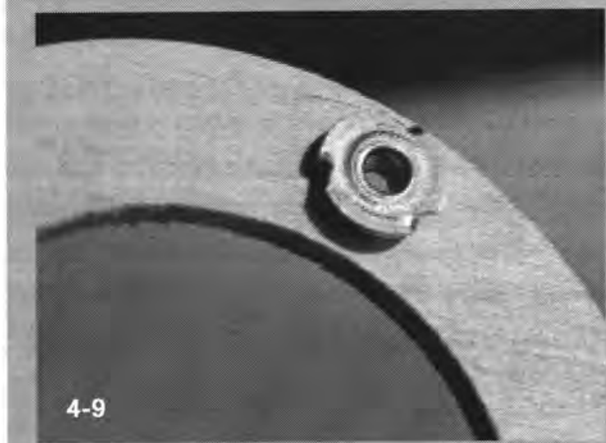
Building a Sample System with Clamps

The retention system in our first example is built into a Loc High-Tech H45 (the same rocket discussed in Chapter 11). The H45 is a good rocket that can handle up to a 38mm motor. But the rocket kit does not come with any means of motor retention.

In this example, blind nuts, motor-retention screws, and clamps will be added to the main centering ring that fits into the aft end of the rocket and onto the motor tube. The centering ring is the stock 3/8" ring supplied in the kit. (In lieu of using the factory rings, you might also consider cutting a ring out of G-10 fiberglass, which is much stronger than wood and may be easier to work with when installing the retention system used here. G-10 is a grade of fiberglass that is often used for fins on high-power rockets. It is a laminate made of fiberglass cloth set in epoxy resin. It is also an excellent material for centering rings and electronics back plates. It is possible to drill holes in a sheet of G-10 along the edge of the material without cracking or splintering the plate.)

The system is based on two 4/40" blind nuts installed in the aft ring. Blind nuts are sometimes referred to as T-nuts and are available at hardware and hobby stores. They can be purchased in small packages that contain almost everything needed for motor retention. They also come in many sizes, so they can be used for motors of all sizes in all types of rockets.

The first step in construction is to drill two small pilot holes in the centering ring. The holes should be 180 degrees apart. In our retention example, a standard 9/64" drill bit was run all the way through the centering ring, allowing the blind nut to fit perfectly in the hole. There is little room for error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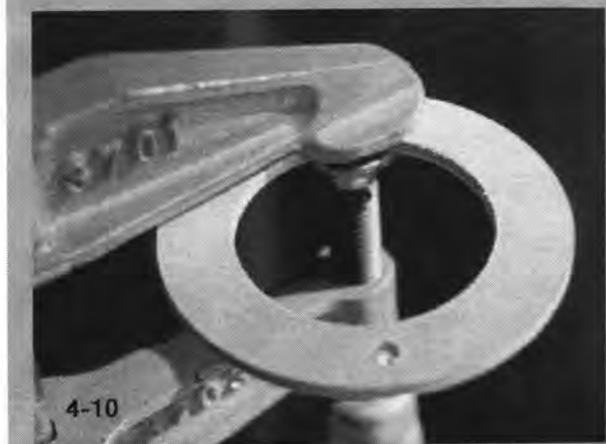

4-10


4-11


4-12

with centering rings that are so narrow. So if you have access to a drill press, use it for this task. With any drill, be sure that the centering ring is firmly attached to a sturdy block of wood so that the drill bit cuts right through the ring without cracking or splintering the ring itself.

Test-fit the nut into the drilled holes in the centering ring. See photo 4-9. If the nut extends beyond the edge of the ring, remove any excess with a grinder. As shown in photo 4-10, a clamp was used to secure the nut in place.

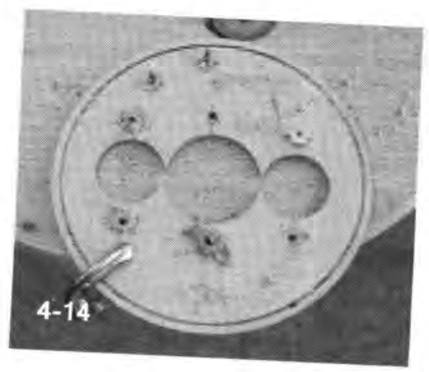

4-13

Epoxy is then applied carefully around the edges of the nut, taking care not to get any epoxy on the inside threads. Consider filling the center of the blind nut with a tiny dab of grease. The grease will help prevent any epoxy from inadvertently leaking and sticking to the threads of the nut. Once the grease is applied, insert a machine screw into the nut. Then, carefully apply small amounts of epoxy to the edges. After the epoxy has dried, try to remove the machine screw. It should come out easily if it is free of epoxy.

That's it for installation. In less than an hour a sturdy motor retention system has been added to this rocket with a minimum of effort and very little cost. See photo 4-11. On launch day, clamps or washers are added to the screws to keep the motor in place. As illustrated in photos 4-12 and 4-13, small pieces of brass or copper tubing can be used as stand-offs for the clamps to secure the motor to the centering ring. The choice of clamps is up to the rocketeer. The clamps used in this example were obtained from Giant Leap Rocketry. They are easy to use on launch day and do a good job of securing the motor.

Photos 4-14 through 4-16 illustrate the same basic retention design, but on a much larger rocket. These photos show the aft end of a LOC Bruiser EXP. The EXP is a 7.51" diameter rocket with three motors, a central 54mm mount and two outboard 38mm mounts. Each motor will need motor retention.

As illustrated, holes were drilled in the aft centering ring for each motor, two pilot holes per motor. It is possible to use just one hole and one clamp for each motor. However, with so much room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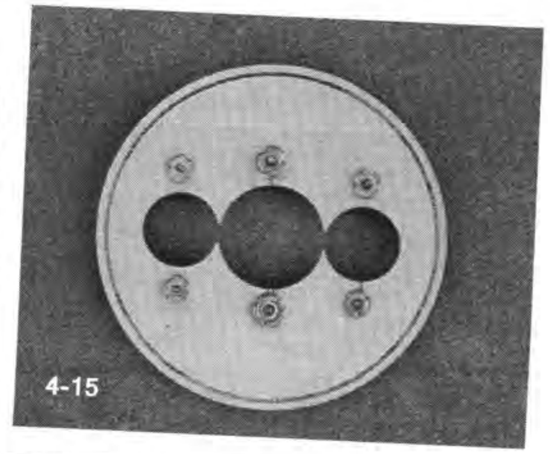
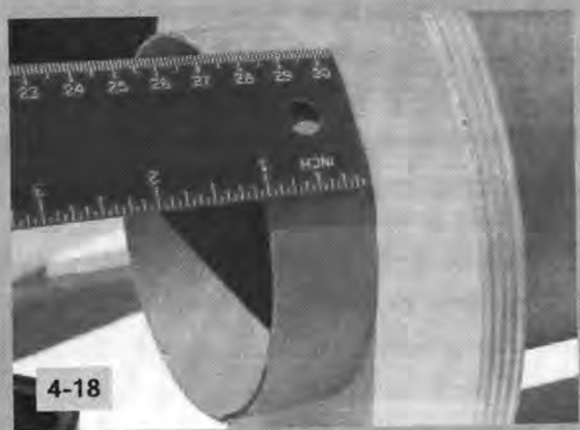

4-15


4-16

This 7.51" aft ring on a LOC Bruiser EXP was drilled for clamps to retain a pair of Aerotech 38mm J350s and an Aerotech 54mm K700.


4-17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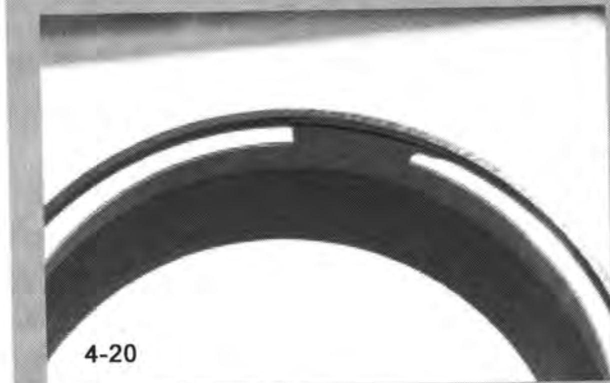
4-19


4-20

on the aft ring, two holes make more sense because they provide extra protection in the event one of the blind nuts is damaged or falls out after repeated use.

Retaining Rings

Another method of motor retention is the use of a retaining ring. This method has been popularized by the Slimline motor retainers (available through rocketry outlets such as Giant Leap Rocketry) and Aero Pack motor retainers.

The original Slimline system featured a stainless-steel retaining ring that secured the motor in place in the rocket, without special tools, and was easily installed and removed. See photo 4-17.

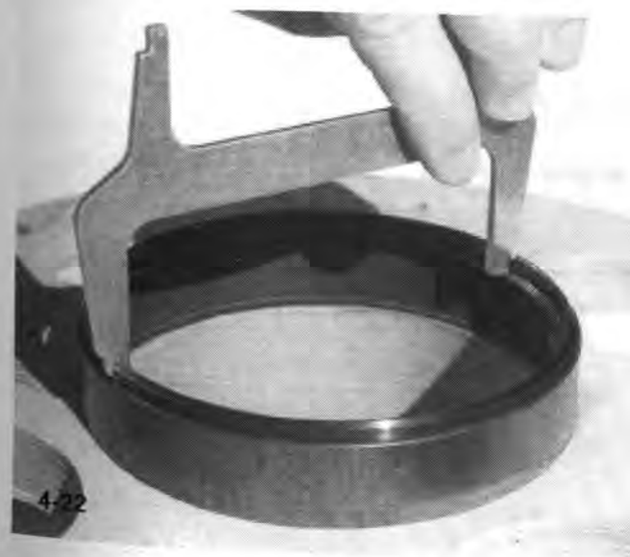
In our example, we will be using the Slimline to secure a 98mm Aerotech M1419 reloadable motor. The casing for this motor is the 98/7680. The diameter of the rocket is 7.5 inches. The motor retainer will be attached to the motor tube with JB Weld, available at automotive and hardware stores.

The first step was to do some test-fitting. The 98/7680 motor case was placed into the motor tube. The centering ring should float freely at this time–it is not yet attached to the motor tube with epoxy. Next, place the Slimline cylindrical aluminum sleeve over the motor and that portion of the motor tube that extends beyond the aft centering ring. Place the retaining ring into the groove on the sleeve. If the space between the ring and the motor case is too large or too small, simply slide the aft centering ring forward (or aft) along the motor tube. The fit of the motor in the tube should be snug. It should not rattle around or move too much with the ring installed.

In our example, we found that the best fit was accomplished with the motor tube sticking out about one inch beyond the aft centering ring. See photo 4-18. Once the fit was found satisfactory, we placed a mark on the motor-mount tube and then removed the sleeve. It was time to apply the JB Weld. Being careful not to get any of the adhesive on the groove of the sleeve, we applied JB Weld to the outside of the phenolic motor tube, and the aluminum sleeve was then reattached to the end of the tube. See

photo 4-19. To insert the motor, remove the ring and place the motor all the way into the tube. Then place the ring on the sleeve again. The motor should be held in place. See photo 4-21.


4-21


4-22

Top: The original Slimline retaining ring which snapped into place. **Above:** The newer ring threads into place.

In 2004 the Slimline system was revised. Now, instead of a retaining snap-type ring (photos 4-20 and 4-21), the system uses a threaded ring that screws into the aluminum sleeve to secure the motor. See photo 4-22 for an example of the new system.

Aero Pack International's Quick Change Motor Retainers are another means by which motors can be secured with a retaining ring. Aero Pack's products can be found on rockets at every large launch in the country. They provide for a quick and easy way to install and remove motors from a high-power rocket. These retainers can also be used in clusters. In the five-motor cluster shown below, right, only the central motor has an Aero Pack retainer.

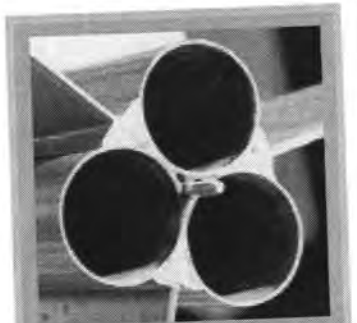
Note that the flange is threaded on the outside. Those threads accept a cap that is threaded onto the flange after the motor is placed into the motor tube. The cap secures the motor in place for fight.

The Use of Motor Adapters

When a high-power rocket is constructed, a motor tube of a specific diameter is selected and permanently affixed in the rocket. If the motor tube is 54mm in diameter, the rocket can hold 54mm motors. If the motor tube is 98mm in diameter, it can hold 98mm motors, and so on. Can the user ever fly the rocket with a motor that is smaller than the motor tube? The answer is yes–with a motor adapter.

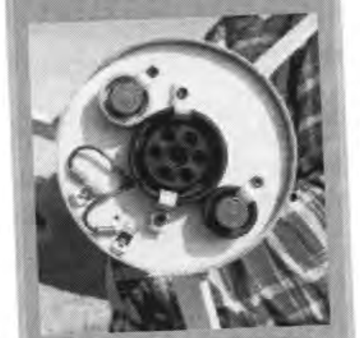
Quick CHANGE

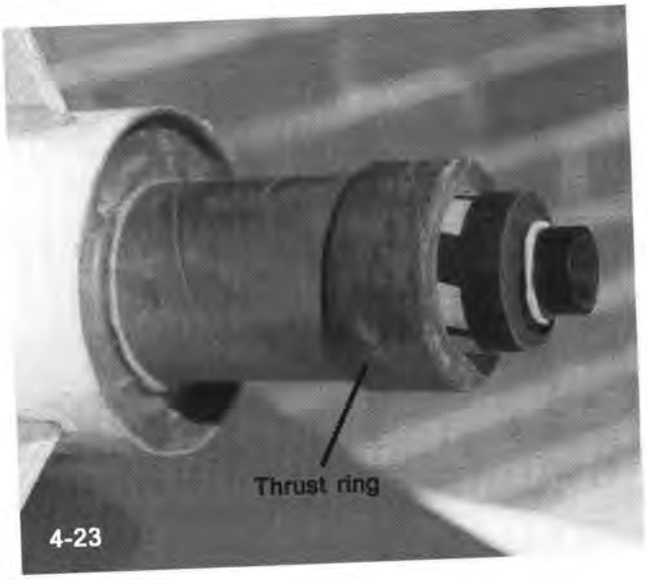
Another popular motor retention device is Aero Pack's Quick Change motor retainer. These retainers have a threaded metallic flange that is attached with screws directly to the aft centering ring. The threads on the flange accept a threaded cap, shown above. The motor is placed into the tube, the cap is threaded on, and the motor is secure. Aero Pack makes motor adapters for most popular high-power motor-tube diameters. It is a quick way to change from one motor to another.



Three RULES

Well-designed motor-retention systems have at least three elements in common. First, they secure the motor in place during flight and recovery. Second, they are easy to use on launch day, with only a minimum of effort in the field. Third, they are constructed to minimize or even eliminate any interference with the motor's exhaust nozzle, which must be kept free of any obstacles. If you combine these three criteria, you will be on the road to success in high power.





4-23

This simple motor adapter allows a 29mm single-use G motor to be used in a 38mm motor mount. The adapter is created from reinforced phenolic tubing, and has its own thrust ring. It sells for about $20 and is reusable.

Motor adapters allow rocketeers to use motors that are smaller than the rocket's motor-tube size. The adapter fits into the main motor tube, reducing the tube's diameter to accommodate smaller-diameter high-power rocket motors.

For example, a 54mm motor mount may be reduced using an adapter to hold 38mm and 29mm motors. A 98mm motor can be reduced to hold 75mm or 54mm motors.


4-24

The great advantage of having a motor adapter is that it provides the rocketeer with a greater selection of motors to use in any given rocket. A rocket can fly on one launch day with a 54mm K185. On another launch day, and with the use of an adapter, the same rocket can fly with a 38mm J285. Instead of being limited to several 54mm motors, the rocket can be flown on a dozen different motors with the motor adapter.

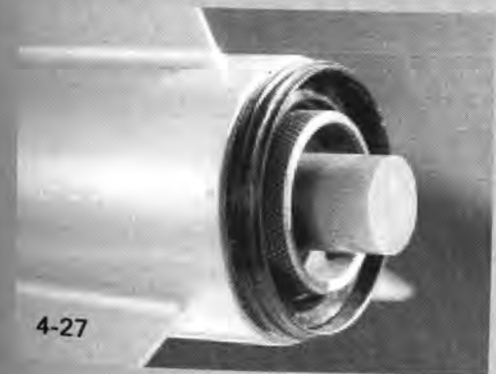
Motor adapters can be purchased as a kit, or they can be scratch-built. The most basic motor adapter is illustrated in photo 4-23. This common adapter is made from phenolic tubing and can be purchased from rocketry stores and dealers for less than $20. The adapter allows the user to reduce a main motor tube from a size of 38mm to 29mm in diameter.

The adapter simply slides into the main motor tube. It can be friction fit, or secured with positive motor retention. Similar adapters are available for larger motor tube sizes as well.

Motor ADAPTERS


4-25


4-26


4-27


4-28

As illustrated in photos 4-24 through 4-28, Aero Pack also produces adapters for their motor retainers, which allow rocketeers to quickly reduce the size of the motor they wish to fly in a rocket already equipped with an Aero Pack system. In the photos, a 38mm adapter is placed into a rocket motor-tube assembly that was fitted with the 54mm system. With the adapter, the rocket can launch on not only 54mm motors but also 38mm motors. Slimline makes similar adapter systems.

Other manufacturers use similar systems to vary the size of the motor inserted into a rocket. For example, Public Missiles uses their "Kwik Switch" system to vary the motor in a given rocket between the sizes of 54mm/75mm/98mm and between 29mm/38mm/54mm.

As illustrated in photo 4-29, the Public Missiles adapters use interlocking tabs on one end, which fit into a plastic coupler in the main tube, called the mother tube. The smaller adapters have a threaded plastic collar on the forward end, which is screwed into the main tube. With the Kwik Switch adapter, the rocketeer picks the motor size he or she wishes to launch with and then inserts the appropriate adapter tube into the main tube. With a simple twisting motion, the adapter tube locks into place. Public Missiles makes these adapters for almost every size, all the way up to 98mm.

Motor adapters can also be scratch-built. Photos 4-30 and 4-31 show a simple system built by NAR member Mike Sccichitano on his Skunk Works 10-inch-diameter Bullpup.

In this example, the main motor tube is 98mm in diameter. On the rear centering ring, four holes were drilled to accept a flange which is mounted on a separate 75mm motor tube. As shown in photo 4-30, the 75mm tube has three additional centering rings along the length of the tube. The entire adapter slides into the 98mm main tube. The three centering rings placed along the length of the adapter keep everything lined up as the adapter slides into the tube. The aft ring on the adapter is then secured to the rocket with screws that run

More Choice

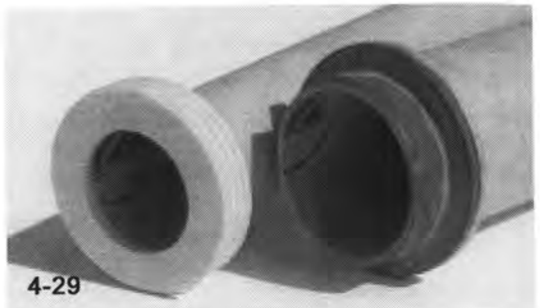
The great advantage in building a rocket with a motor adapter is that it provides you with a larger selection of motors in a single rocket. A rocket can fly one day on an Aerotech 54mm K185 and on the next day with a Cesaroni Pro 38 or perhaps even a Kosdon 29mm motor. Instead of being limited to just 54mm motors, the rocket can now fly on dozens of motors in various power (and price) ranges. Some adapters, like the Slimline unit below, may also function as a motor retainer.

through the drilled holes in the aft centering ring on the rocket. This system worked well when the rocket was flown on a 75mm Animal Motor Works M1850 for a successful Level Three certification flight at the Freedom Launch in Orangeburg in 2003. The rocket can also be flown on 98mm motors without using the adapter.

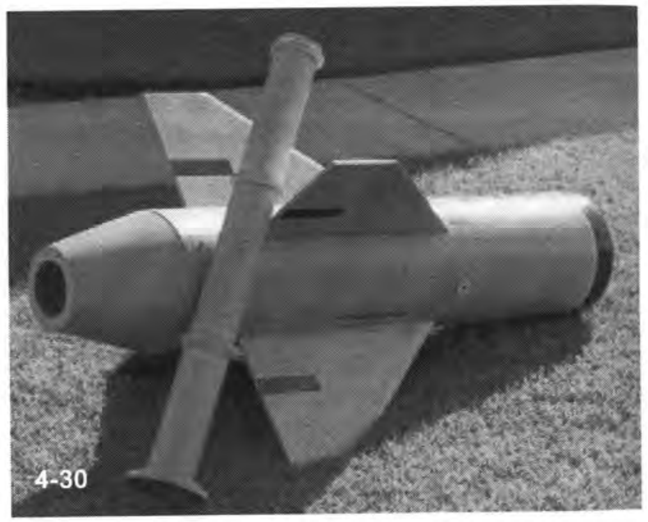
Another adapter is shown in photos 4-32 through 4-34. In this example, built by Tripoli member Jerry O'Sullivan for his 180-pound Nike Smoke, the main motor tube is large enough to handle a 6-inch O motor. But it can also hold a number of other motor configurations, including the three 75mm M motors shown in the photograph.

The motor assembly for the three M motors slides into the aft end of the rocket and is secured in place with screws (you will note in the photograph of the removable housing that individual motor tubes were not used–the three motors simply slide through the centering rings). A number of motor configurations may be used with this type of setup.

If you use a motor adapter, keep in mind that you still need to create a motor retention system. The adapter simply increases the selection of motors available for the rocket. It does not hold the motors in place during flight and recovery. Most adapter systems can be used with the motor retention systems discussed in this chapter.



4-29



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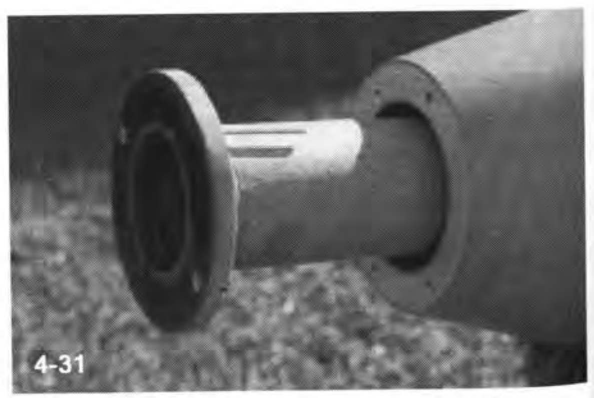


4-31

Top: The forward and aft ends of a PML "Kwik-Change" motor adapter. Above: Two pictures of a homemade adapter that allows the flyer to use either a 75mm or a 98mm high-power motor.

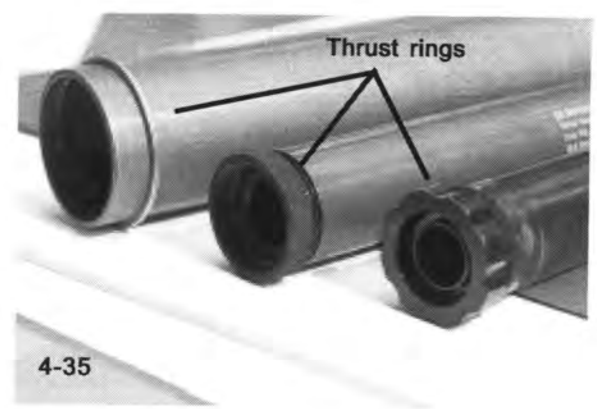
4-32

4-33

Conclusion

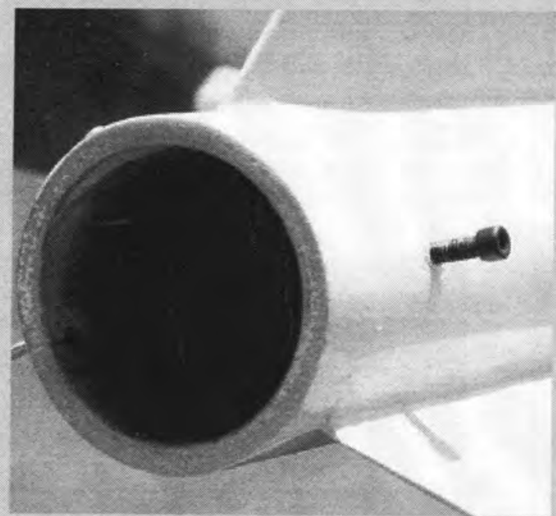
Motor retention is an essential step in high-power rocketry. As illustrated in the photos on the following two pages, there are many ways to accomplish quality motor retention. Plan on building your own system during the construction phase of your high-power rocket, and you will find the process easy and inexpensive.

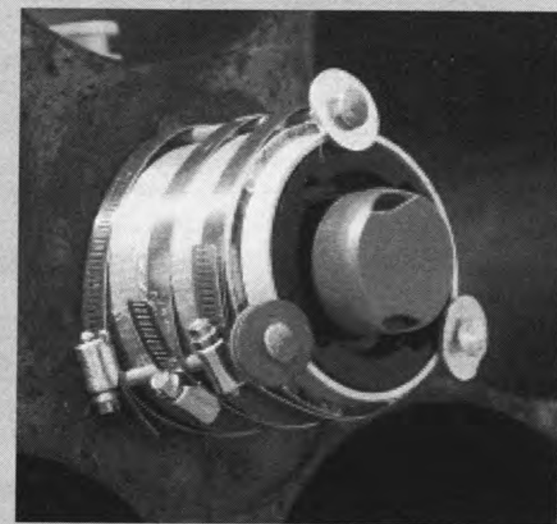
4-34

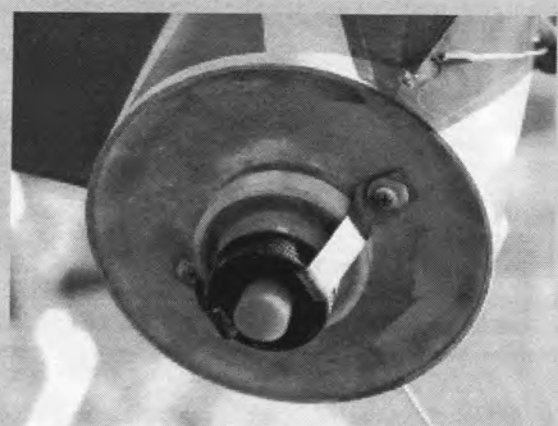


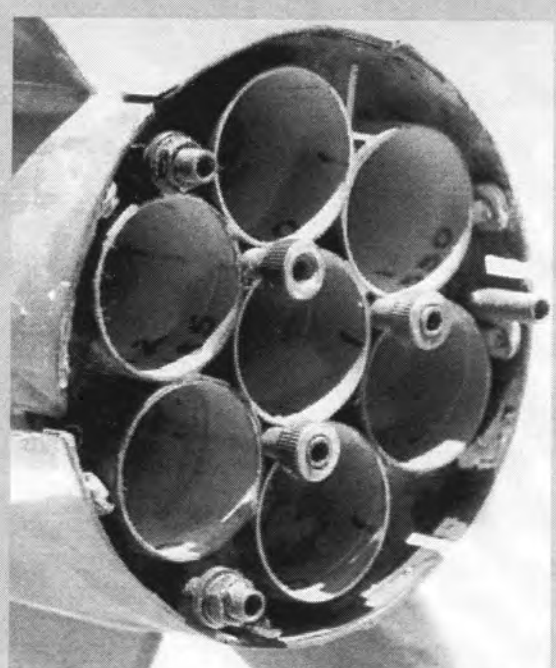
4-35

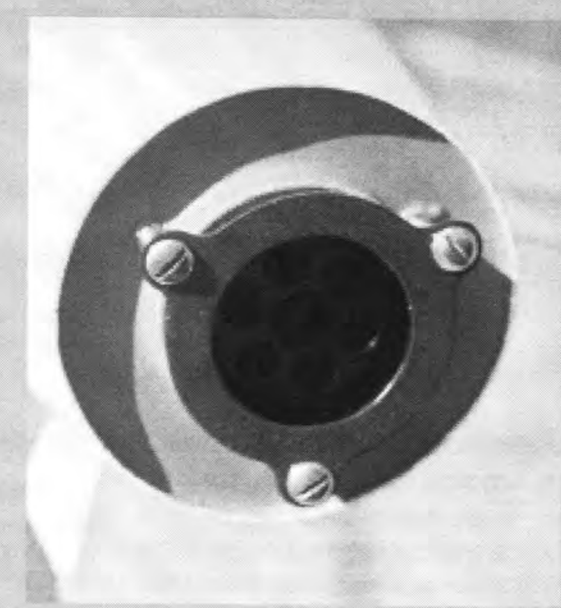
Photo 4-35 (from left to right): Animal Motor Works, Aerotech, and Cesaroni Technology reloadable motor casings. Note that the Aerotech and Cesaroni casings have threaded closures that serve as thrust rings. There is no threaded closure on the AMW motor. The thrust ring on the AMW motor is a snap ring around the outside of the case.

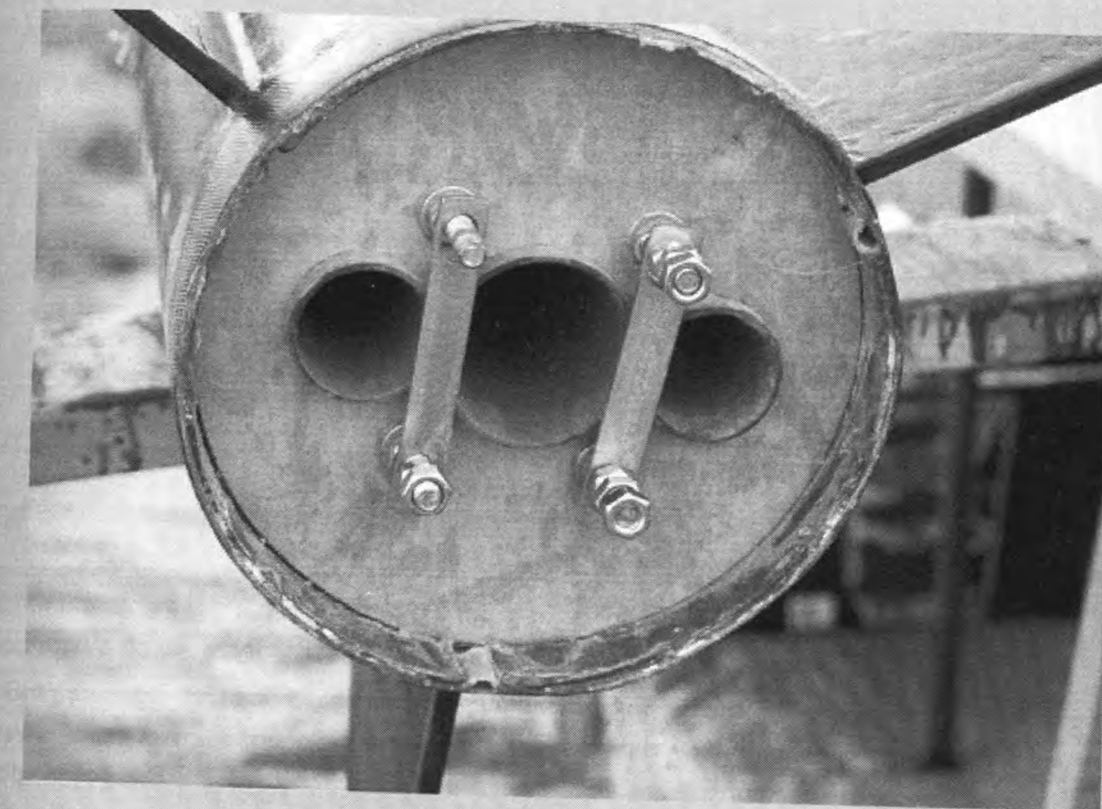


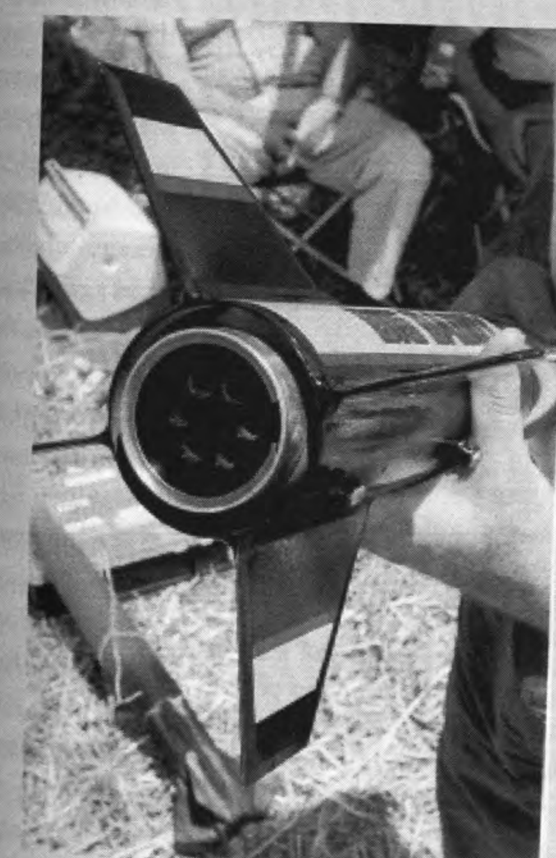


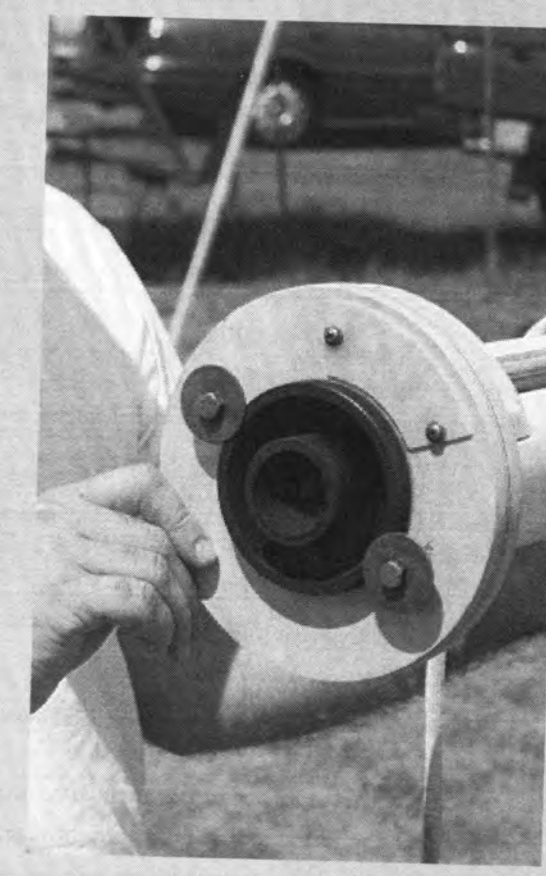


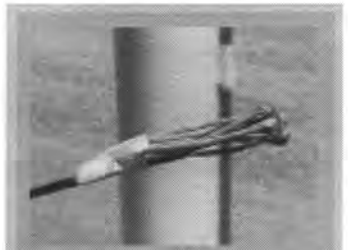












The IGNITER

The typical igniter or electric match costs a dollar or two and is good for one launch. Igniters are also used for on-board ejection charges. Igniters usually come with a length of wire lead that can be up to several feet long. The extra length is cut to size to fit the needs of the particular rocket or ejection system. Some single-use and reloadable motors come without an igniter. However, this varies with each motor maker. So it is best to always have several spare igniters in your rocketry tool box, in case your motor comes without one.

5

High-Power Igniters

The least expensive part of your rocket is also one of the most important

High-power rocket motors are ignited in the same manner as model rocket motors, electrically, by a device known as an igniter. Most igniters are made of fine fusible wire embedded in a flammable igniter head. Two wire leads, several feet long, are attached to the igniter head. In some cases, the flammable head itself conducts electricity and no fusible wire junction is needed. The head of the igniter is typically made of a flammable chemical mixture. When electrical current passes through the wires, the heat generated causes the head to burn, which in turn causes the heat and flame necessary to set off a high-power motor.

5-1

Igniters are inserted all the way into the motor on the pad. They are then connected to alligator clips which run to the launch control box.

The purpose of this chapter is to discuss the basic types of igniters used in high-power rocketry and to provide general guidelines regarding their use on the field.

Igniters and Electric Matches

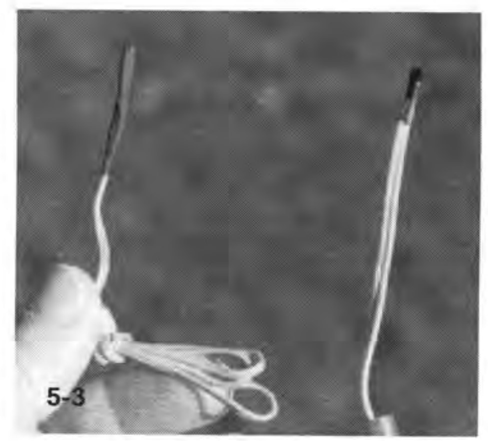
There are two types of electrical devices used in high power to ignite a motor. One is called an electric match and the other is called an igniter. An electric match and an igniter look almost the

5-2

This igniter has been augmented with a sliver of Aerotech Blue Thunder propellant to produce a much hotter and larger flame. This modification is useful when using large Level Two or Level Three motors. All igniters produce a hot spark and should be used with caution.

same. But generally, the head of an electric match is smaller than the head of an igniter and has a smooth, almost polished, finish. See photo 5-3. The electric match produces a brief spark, almost a pop, on ignition. This spark is enough to light many, but not all, high-power motors. Electric matches are also used to activate ejection charges in the rocket.

A traditional igniter produces not only a spark, but also a brief hot flame. The igniter head is often coated with a flammable substance called pyrogen, which gives it a dull, gray appearance. See photo 5-3. An igniter not only looks different from an electric match, but it also may have different voltage requirements.



5-3

An igniter, left, and an electric match.

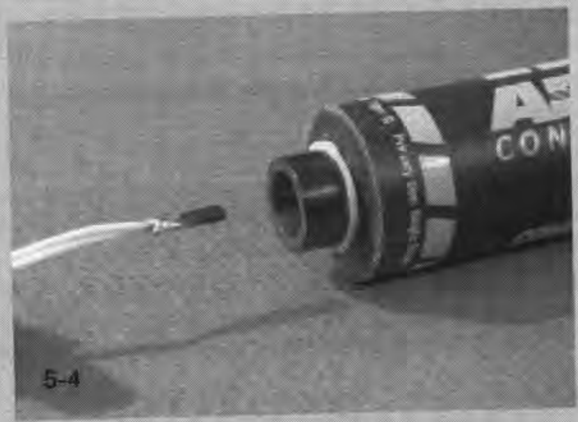
Many traditional igniters require more than a 9-volt battery. That is why igniters are used more often for motor ignition and electric matches are used more often for black-powder charges. The average club launch system operates on at least 12 volts and is usually enough for any traditional igniter. Most electric matches require only 9 volts to light an ejection charge. Still, some electric matches can be used to launch many motors, up though the H, I, or even J range.

Despite these differences, on the launch field, electric matches and traditional igniters are usually just called igniters.

Installation of the Igniter into the Motor

The primary requirement for a high-power igniter is that it transfer enough heat to the motor's propellant to induce ignition of the fuel grains. In order to effectively transfer that heat, the igniter must be placed into the motor.

The installation of an igniter in a high-power rocket motor is similar for almost all applications. The head of the igniter is pushed through the aft end of the motor nozzle and into the motor as far as the igniter will travel. See photos 5-4 and 5-5. In most core-burning motors, this means that the head of the igniter travels the entire length of the core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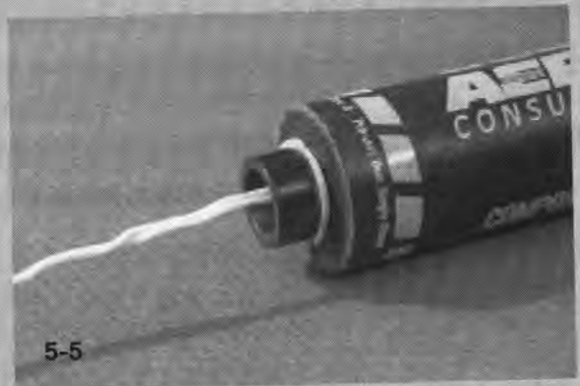
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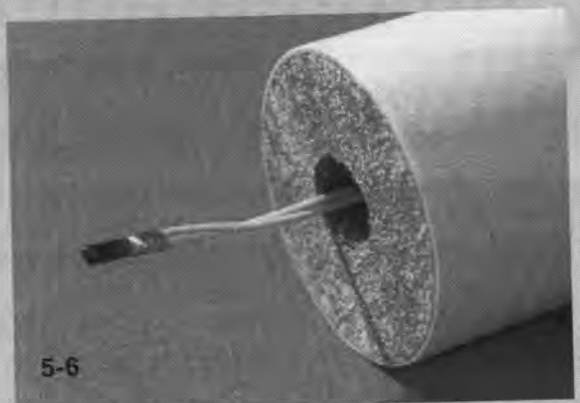
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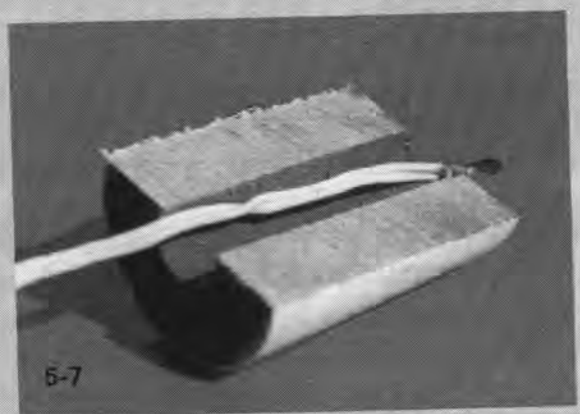
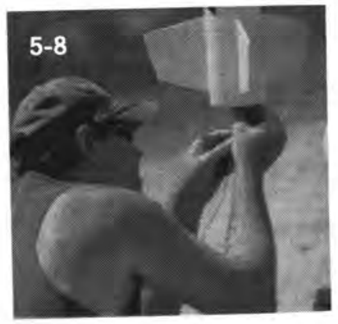

5-7

until it bumps into the delay grain at the forward end of the motor, as illustrated in Diagram 5-1. Photos 5-6 and 5-7 show a single fuel grain and a fuel grain that has been cut in half to illustrate how an igniter sits in the grain. Note how the igniter fits in the core. In motors with multiple fuel grains, such as an Animal Motor Works 54mm K570, the igniter passes through as many as five fuel grains before it reaches the top of the motor.

In some motors, it is important that the head of the igniter actually touches the fuel grain at the top of the motor core. To help ensure that this occurs, some rocketeers will bend over the top inch or so of the igniter wire before it is inserted into the motor core. This bend in the line helps keep the igniter head in close proximity within, or touching, the fuel grains.


5-8

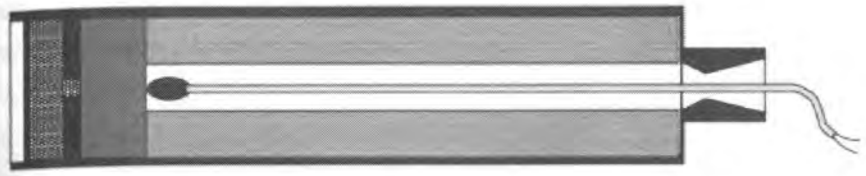
Once the igniter is inserted all the way into the motor, it is then secured to the motor nozzle. This is done with a piece of masking tape, a plastic cap, or other devise. Be sure not to completely block the exhaust nozzle with the tape or cap. (For a view of the cap on an H motor, see photos 2-32 and 2-34.)

Do not underestimate the importance of securing the igniter to the motor. If the igniter is not secured, it can easily be dislodged, even by a slight wind, while the rocket awaits its turn on the launch pad. If the igniter is dislodged by the wind, it can fall out of the motor entirely, necessitating another trip to the launch pad and delaying your flight.

Igniter Use at the Field

The use of an igniter on the field is simple. The rocket motor is assembled and then installed in the rocket at a location away from the launch area–either a prep area or even a parking lot. Once the rocket motor is installed and the rocket is ready for launch, the owner of the rocket carries it to the RSO table for inspection. The igniter is not in the rocket at this time. It is not installed until the rocket is vertical and on the pad.

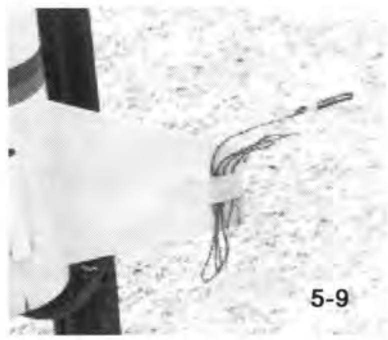
The Igniter in a Motor



As shown in this illustration, the head of the igniter is inserted through the aft end of the motor and the nozzle all the way into the top of the motor core. The igniter lead that is exposed is attached to the alligator clips near the pad (not shown). Illustration by Ray Dunakin.

Diagram 5-1

At the RSO table, the rocketeer will be asked what type of igniter he or she is using for the rocket. At some fields, the igniter is tested at the RSO table to make sure it is in good working order. Once the rocket is approved for launch, the owner carries it out to the launch pad. Many rocketeers use a small piece of masking tape to secure their igniter to the side of the rocket as it is being carried to the RSO table and then out to the field. See photo 5-9.

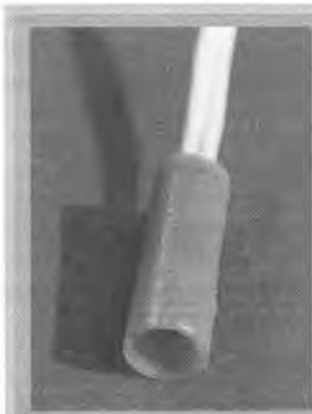

5-9

At the designated launch pad, there will be a pair of alligator clips nearby. These clips, which are connected to wires that run back to the main launch-control box, will be attached to the igniter. When the appropriate button on the control box is pushed, the igniter will light the motor.

Hooking Up the Leads

Igniter leads are attached to the main launch control system by wrapping the exposed wires of the igniter around the alligator clips provided at the launch pad. Before making your trip out to the pad, strip off at least one to two inches of insulation from each end of the igniter leads.

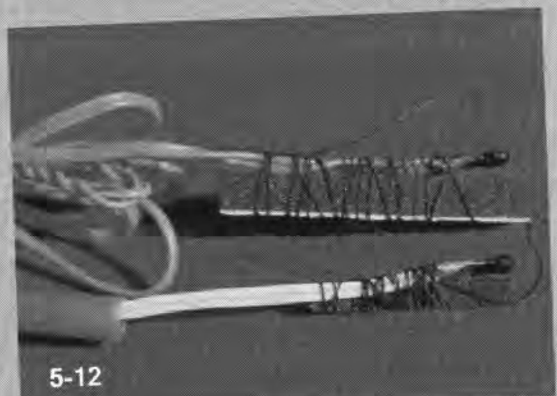
At the launch pad, be sure the alligator clips are clean and free of residue before the igniter leads are attached to the clips. After many launches these alligator clips will become dirty and lose their conductivity. It is a good idea to keep a piece of sandpaper or other abrasive in your pocket to lightly scuff and clean the alligator clips before attaching your own igniter. Once the



The COVER

Some brands of electric matches come with either a plastic cap or an elastic cover that protects the head of the igniter during transport and prior to insertion in the rocket. Remove the cover only when the igniter is about to be placed into the rocket. Removal of the cover prior to that time can lead to accidental damage to the head.

5-11



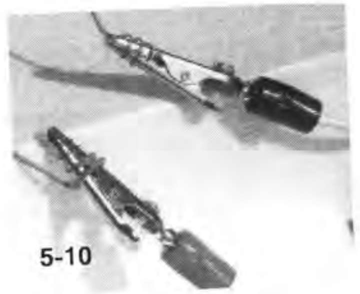
5-12

5-13

5-14

clips are clean and shiny, wrap the one inch of stripped wire tightly around the clips for a good electrical connection, as illustrated in photo 5-10.

Always be sure that the launch-control system is off when hooking up your igniters to the alligator clips. Many rocketry clubs have a failsafe system in place to ensure that a pad is not armed, or "hot," when rockets are being set up at the launch pad. If you are new to a particular club or launch site, be sure to familiarize yourself with the local procedures before hooking up your rocket. Also, test the main control box leads yourself at the pad–either with your igniter before it is installed in the rocket or with a small test light.



5-10

Before you head back to the flight line, take one last look at the igniter and the alligator clips. Be sure that the clips are not touching any metal, or each other. If they are, reposition them. If the clips touch each other or the metal base of the launch pad or a metal standoff, they will short out and fail.

The Use of Igniters in Large-Core Motors

Most commercial igniters work well with 29mm, 38mm, and even 54mm motors. However, with large Level Two and Level Three projects, the use of igniters begins to change.

Many traditional igniters will not produce a spark large enough to ignite the propellant of a large core motor. This is true of most electric match-style igniters that do not contain any pyrogen in the head. In addition, the central core is much larger in 75mm and 98mm motors, and when placed into one of these, the igniter has a tendency to get lost. Without some type of support or brace, most igniters will simply fall out of the motor.

Fortunately, these problems are easy to correct.

Most large core motors are ignited with commercial igniters or electric matches that are modified

or enhanced to guarantee a hot ignition. This may be accomplished in a number of ways. For example, a typical igniter or electric match can be supplemented by small slivers of Aerotech Blue Thunder propellant. Blue Thunder produces a very hot, bright spark when attached to an igniter and aids in the ignition of large or otherwise difficult-to-ignite motors. As illustrated in photos 5-11 through 5-14, Blue Thunder propellant can be harvested from a reload motor kit, such as the Aerotech H242. Simply take one of the fuel grains in the kit, and, using a hobby knife, carefully slice off a few slivers from the grain. (Obviously, the reload kit cannot be used any longer, so keep the fuel grains in a safe place for additional igniter use in the future.)

The Blue Thunder may be connected to the igniter wire with Super Glue or another adhesive so that a portion of the propellant is in close proximity to the igniter head. You may also attach the propellant with string, wire, or even thread. As shown in photo 5-12, tie a knot around the propellant and the igniter leads and place the propellant in close proximity to the igniter head. Once the igniter is activated, the Blue Thunder will also ignite and there will be a large, hot flame, with plenty of spark to ignite most Level Three and even experimental motors. See photos 5-13 and 5-14.

If you are using augmented electric match-style igniters for large-core motors or even for outboard motors in a cluster, be sure to test fire a few of your matches on the ground first to see that your design works and produces a good flame. Otherwise, your rocket may end up carrying the weight of loaded motors that never fire.

5-15

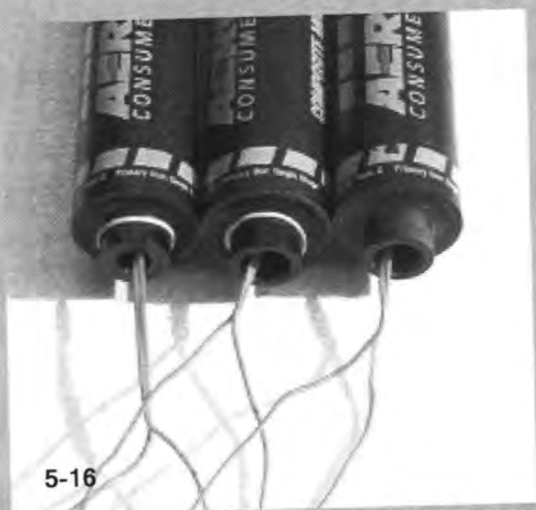
The igniter in this 98mm M motor is wrapped around a wooden dowel for support. The dowel extends out of the motor a few inches and will be supported by the deflector plate.

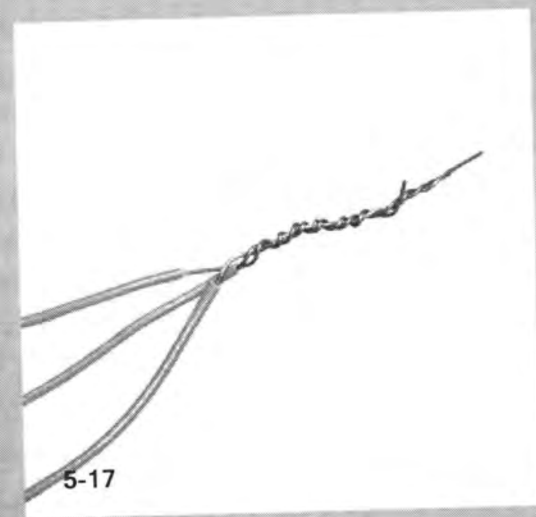
There are few things more exasperating for you–and for the rocketeers in line behind you–than to discover at the launch pad that your modified igniter will not fit into the nozzle of the motor. To avoid this problem, test-fit your modified igniter through the opening of a motor nozzle before installing the igniter for the first time on the launch pad. For safety reasons, don't test-fit the modified igniter on a loaded motor. Instead, use an old motor nozzle of the same size that has retained most of its original shape. This is a good reason to keep old nozzles in your rocketry tool box.

Another method used by rocketeers to ignite large-core motors–especially experimental motors–is to attach propellant shavings to the igniter with glue or epoxy. In some states, small amounts of Thermalite or Themite fuse are used.

Securing the Igniter in a Large Motor

The most common method used to secure or fasten an igniter in a large-core motor is to wrap the leads of the igniter around a thin wooden dowel. See photo 5-15. After the dowel is wrapped, apply a couple of small pieces of masking tape to the wire and the dowel to make sure it all holds together. This gives the igniter wire some stability and also makes it easier to slide the igniter all the way into


5-16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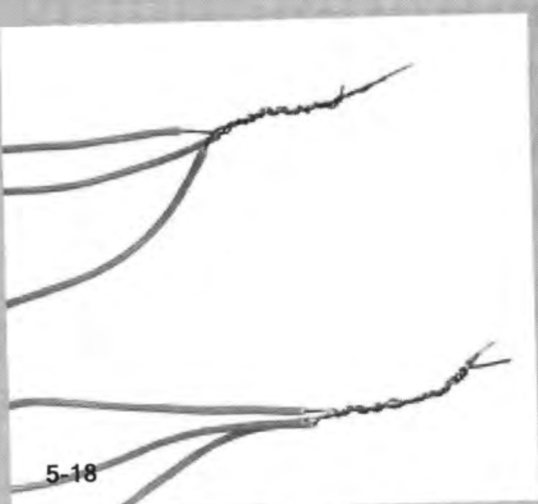
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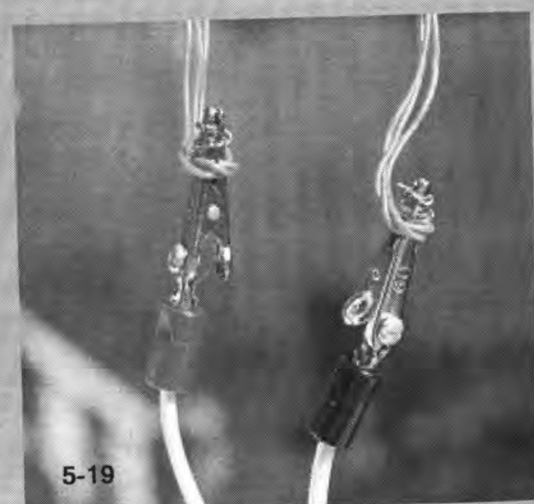

5-19


5-20


5-21

the motor on the pad. The dowel does not need to be large in diameter–just thick enough to provide support to the igniter leads and the igniter head. You do not want a dowel that plugs up the motor nozzle, either. The dowel must be thin enough to fit in the motor nozzle and also reach the full internal length of the motor core. The head of the igniter extends just a bit beyond the upper end of the dowel. The lower point of the dowel is braced against the pad or blast deflector. This usually holds the igniter securely in place.


5-22

The use of igniters in clusters

Rockets that are equipped with multiple motors are known as clusters. Clusters require special consideration when it comes to igniters. Since every motor in a high-power rocket must have its own igniter, a cluster rocket needs to have the same number of igniters as motors.

The challenge with clusters is to ensure that each motor receives the appropriate amount of electrical current to simultaneously light. If any igniter fails (or fails to light in a timely manner), then the motor it is attached to will fail, and the rocket may develop asymmetrical thrust and crash. (See Chapter 13.)

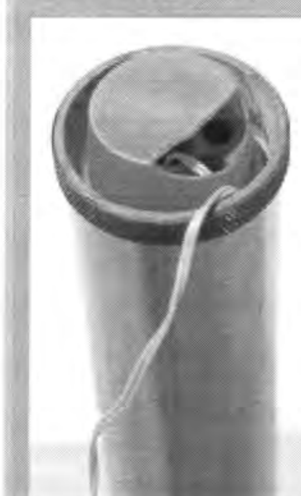
Fortunately, wiring for clusters is not difficult and can be easily mastered. First, install the igniters in parallel. Do not use series wiring. As pointed out by Hyam Sosnow in his article on clusters in the October 1999 issue of *High Power Rocketry* magazine, series wiring sends the electrical current through the igniters one after another in a line. In fact, noted Sosnow, if the first igniter burns, the circuit may be broken and the remaining igniters–and motors–will not light. Parallel wiring avoids this problem.

As illustrated in photos 5-16 through 5-21, parallel wiring for a cluster is simple. Here, three igniters are used to demonstrate wiring for a three-motor cluster. The motors are single-use G motors from Aerotech.

First, strip off about an inch of insulation from each of the igniter leads. Next, take one lead from each igniter and twist them together, as shown in photo 5-17. Repeat this with the remaining three leads. The end result should look something like what is illustrated in photo 5-18. If this were a four-motor cluster there would be two sets of four twisted leads, and so on. In the end, the single pair of twisted leads that remains is attached to the alligator clips of the launch system as if it were a single igniter, as shown in photos 5-19 through 5-21. For additional information on igniters and clusters, see Chapter 13.

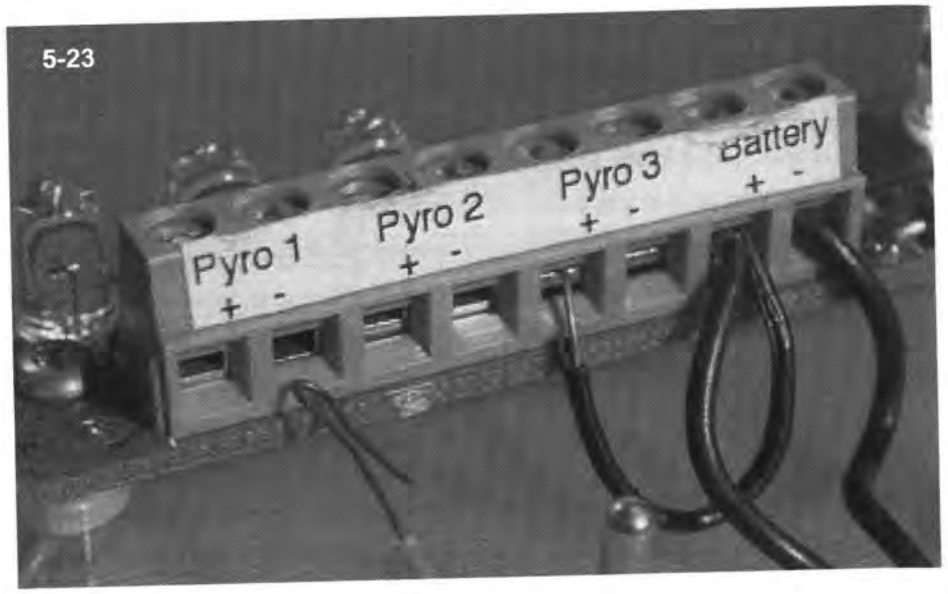
The CAP

With some high-power reload kits, such as Cesaroni Technology (above) or Aerotech (below), a plastic cap is supplied to use with the igniter. The cap fits snugly over the motor nozzle and the igniter wire. This secures the igniter in place and prevents wind or other small bumps from dislodging the igniter. Be sure to slice a vent hole in the cap if it does not come with one. In lieu of a cap, masking tape works well, too.



Think SAFETY

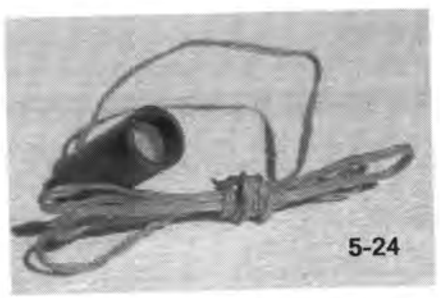
Be sure the launch-control system is off when you are hooking up your igniters on the pad. Many clubs have some type of failsafe system in place to ensure that the pad is not "hot" when rockets are being loaded. Be familiar with the local procedures at the field where you fly. Also, get in the habit of testing the leads on your own with a test light or even a spare igniter. When in doubt, ask questions.



5-23

The Use of Igniters with Ejection Charges

Igniters and electric matches are also used to activate ejection charges. When used for this purpose, the igniter head is usually placed in a container of black powder and the igniter leads are attached to a timer or altimeter. At a predetermined time (with a timer) or altitude (with an altimeter), the igniter receives power and the ejection charge goes off. Gases from the charge fill the rocket body and force the airframe apart. This leads to deployment of the rocket's recovery system.



5-24

When using igniters with altimeters (or any electrical device), always make sure that the igniter leads are secured firmly to the altimeter. If a lead pulls free during launch, the igniter will be rendered useless, and deployment will not occur.

Many high-power rockets have turned into lawn darts because the igniter wires pulled out of their altimeter ports under the rigors of launch. Do not let this happen to your rocket. Take your time when inserting the leads into the altimeter ports or channels.

On altimeters with multiple ports, be sure the igniter wires are inserted into the correct port. The failure to insert the leads into the correct port is also a common cause of deployment problems. It usually occurs when the rocketeer is in a rush, or tired. So take your time. Identify the correct port. Double over the stripped end of the igniter lead before inserting the lead into the altimeter port.

This will give the port more wire to hold onto and will help ensure that

5-25

A fisheye view of Dan Lord's magnificent five-motor Nike Smoke as the 180-pound rocket sat near the pad at LDRS23. Note the igniter wires tied in a neat pile and taped to the side of the airframe.

nothing comes loose during flight. See photo 5-23.

Many igniter wires are made of solid-core copper. This is a good wire, but it can be nicked or otherwise damaged if the user is not careful when stripping the insulation off the wire. Use quality wire cutters when stripping the ends of your igniters. After stripping the wire, examine it to make sure the solid wire was not accidentally cut or nicked. As an alternative, use stranded wire. This should reduce the chance that a nick or cut in the wire will lead to total failure.

Finally, be sure to give the igniter leads a small tug after they have been installed, to confirm that the leads are tight and properly secured. For more information on igniters, ejection charges, and deployment, see Chapters 6, 8, 9, and 10.

Making Your Own Igniters

Commercial igniters are among the least expensive components of high-power rocketry. A good igniter usually costs only a dollar or two. But many rocketeers prefer to scratch-build their own igniters, reducing the cost even more and guaranteeing a little more control over the quality and strength of the igniters. There are several suppliers of igniter kits, including Rocketflite and IgniterMan. These suppliers provide all the instructions and raw materials necessary to build a quality igniter for any high-power rocket motor.

5-26

Generally, a high-power rocket igniter can be created with wire, pyrogen and an oxidizer. Pyrogen is the flammable substance placed at the head of an igniter to light the fuel grains in a rocket motor. An oxidizer is a substance that provides oxygen to the combustion process.

The typical igniter kit is supplied with a small bottle of pyrogen and a smaller amount of oxidizer. These two substances are mixed together in a bottle or other container until they are syrupy (one maker describes the consistency as similar to chocolate syrup). When the proper consistency is achieved, wire supplied in the igniter kit is dipped in the pyrogen mix. When the wire is withdrawn from the mix, the pyrogen sticking to the wire is allowed to dry and cure, and then the igniter is ready to use. Always follow the instructions of the manufacturer when making igniters from kits.

For a current list of igniter suppliers, check with web sites such as Rocketry Online.

Igniter Safety and Failures

Igniters are powerful and should always be handled with care and caution. Igniters should never be handled by children. Since high-power igniters produce a hot flame or spark, they should not be tested indoors or near any flammable materials. Yet when used properly, most commercial igniters are safe and reliable and provide dependable motor ignition at a very low cost.

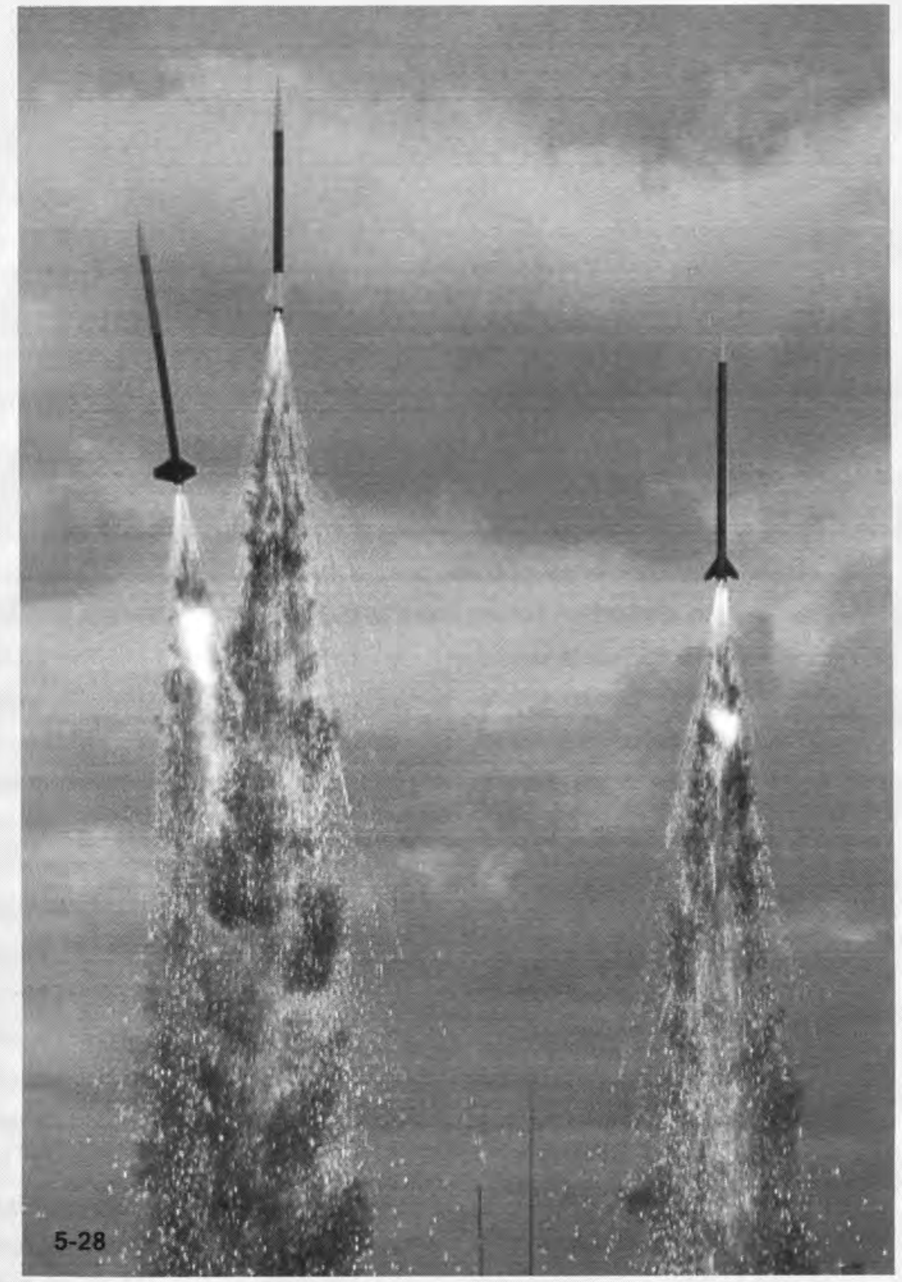
5-27

The power of good igniters: Tripoli member Rick Boyette's multiple motor rocket lifts off at LDRS23 on five motors all started at the same time. For more information on this rocket, see Chapter 18.

The Code for High Power Rocketry has several provisions regarding igniters. NFPA 1127 Section 4.13.5 provides that any ignition device shall be installed in a high-power rocket motor only at the launch pad or within the prepping area designated by the RSO for high-power launch preparation. Section 4.13 also notes that a high-power rocket shall be pointed away from spectators and others once the igniter is installed. Again, use common sense here. Always treat a rocket that is equipped with an igniter (either in an ejection charge or in the motor) as a loaded gun. Never point it in the direction of anyone.

Despite a person's best efforts, igniters sometimes fail because of an unseen defect or a problem with the motor. Failure can occur if the wind dislodges the igniter from the motor as the rocket sits on the pad, or causes the igniter leads to cross or touch the metal base plate of a launch pad. The motor may simply refuse to light. Sometimes a motor lights for a brief moment and then goes dead on the pad. (See also Troubleshooting chart in Appendix 1.)

Whatever the cause, most rocketry clubs allow the user at least one opportunity to bring a new igniter out to the pad and try again, without having to take the rocket down and get back in line. But always wait until the range is opened again. Section 4.18.4 of the Code for High Power Rocketry provides that a rocket that has misfired shall not be approached until (1) the safety interlock on the control box has been engaged, (2) at least one minute has passed, and (3) the RSO gives permission for the owner of the rocket to inspect it.



5-28

Up, up, and away! The simultaneous ignition of three Animal Motor Works M2200 Skidmark motors makes for a spectacular launch of this three-rocket drag race at the 2005 Florida Winter Nationals near West Palm Beach, Florida. The three rockets were owned by John Clifton, Tim Lehr, and Gonzalo Ortega.

Black POWDER

There are different types of black powder. The type used most often in high-power rocketry for ejection charges is known as 4F, or FFFF, meaning very fine grain. It is built into many single-use motors at the forward end. On some reloadable motors, it can be poured into a well in the forward closure, or it can be placed elsewhere in the rocket in a special ejection canister that is separate from the high-power motor.

6

Ejection Charges

The mechanics of motor-based and electronics-activated ejction charges

High-power rockets use the same basic method of parachute deployment as model rockets. A model-rocket motor holds a tiny ejection charge of black powder in the forward end of the motor. At a preset time after motor burnout, the ejection charge ignites, filling the body of the rocket with hot gas. This gas over-pressurizes the inside of the rocket body, which forces the rocket apart–usually at the nose cone–and leads to release of the parachute.

Ejection charges in high-power rockets accomplish the same task. The ejection charge over-pressurizes the airframe, which separates the rocket into at least two pieces, allowing the recovery harness and parachute to be pulled out of the rocket at an altitude high enough for a safe descent and recovery. However, in high-power, there is more variation on this theme. High-power rockets have at least two types of ejection charges. These charges may be part of the rocket motor (as in model rockets) or they may be separate and distinct from the motor and activated by on-board electronics.

6-1

A black powder ejection charge is sealed in the well of a reloadable motor.

The purpose of this chapter is to explain the basics of ejection charges and their general use in high-power rocketry. This will include discussion of the use of ejection charges in motors and the use of charges that are controlled by electronics.

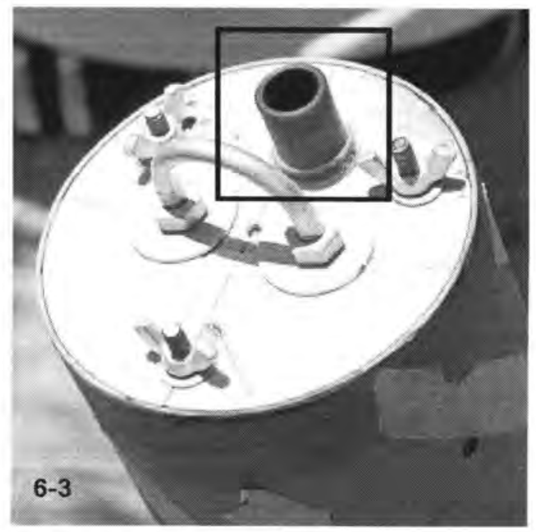
6-2

The forward closure on some Aerotech motors contains a well for the black powder ejection charge. In the center of the well is a tiny hole through which some of the powder will trickle and come in contact with the delay grain. This photo shows 29mm, 38mm, and 54mm forward closures.

Basic Principles of Ejection Charges

In a simple, two-piece high-power rocket, the nose cone is connected internally to the airframe of the rocket by a cord or tether. In large rockets the attachment may be referred to as a recovery harness. The parachute is connected to this harness. The rocket also contains an ejection charge. The ejection charge is nothing more than a container of black powder located somewhere in the rocket.

When the ejection charge is ignited, the internal body of the rocket where the charge is located becomes pressurized with gas. If the charge is sufficient, the gas will actually over-pressurize the rocket. The gas, having nowhere to go, escapes the rocket by seeking the path of least resistance. This usually means the nose cone of the rocket is forced off the airframe. As the body and cone travel apart, the recovery harness is pulled out of the rocket, deploying the parachute.



6-3

An ejection-charge canister in the bulkhead of a rocket. The canister holds black powder and will connect to an altimeter via an electric match.

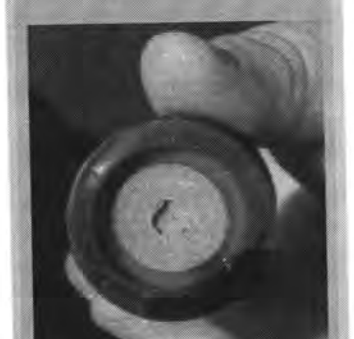
Typically, although not always, the airframe and the nose cone remain connected to each other by the recovery harness as the rocket descends. In some rockets, the nose cone and the airframe have separate parachutes and they descend independently of one another.

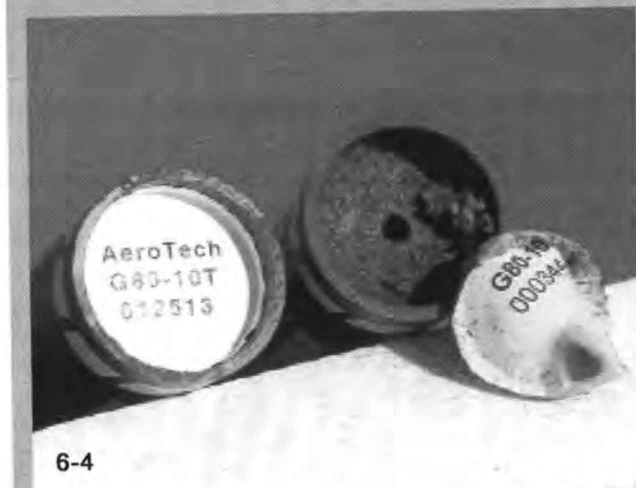
There are two methods used in high power to activate ejection charges. These methods are (1) motor-based ejection charges and (2) electronic-activated charges. Some rockets use both methods.

The substance commonly chosen as the ejection charge is black rifle powder. Black powder is made with potassium nitrate, is easy to ignite, and burns quickly. It is not sold in hobby stores. It can be purchased in gun stores and is

Delay GRAIN

The delay grain in a typical high-power rocket motor separates the propellant from the deployment charge. It is usually a pyrotechnic element that burns at a known rate. It is ignited at the same time the motor ignites. Delay grains are available in different burn times, like the Aerotech grain, above. Or, delay grains can be modified to burn at different rates, like the Cesaroni grain, below.



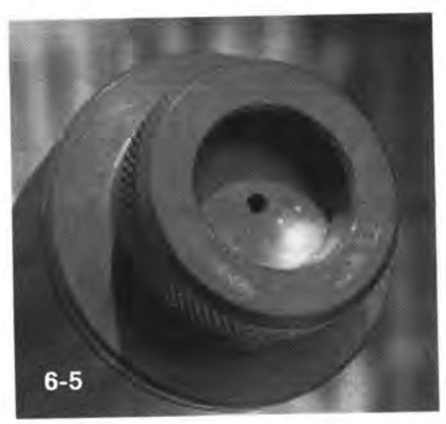


6-4

The black-powder ejection charge in many single-use motors is located beneath the label at the forward end of the motor. After the motor has been flown, the well containing the powder will be empty.

usually sold in one-pound cans. A single can of black powder sells for less than $20 and should last scores of flights.

There are different kinds of black powder. The type used most often in high-power rocketry is designated FFFF–also called 4F. Black powder is explosive and must be handled with care. It should be stored in a cool, dry place and away from excessive heat or open flame. Some state and federal laws require black powder to be kept in an explosives magazine. So check with your local rocketry club, gun store, fire marshal, or ATFE office to find out how you should be keeping your black powder safe. Naturally, black powder must be kept out of the hands of children and other unauthorized persons.



6-5

The forward well in this reloadable motor has a tiny hole through which the burning delay grain and the black powder will come into contact.

Motor-Based Ejection Charges

Motor-based ejection charges use a small amount of black powder located in the forward end of the rocket motor. Single-use motors in the E, F, and G range have the charge built into the motor, usually just beneath the motor label, as illustrated in photo 6-4. At the moment the main motor propellant ignites, a delay grain within the motor is also ignited. The delay grain is located between the main propellant and the black- powder charge. The delay grain burns at a much slower rate than the propellant. After the delay grain is consumed–usually several seconds or more into the flight–the black- powder charge is ignited, the rocket body is pressurized, and deployment occurs.

6-6

In single-use motors, you can determine the length of time between motor burnout and ignition of the ejection charge by looking on the motor label. For example, in the G80-10 motor, the number 10 represents the delay time, in seconds, between motor burnout and ignition of the ejection charge. In this case, the black powder charge will ignite 10 seconds after the G80 has burned out. A G80-14, on the other hand, will have an ejection charge that activates 14 seconds after main motor burnout.

Motor-based ejection charges are also used on many reloadable motors. However, with some, the rocketeer adds the charge to the motor; it is not built-in as with single-use motors. Instead, the black powder for the ejection charge is placed in a well located in the forward closure of the motor. A chamber or divider in the forward closure separates the black powder from the delay grain.

6-7

In Cesaroni motors the delay grain for the ejection charge can be adjusted with this tool.

In Aerotech motors, for example, there is a tiny hole located in the center of the well. See photos 6-2 and 6-5. This small hole allows some of the powder to trickle through and come in direct contact with the delay grain. When the delay grain is consumed, the powder in the well is ignited, and deployment occurs.

Many Cesaroni motors, on the other hand, come with a built-in ejection charge. See left closure in

Keep CLEAN

When handling your ejection charges and delay grains, it is important to keep your hands clean. Grease, dirt, or other contaminants that make their way onto the delay grain can prevent the ejection charge from firing. Since field conditions are often dusty or dirty, bring along some type of hand cleaner to every launch, and wash up before you assemble any high-power motor. This will reduce the chance that a malfunction in the motor-based charge will occur.

Plugged CLOSURE

Not all reloadable motors have motor-based ejection charges. For example, Animal Motor Works motors rely solely on electronic-activated ejection charges. There is no black-powder well on an AMW motor. Instead, AMW provides a threaded hole in the forward bulkhead that can, if desired, accept an eyebolt for a point of attachment for recovery systems. (See photo above.) Aerotech also provides "plugged" forward closures for some of its motors. These closures can be used to attach eyebolts or they are simply solid, as seen below.

6-8

photo 6-6. The charge is pre-sealed from the factory.

The size of the forward well and the amount of powder that it holds depend on the size of the motor. A larger motor case can hold a larger amount of black powder in the well. (See photo 6-2.)

Typically, the ejection charge is the last thing placed in the motor. After the motor is loaded with the fuel grains and all other necessary components, the powder is placed in the well, and then a small seal is placed over it to ensure that none of the powder leaks out during handling or flight. The motor is then inserted into the rocket.

6-9

In late 2004, Aerotech changed the look of its single-use G motor. This is the ejection-charge end of a G40-7 motor.

In reloadable motors the timing of the ejection charge depends on the type of delay grain selected for the motor.

Delay grains for reloadable motors operate on the same principle as grains found in single-use motors. Motors can be flown with grains of various delay times. Grains for Aerotech reloadable motors are typically identified as "short," "medium," or "long." These terms translate (roughly) into time periods of 6,10, or 14 seconds.

Cesaroni Technology motors, by contrast, come with a delay grain that is set for a maximum time (i.e. 15 seconds) that can be shortened with a special adjustment tool. (For more information on how to use the tool, see Chapter 3.)

Troubleshooting Motor-Based Charges

Motor-based charges occasionally fail to ignite, or they ignite too early or too late. These problems can usually be traced to a few common errors during assembly of the motor.

One common mistake occurs when the rocketeer inadvertently places grease on the bottom surface of the delay grain. Grease, dirt, or other contaminants on the bottom of the delay column–the side facing the igniter–can prevent the grain from igniting. So always be careful to handle the delay components with clean hands, free of grease and dirt. This is not always easy to do, especially in the outdoors, where most launches take place. Personal cleaning cloths, such as Wet Ones, Handi-Wipes, or other lubricated napkins, are a big help on the field to keep clean.

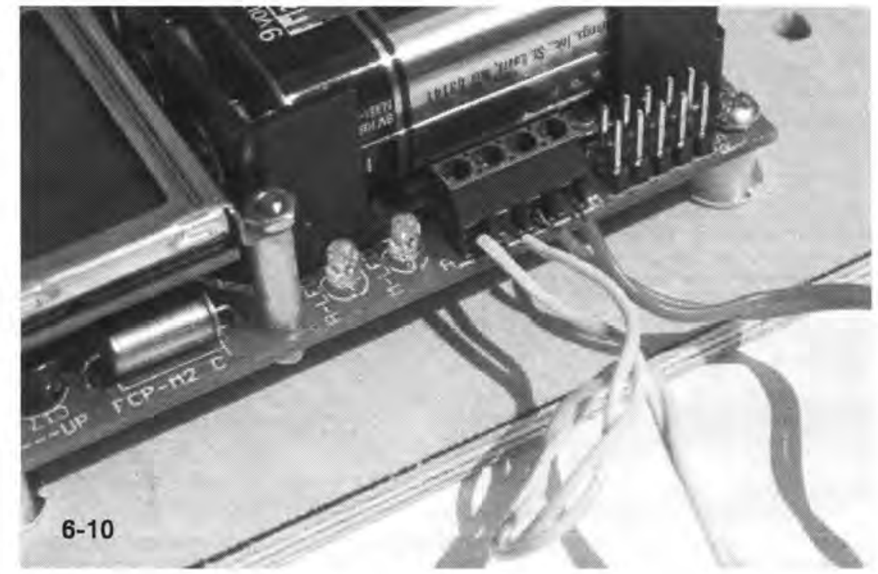
Another problem occurs when dirt or other foreign material blocks the tiny hole in the forward closure, preventing contact between the black powder in the well and the burning delay grain. This is a problem that occasionally develops with Aerotech motors. So be sure that the well remains free of dirt or grease or anything other than ejection powder. Be extra careful, after using a reload, to clean the forward well thoroughly to prevent the tiny hole from being clogged for the next flight.

A third problem develops when the paper coating of the delay column in an Aerotech reloadable motor is torn or damaged. This can cause the column to burn too quickly, reaching the black powder early and causing sudden, early deployment of the parachute. So be sure that when the delay column is inserted into the forward closure it is undamaged. Refrain from tearing away any of the paper surrounding the grain to make it fit better.

For additional discussion on problems with motor-based ejection charges and their solutions, see the article by Tom Montemayor entitled "Ejection Difficulties" on the Dr. Rocket web site.

Electronic-Activated Ejection Charges

One of the most common methods used to activate



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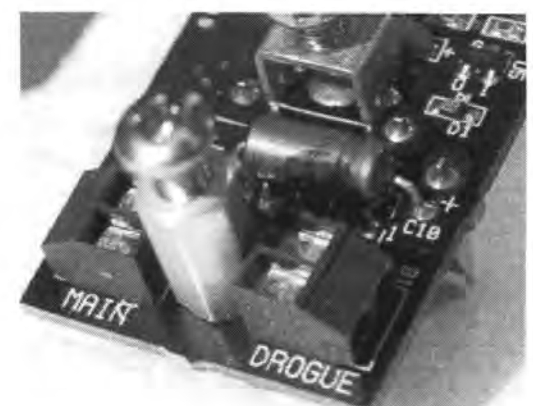
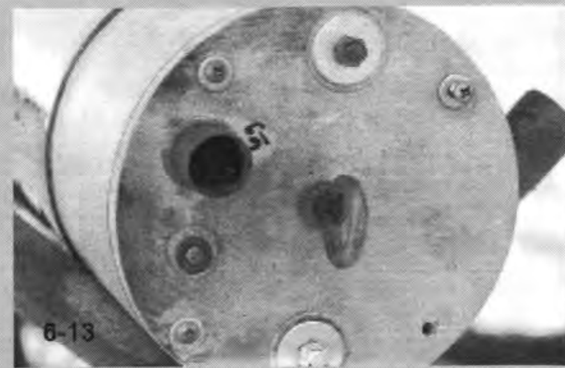


6-11

Most altimeters have four ports to connect two separate electric matches for ejection charges. Above: An Olsen M2 has provisions for a charge at apogee and at a lower altitude. Left: A blacksky altimeter with ports for the main and drogue parachutes.

ejection charges in a high-power rocket is with on-board electronics, primarily altimeters, sometimes timers. In this method, an igniter wire runs from the ejection charge to the altimeter (or timer). When the


6-12


6-13


6-14


6-15


6-16


6-17

altimeter or timer detects the appropriate altitude (or time), the charge will be fired.

Most altimeters have the ability to activate at least two ejection charges, using two separate igniters (and two separate channels on the altimeter). The first charge is ignited when the altimeter detects the rocket is at, or near, apogee. This charge is used to deploy a small, drogue parachute. The second charge is set to ignite at a lower altitude. This charge will deploy the larger, main parachute.

This method of using two different charges to control recovery is known as dual deployment. It is particularly useful on windy days or on small fields where the rocketeer is trying to minimize a rocket's drift during recovery. The drogue parachute allows the rocket to drop quickly from a high altitude with very little drift. The main parachute is deployed when the rocket is close to the ground. For additional discussion on dual deployment, see chapters 8, 9, and 10.

Altimeter-controlled ejection charges also use

black powder. However, with electronics-activated charges, the ejection charge may be located anywhere on the rocket, provided that the charge is in a location that will allow it to pressurize a chamber containing the recovery harness.

As illustrated in photos 6-12 through 6-17, ejection charges are commonly placed on or near rocket bulkheads. The charge is often contained in a canister or other holder that is attached directly to the bulkhead. The bulkhead typically separates the ejection charge from the electronics that control the charge. This is because ejection charge gases are harmful to altimeters (and other electronics)–as discussed in more detail in Chapter 8.

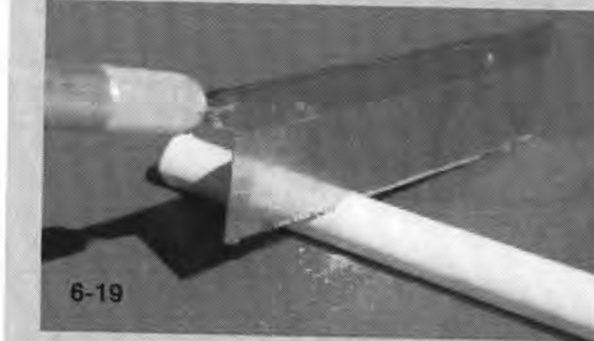
The ejection charge can be placed in any of a number of different holders or containers. Some of these containers are single-use, which means they are destroyed along with the charge. Some are reusable, which means that, after the rocket is recovered, the container is cleaned and made ready for the next flight.

Building and Loading Ejection Charges

The shapes and sizes of ejection-charge containers seen at high-power launches today vary, depending on the size of the rocket and the amount of the charge. Ejection canisters can be homemade or purchased from a commercial supplier. The most basic canister is nothing more than paper folded back on itself to hold a small amount of powder and the igniter head.

Another simple homemade canister commonly used is made of cardboard discarded from coat hangers and a little epoxy, as illustrated in photos 6-18 to 6-22. The cardboard sleeve of the hanger is removed from the wire and cut into sections. A small bit of epoxy is poured into the bottom of each section while the cardboard rests on wax paper. When the epoxy dries, it is removed from the wax paper and a hole is drilled into the center. This allows an igniter to be placed into the sleeve. The cardboard is filled with the appropriate amount of black powder and sealed with epoxy. (This technique was demonstrated several years ago by

6-18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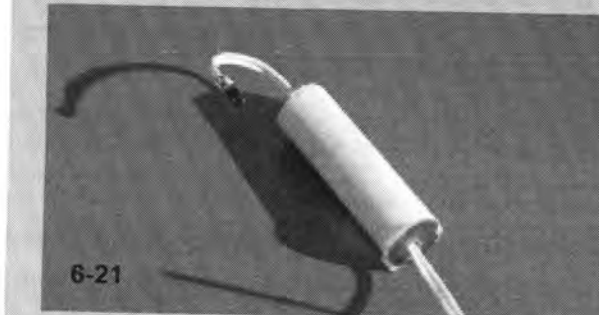
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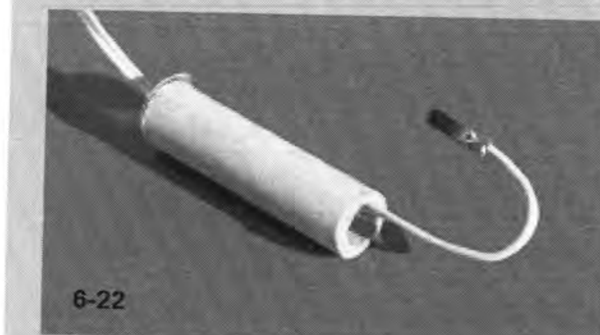
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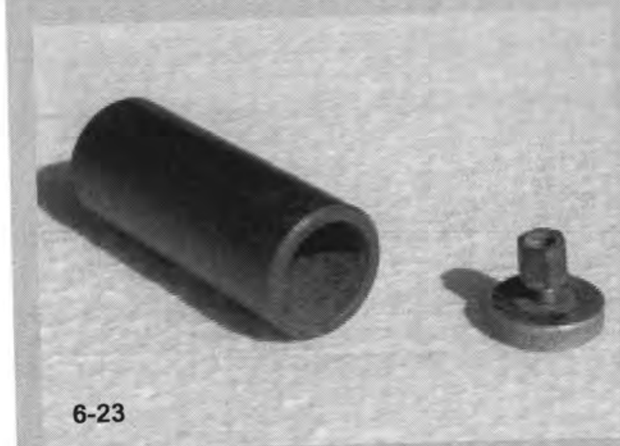
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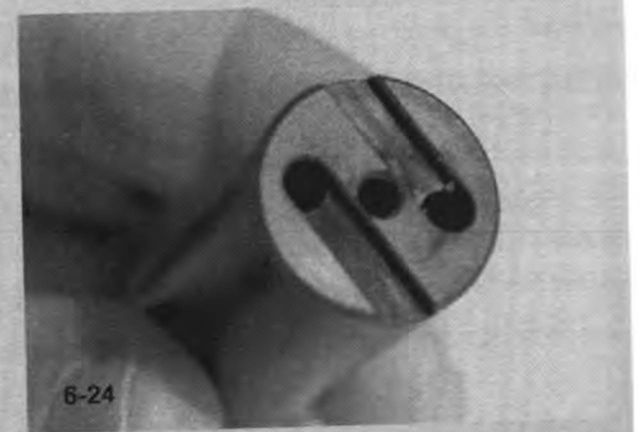
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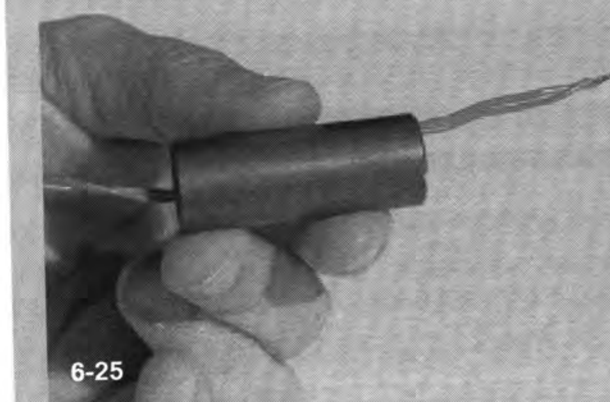
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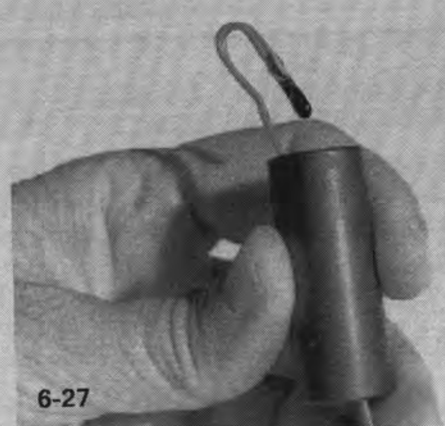

6-27


6-28

Darrell Mobley in a Rocketry Online technical article.) Be sure to seal up the hole in the epoxy where the igniter lead passes into the holder before the black powder and wadding are added.

As for commercially manufactured ejection charges, Spacetec offers options that work very well for black-powder charges. Spacetec canisters are metal, come in several sizes, and can hold up to several grams of black powder. Spacetec canisters have grooves in the mounting hardware that allow for passage of most commercially made igniter leads. See photos 6-23 and 6-24. These grooves allow igniter wire to be routed out of the canister–where the igniter head is held–while maintaining a good seal for the powder contained within. The seal effectively prevents any powder from leaking out of

the aft end of the canister during flight.

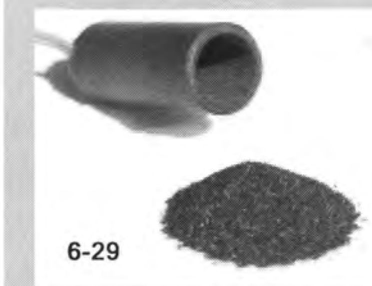
Loading a Spacetec canister requires only a few simple steps.

The first step is to run the igniter wire through the hole in the bottom of the can. Pull the igniter far enough into and then through the canister so as to allow you to fold the tip of the igniter wire in on itself. Then pull the wire from the opposite direction until the head of the igniter is at the base of the canister. See photos 6-25 to 6-27. The igniter head should end up at the aft end of the canister.

Next, secure the igniter lead in the groove on the bottom end of the canister. Then attach the aft closure to the canister and tighten it down. As you can see, the igniter wire is secured in place and the aft end is sealed, as illustrated in photo 6-28.

Pour the appropriate amount of powder into the open end of the canister. Then add a few bits of ejection wadding. The wadding and powder should cover the head of the igniter. Pack the wadding into place with a wooden dowel and then seal the opening with an adhesive sticker or tape. See photos 6-29 to 6-37. The charge is now ready to go. It can be mounted in the rocket in the appropriate chamber and the igniter wire can be connected to the altimeter. Be sure the altimeter is off when the charge is hooked up to the altimeter.

One more example? How about an ejection canister made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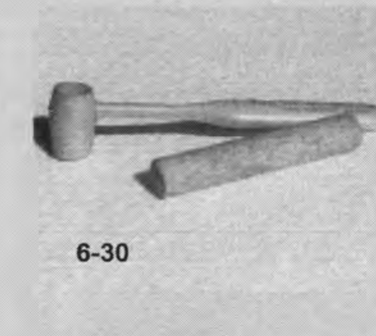
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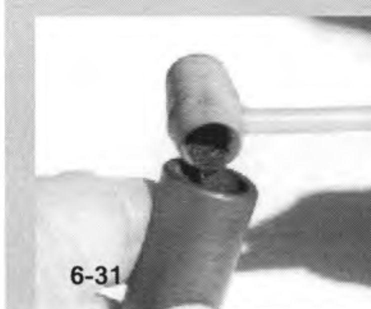
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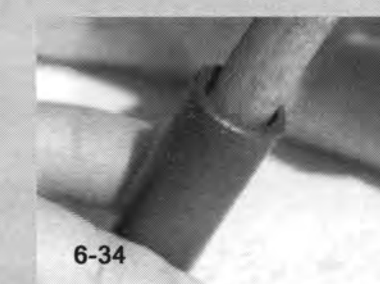
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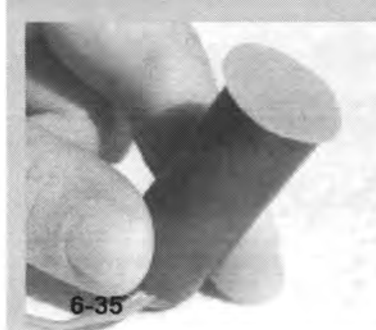
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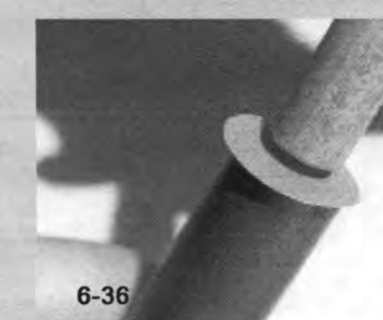
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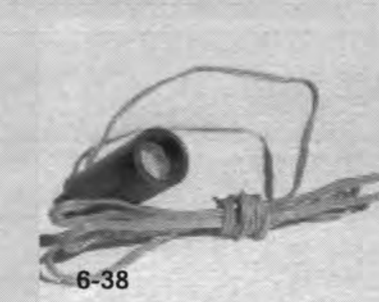
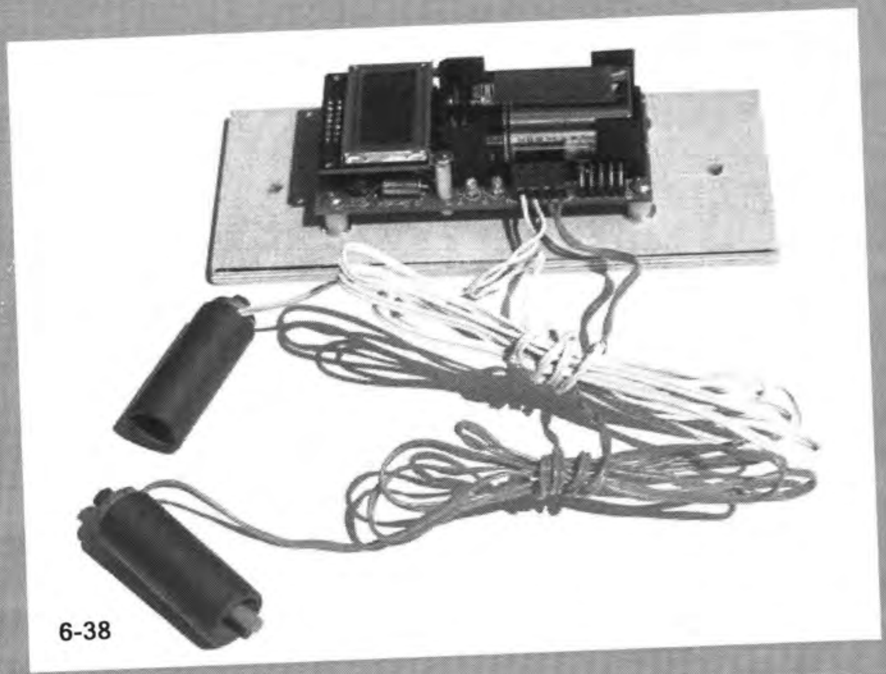

6-38

Don't GUESS

Picking the appropriate delay time for a motor-based ejection charge can be tricky for new flyers. Experience plays a big role. And so do pre-flight simulations run on programs such as Wrasp and RockSim. But even new flyers can avoid zippers and core samples and lawn darts by following one of the most important rules in high-power rocketry: Ask questions. By paying attention to the habits of good flyers, you will improve your own chances of flying safely and recovering your rocket intact. There is a lot of experience at every local launch. Take advantage of it.



6-38

for less than a dollar? Photos 6-39 through 6-46 illustrate the construction of an ejection canister from 1/2" schedule 40 PVC tubing, an end plug, and a screw and wingnut.

First, cut a small section of tubing to length. Next, drill two holes in the 1/2" PVC end cap--one hole in the bottom of the cap for the screw and one hole in the side of the cap for the igniter wire. See photos 6-40 and 6-41. Make the hole in the side as low as possible.

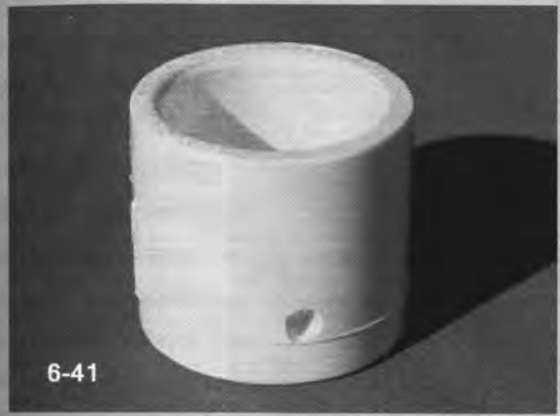
Next, place the cut section of PVC tube on wax paper. Mix some slow-drying epoxy in a cup and pour about 1/4" of epoxy into the tube. The epoxy will settle in the bottom of the tube and dry. When it is dry, pull it off the wax paper and drill a hole in the center of the epoxy. The igniter will pass through this hole and the igniter or electric match will sit in the tube. See photo 6-42 and 6-43.

Now, drill a hole in the bulkhead of the rocket. Attach the PVC end cap to the bulkhead with a screw and wingnut. Then, run the igniter wire from the tube into the end cap and out of the hole on the side of the cap. See photos 6-44 and 6-45. The finished assembly is ready for black powder and a cover. It can be loaded in the same manner as the Spacetec canister. (For more information on hooking up this type of charge in an altimeter bay, see Chapter 9.)

Another ejection canister is produced by Robby's Rockets. These canisters are also made of metal and are reloadable. However, instead of ignition by igniter wire, the black powder charge is ignited by a flashbulb that provides the heat necessary to ignite the powder. As illustrated in photo 6-47, the Robby's kit comes complete with a measuring cup, several flashbulbs, a wooden dowel, and a metal canister. The flashbulb comes with leads that are

6-39

6-40



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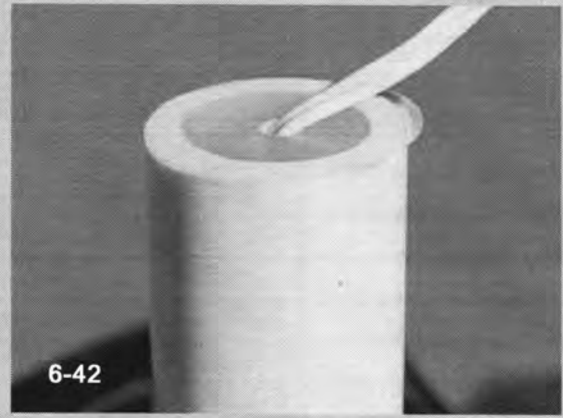

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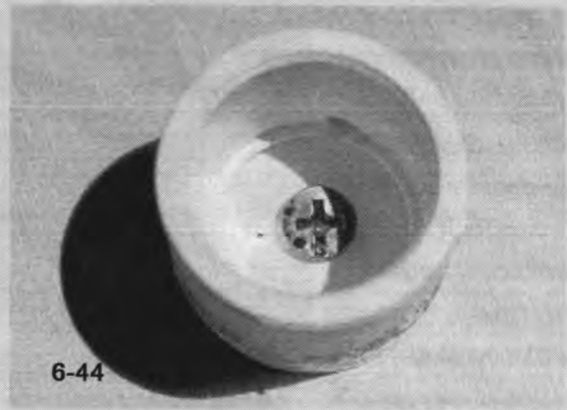

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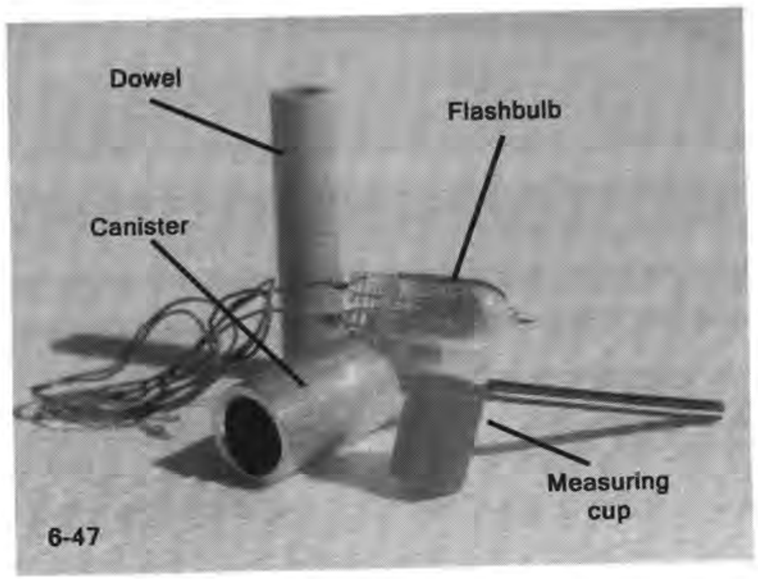
6-46

connected to the altimeter. The leads are run out of the aft end of the canister and the bulb is pulled into the forward opening of the can.

The installation of the powder and wadding is then accomplished in the same manner as in the Spacetec example, discussed earlier. Be sure when using this system that the canister is well-sealed, especially where the flashbulb exits the canister.



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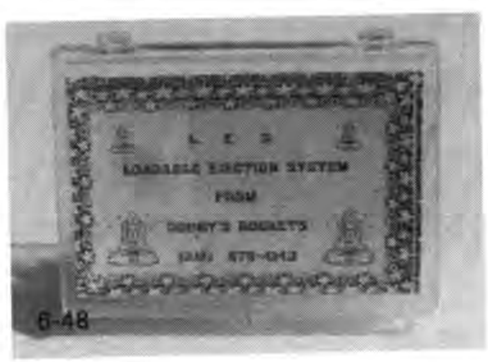

6-48

Robby's Rockets uses flashbulbs to ignite black-powder charges in its ejection canister.

As always, do not handle black powder in the vicinity of excessive heat or an open flame. Be certain that the igniter is not connected to any live power supply until the rocket is loaded and ready on the pad, and wear eye protection whenever handling ejection charges because charges occasionally go off unexpectedly.

Ejection Charge Timing

The timing of an ejection charge is important to the safe recovery of the rocket. Ideally, the ejection charge should be activated when the rocket is traveling slowly: at, or near, apogee. If the charge goes off too early or too late, serious problems can occur.

The timing of an ejection charge is usually controlled by the altimeter in electronics-based systems. However, with motor-based ejection charges, the user must choose a delay grain that will (hopefully) allow the charge to activate at, or near, apogee. This is not always an easy task.

One day a couple of years ago, I purchased a single-use H motor with a delay time of more than 14 seconds for my three-inch Public Missiles Systems Amraam. The Amraam was one of my favorite rockets. I had certified Level Two with the Amraam years earlier using a powerful Aerotech J350, and I had always used motor-based ejection charges in this rocket. But due to a motor shortage, the single-use H motor was the only motor available that would fit in this particular rocket, so I bought it. Certainly, I thought, the average thrust or total impulse of the single-use H motor would pose no problem for the Amraam.

So I stuffed the H motor into the rocket and headed out to the pad. The trouble was, I had not given any thought to the delay time of the H motor, or to the fact that the H motor was not going to lift the Amraam anywhere near as high as the J350. My trusty Amraam launched off the pad straight and true, turned over at a low apogee, and returned as a lawn dart into the hard, hard ground–all in about 14 seconds. The ejection charge did eventually go off, at or around impact. The rocket was destroyed. Why? In my rush to use whatever motor was available, I had neglected to consider that the lower impulse of the H motor (as compared to other motors that had been used in this rocket) and the long delay time meant

that the rocket was likely to suffer serious damage from a late deployment. Even if the ejection charge had gone off a few seconds before impact, the late deployment at high speed might have seriously damaged the rocket.

Likewise, if the delay of the ejection charge is too short, another problem may arise. Most high-power rockets continue to travel and gain altitude at a high rate of speed even after motor burnout. This is referred to as the coasting portion of the fight. If the delay time on an ejection charge is too short, the charge may be activated when the rocket is traveling too fast and in a vertical trajectory. When the inside of the rocket body pressurizes, the recovery system is yanked out of the rocket violently due to the high speed of the rocket. In these situations, it is common for a linear tear to occur in the airframe of the rocket as the recovery harness cuts through the rocket body. This tear is referred to as a zipper because the harness literally zippers a line down the side of the airframe. A zipper can also occur if deployment occurs too late, well after the rocket has turned over at apogee and is traveling back toward the ground.


6-49

A zipper occurs when deployment is too early or too late. The rocket is traveling too fast and the recovery harness slices through the airframe.

The prevention of zippers is discussed in more detail in Chapter 10. However, as a general rule, picking the appropriate ejection-charge time is a good way avoid one. Experience plays a big role here: The more rockets you launch, the better feel you will have for what ejection charge time (6, 10, 14 seconds) works best for the type of rockets you are flying. An even better method of picking the right time for an ejection charge in a motor-based system is to use a computer program, such as RockSim, Wrasp, or Winroc to calculate before launch the expected altitude and apogee of the flight. With this information, you will be in a better position to correctly pick a delay time that is appropriate for the motor you have chosen.

How Much Black Powder is Necessary?

There are a number of mathematical equations and computer programs available to determine the amount of black powder necessary to safely and reliably activate the deployment system in any given rocket.

For example, in his excellent work, *How to Make Amateur Rockets*, author John Wickman offers various equations necessary to make the requisite powder calculations. In addition, web sites such as Rocketry Online contain information on black-

How much black powder is necessary?

Black powder (grams) = compartment diameter (inches) x compartment diameter (inches) x compartment length (inches) x 0.006.

(Note: The compartment is the payload bay, not the altimeter bay)

Source: Missile Works RRC2 instruction sheet

Diagram 6-1

powder calculations that can be used to estimate the amount of powder necessary. One of the more popular sites for this information is www.wrasp.com. An ejection-charge calculator can also be found at www.info-central.org. This calculator will allow the user to vary the amount of pressure used to separate a rocket of a given size. (Calculators are a good way to make estimates for ground-testing your charges only.)

The remains of an N motor casing unearthed from the Black Rock Desert floor after an ejection-charge failure from 25,000 feet.

Some altimeter makers provide calculations and equations with their altimeter instructions. For example, Missile Works, in the packaging instructions for its popular RRC2 altimeter, recommends the following equation be used to determine the correct amount of powder for the ejection charge: Black powder (grams) = compartment diameter (inches) x compartment diameter (inches) x compartment length x 0.006. This equation is another good starting point for ground-testing the ejection charge on your rocket.

How does it work on a real rocket? Let's take our LOC Bruiser EXP as an example (built in Chapter 12).

To complete the equation for the correct charge, we need the diameter of the rocket (or payload bay) and the length of the compartment in which the charge is located. (Note that this is not the altimeter-bay compartment. That compartment is to be kept free of any ejection-charge gases. The payload bay holds the parachute, etc.)

The EXP has a diameter of 7.51 inches. The length of the modified upper bay, just beneath the nose cone, is 10 inches. So 7.51 x 7.51 = 56.40. Now multiply 56.40 by 10. The answer is 564. Finally, multiply 564 by 0.006. The answer is 3.38 grams of black powder. With that amount, we can conduct a ground-test to ensure that we have arrived at the correct amount of powder.

Redundant, or extra, ejection charges are a must in large high-power rockets.

Ground Test Your Charges

No matter which calculation or computer program you utilize to determine the correct amount of powder for your ejection charge, there are a couple of practical rules to keep in mind before launching your rocket.

First, *always* test your deployment system on the ground before you launch the rocket. This is particularly important in large Level Two and Level Three rockets and in any rocket of unusual design. These rockets can weigh 30, 40, 50 pounds or more. If there is insufficient ejection charge on board to ensure deployment, the result will be a very heavy lawn dart. This means destruction of the rocket and can be a serious hazard to everyone in the vicinity.

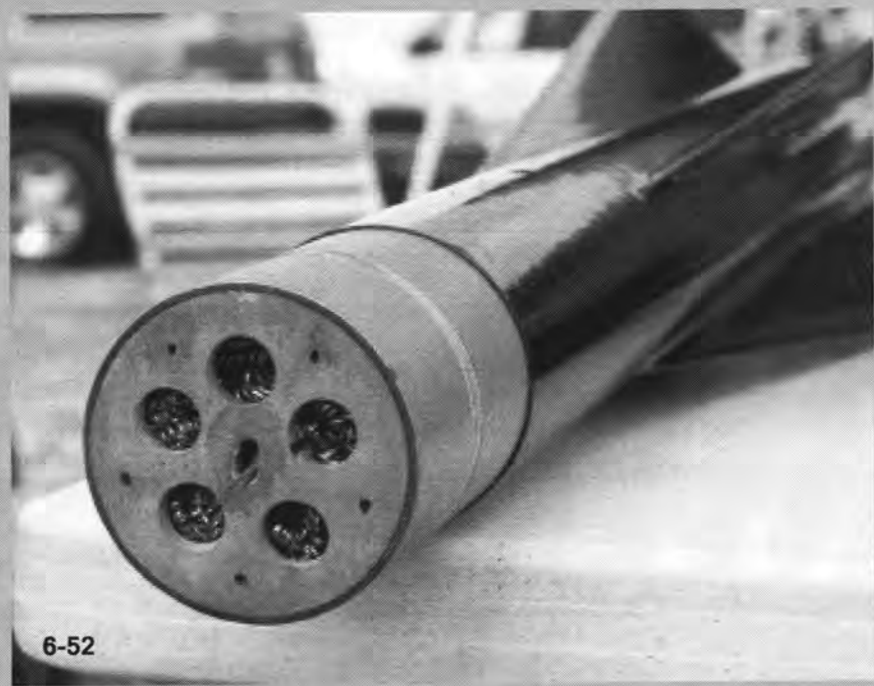
The best computer program in the world may not be an accurate predictor of how a given charge will work in a particular rocket that is loaded and ready to be launched. This is because of the many variations that can occur between rockets, even of the same length and diameter. One rocket with a tight-fitting nose cone or payload bay will probably require more black powder than an otherwise similar rocket with looser-fitting components. A rocket with a large parachute that is packed tightly into the airframe may need more of an ejection charge than the very same rocket with a smaller parachute.

Therefore, always test-fire the charge on the ground after the completion of any new high-power project.

To test the charge, load the rocket and set it up with all recovery equipment you expect to use on launch day. Be sure all recovery lines are connected and in place. Place the rocket on a flat piece of ground and be sure there is plenty of

Shear PINS

Shear pins are used in high-power rocketry to keep airframe components together when the first ejection charges fire, or, to prevent drag separation. Typically, they are placed in the nose cone to keep the cone on the rocket and to keep the main parachute inside until the correct altitude is reached. If you plan on using shear pins, be sure to test the pins with your ejection charges on the ground. See Chapter 10 for more information on these nylon or plastic pins.


6-52

This baffle and wire-brush system is one way to protect your parachute and recovery harness from direct exposure to harmful ejection charge-particles. For more information on protecting recovery equipment from ejection charges, see Chapter 10.

space both in front of the rocket and behind it. Move everyone to a safe distance away (never directly in front of the rocket or directly behind it), and then activate the charge.

If there is enough black powder on board, the body of the rocket should separate easily and completely. In fact, the forward end of the rocket should almost leap away from the main body.

If the rocket fails to separate, there may not be enough powder in the charge. Another possibility is that the body halves on the rocket fit too tightly (as a rule of thumb, you should be able to pick up the rocket by its nose cone without separation). In either event, you need to try again and get the system perfected prior to launch.


6-53

Nomex cloth will protect parachutes and recovery lines from ejection charges.

A second practical rule of thumb in this area of ejection charges is the old rocketry adage "blow them apart or blow them up." This means that it is always preferable to put a little too much black powder in the charge, rather than not enough. An insufficient charge (one that fails to cause separation) will lead to destruction of the rocket. Too much powder, on the other hand, rarely has the same result. At worst, if your powder calculations are way off, you may blow a hole in the rocket. So when in doubt, err on the side of a little too much powder.

Redundant ejection charges

Do not rely on a single ejection charge in any large high-power rocket. If you are using multiple altimeters, use multiple ejection charges. More than one ejection charge helps ensure that deployment will occur. Ejection charges can fail. So why rely on a single charge when it is so easy to put two charges in a rocket? Three or four years ago it was common to see large projects with only one altimeter and one ejection charge. Many of these projects ended up deep in the ground. Today, most large rockets contain multiple ejection charges and more than one altimeter. This is the better practice.

Protection from Ejection Charges

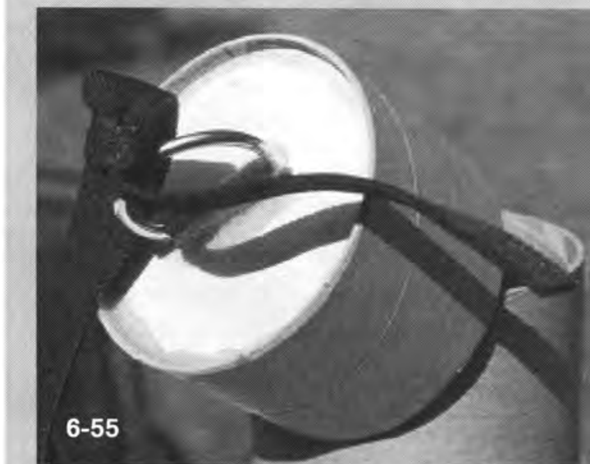
The hot gases that are released by the ejection charge will damage your parachute and recovery equipment unless you take steps to protect them. Several different products are available to accomplish this task.

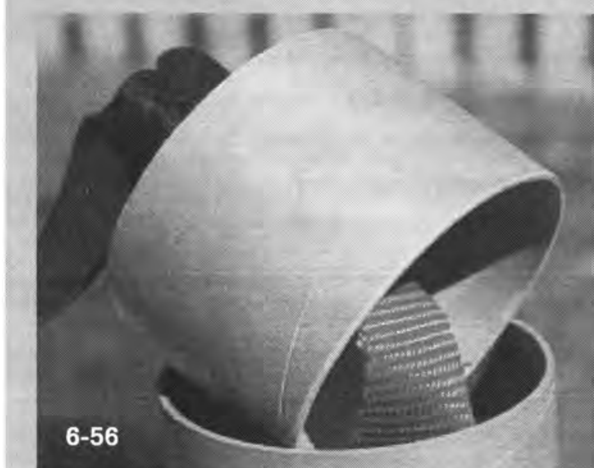
At a minimum, always protect the parachute with some type of heat-resistant or fireproof cloth, such as Nomex, which is placed between the ejection charge and the parachute. Heat-resistant cloth is available from most high-power rocketry retailers. The cloth usually slips on one end of the shock cord or recovery harness and is placed right above the charge. One cloth can be used for many flights. See photo 6-53.


6-54

Another method used to protect recovery equipment from ejection-charge gases is the use of a piston-style ejection system. See photos 6-54 through 6-57. This mode of ejection–made popular by the many Public Missiles Systems rockets that utilize it–places a piston between the ejection charge and the parachute. The gases from the ejection charge force the piston to move forward along the vertical axis of the rocket, leading to separation and deployment. When properly in-

Piston Ejection


6-55


6-56


6-57

stalled, the piston prevents any gases from coming into contact with the recovery components. When using piston-style ejection, be sure to check the piston for a good fit after each flight. If the piston does not slide in and out of the airframe easily, it may get stuck on the next flight.

You can also shield recovery equipment from ejection-charge damage by building a baffle between the charge and the parachute. In his article "Anti-Zipper Design" in the January 2004 issue of *Extreme Rocketry*, Brad Vatsaas describes a system that provides good protection from ejection charge trouble. Vatsaas places a bulk plate between the ejection charge and his recovery equipment. The bulk plate is thick enough to allow him to drill multiple holes in the plate–almost like Swiss cheese. On the underside of the drilled-out bulk plate, Vatsaas fastens a couple of wire mesh kitchen scrubbers. The ejection charge is located beneath the wire mesh scrubbers. When the charge ignites, the wire mesh allows the gas to pass through the scrubbers (and then through the bulk plate holes) while arresting the flame and catching any hot particles from the charge.

6-58

A shunt or switch to make "safe" on-board ejection charges is required for a NAR Level Three certification attempt and is used by many rocketeers on projects of all sizes.

Recently, Tom Rouse of San Jose, California, has released a product that eliminates the use of black powder altogether for ejection charges in high-power rockets. Rouse's system, known as CD3, utilizes carbon-dioxide to cause separation and deployment. This system is more expensive than ordinary black-powder charges, but it may be useful to the rocketeer aiming for extreme altitudes where the efficiency of black powder may be low. This system also eliminates the need for wadding or heat-resistant cloth to protect the parachute from hot ejection gases.

Safety and Ejection Charges

Always treat a loaded ejection charge as carefully as you would handle a loaded gun. Consider it armed, unless you know for certain otherwise.

Never point a rocket in the direction of a person if the rocket has an ejection charge on board. At almost every regional rocket launch, one will hear stories of electronics-activated charges that suddenly fired while a rocketeer was preparing his or her rocket under a tent, or while testing electronics, or "suddenly" on the launch pad. The cause of these misfires is usually human error, but often the cause is never determined. It happens. Do not let it happen to you.

Pay careful attention to the instructions of any electronics used in your rocket when it comes to ejection charges. Some manufacturers caution users not to turn their altimeters on and off again quickly, as this may lead to a firing of the ejection charge. Other makers warn against arming an altimeter or timer while a rocket is horizontal on the pad and then raising the rocket too quickly to the vertical position. This movement may cause the on-board electronics to mistakenly fire the charge.

Do not look directly into a rocket airframe that contains a live charge. Again, these charges can fire prematurely and without warning. If for some

6-59

On-board ejection charges will sometimes fail to go off during flight. So a rocket's charges may still be armed after landing. For this reason, wait for the owner before getting too close to any rocket. Do not touch a downed rocket without the owner's permission.

reason you do have to peer into a rocket tube with charges on board, wear eye protection. In fact, it is always a good idea to wear eye protection whenever you handle ejection-charge materials.

Many rocketeers build safety mechanisms into their ejection-charge circuits to protect against accidents. This is usually accomplished by wiring a shunt or switch into the ejection-charge/igniter/altimeter circuit. When armed, the shunt or switch prevents any current from reaching the igniter head–even if the altimeter mistakenly sends an electrical signal. The switch or shunt is not disarmed until the rocket is vertical and on the launch pad. This procedure is known as "safing" the ejection charge. It is a requirement for Level Three certification flights with NAR.

6-60

A safety switch of some kind is a good idea, although it is generally not required in high-power rocketry with the exception of NAR Level Three certification flights (see Chapter 14). Of course, some people prefer not to add additional switches or shunts to their already complicated recovery systems, as additional devices can mean another opportunity for breakdown. But careful planning should prevent this.

Finally, always approach a rocket that has returned from flight with caution. Many high-power rockets are equipped with multiple ejection charges. Sometimes not all of these charges are triggered during flight. So never touch any rocket that has landed without verifying that the charges have all been blown or without the owner's express permission. This is common rocketry etiquette and an important safety rule.

The RSO

Every high-power launch field has a Range Safety Officer, or RSO. The RSO inspects rockets prior to launch and has responsibility for safety on the field. The RSO is usually a member of the local club and a Level Two or Level Three flyer. At many launches, club members take turns during busy launch days doing RSO duty. It is a good way to meet new members and an important part of any high-power launch. Tripoli has recently published a set of guidelines for RSO duty. They are available on Tripoli's web site.

7

Launching the High-Power Rocket

The basic operations of a high-power rocketry event

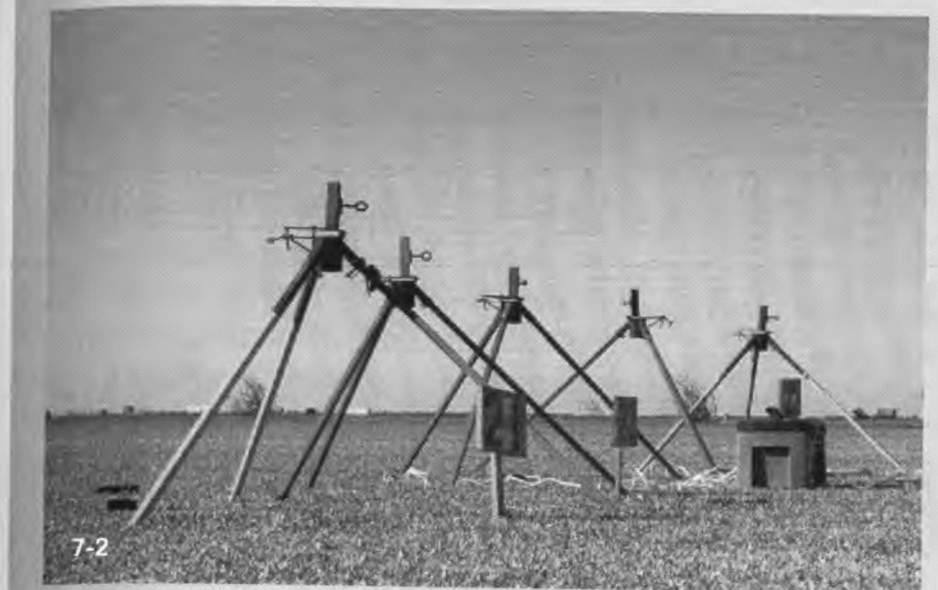
The purpose of this chapter is to review the basic operations of a high-power launch. The chapter will also review the safety and legal requirements for launch fields and the use of high-power launch equipment, especially launch pads.

The High-Power Launch

High-power rocket launches are held all over the United States and are, for the most part, organized and sponsored by local chapters of Tripoli or NAR. Most are open to spectators, but you must generally be a member of either Tripoli or NAR to launch a high-power rocket.

A high-power rocketry field operates like a gun range. The range is operated by one or more Range Safety Officers (RSOs). The Code for High-Power Rocketry provides that the RSO must be "a certified user with the overall responsibility for the safety, setup, and launching of all rockets at a high-power rocket launch."

The rockets are launched by a



At most launches, the local club maintains the launch equipment. The equipment consists of multiple launch pads, signs for the pads, control-box equipment, and other items necessary for the launch.

Launch Control Officer (LCO). At most ranges, the LCO will broadcast over a loudspeaker (or a radio system) a countdown that ends with the push of a button and the subsequent launch of a rocket from the appropriate pad. Either the RSO or the LCO (or both) will "open" or "close" the range. When the range is open, people are allowed to walk to the launch pads, load their rockets, connect igniters, and return to the spectator area. When the range is closed, all unauthorized persons must clear the launch area so that launching can begin.

A launch pad that tilts is helpful when loading large rockets, such as this 7.51-inch V2 replica.

The Duties of the Range Safety Officer

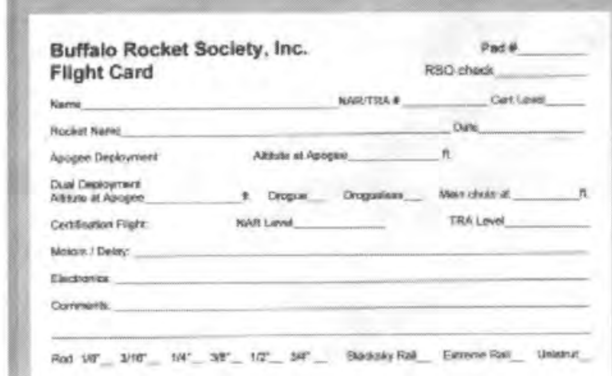
Prior to launch, the owner of the rocket fills out a flight card and presents the card to the RSO, who is usually sitting at the RSO table. Although there is some variation in the format of the cards used around the country, most flight cards ask for the rocketeer's name and his or her NAR or Tripoli number and certification level. The cards also ask for basic information about the rocket to be flown, such as its weight, the type of motor used, the type of igniter used, and whether this is the first flight of the rocket. The flight card may also ask about electronics (if any) that are in the rocket and what type of launch pad the rocket will require (rod, rail, or other). The rocketeer fills out the form, signs it, and then presents it to the RSO. The RSO will review the card and then inspect the rocket. If everything is in order, the rocket is cleared for launch and assigned to a pad.

The Code for High Power Rocketry mandates inspection by the RSO of any rocket before it is launched. But there is a lot of variation in how the inspections are performed. Still, a few common denominators emerge. The RSO will review the flight card, look at the fins (are they straight?) and the motor retention (will it work?) and will probably ask the builder if the rocket has flown safely before.

Flight CARDS

Most high-power rocketry clubs have flight cards that must be filled out prior to the launch of every rocket. The basic information on the cards is similar, but there is some variation around the country. Shown below are three examples, from South Carolina, New York, and California, respectively.


ROSCO
Owner:
NAR #:
Rocket Name:
Configuration: □Single-Stage □Multi-Stage □Clustered
□Scale □Payload
Recovery: □Parachute □Streamer □Tumble □Helicopter □Glider
□Other
□Altimeter Brand:
Main @ ft.
Backup @ ft.
Certification Attempt for □NAR □TRA □Level 1 □Level 2 □Level 3
Certification Team:
□Heads-Up Flight
LAUNCH CREW USE ONLY
□Safety OK (INITIALS)


Buffalo Rocket Society, Inc.
Flight Card
Pad #
RSO check
Name NAR/TRA # Cert Level
Rocket Name Date
Apogee Deployment Altitude at Apogee ft.
Dual Deployment Altitude at Apogee ft. Drogue Drogueless Main chute at ft.
Certification Flight: NAR Level TRA Level
Motors / Delay:
Electronics:
Comments:
Rod 1/8" 3/16" 1/4" 3/8" 1/2" 3/4" Blacksky Rail Extreme Rail Unistrut


TRIPOLI CENTRAL CALIFORNIA FLIGHT RECORD
Date: 8-15-02 Rail/Rod Size: 1/4
Certification Flight? Level: □1 □2 □3 Prefect/TAP Observer:
Your Name/City: Team DWS Tripoli/NAR#: Current Cert. Level: 2
Rocket Name: Color: of Rocket?
Rocket Length: 43 Diameter: 2.5 Liftoff Weight: 2.5 lb oz
Rocket Built From: □Kit Manufacturer: □Custom Modifications:
Motor(s): H45 Igniter Type/ Ohms:
Recovery: □Motor Ejection □Electronics (main only) □Dual Deployment □Other:
Electronics: Altimeter Reading: Ft
Please sign here:
Check here □ for additional notes on reverse side
LCO Post-Flight Evaluation: □Good Flight □Motor Failure □In Flight Failure □Recovery Failure
LCO Comments:

The RSO may quickly analyze the thrust-to-weight ratio of the rocket. If the rocket is from a well-known kit and appears to be well built, then the inspection may be short. If the rocket is an unusual scratch-built design, then more questions may be asked: "Where is the center of gravity? Where is the center of pressure?" The more complicated the rocket, and the bigger the rocket, the more questions will be asked. If the builder is known at the field and has a reputation for building safe rockets, then the inspection will be quicker than for a stranger or for someone who is known for crashing rockets.

In any event, it is up to the judgment of the RSO whether the rocket will fly or not. The RSO has the ultimate authority on the field to make this determination and his or her decision may not be overturned by anyone else on the field. Of course, the builder of the rocket is always free to try to persuade the RSO to reconsider by providing additional information or flight data to the RSO.


7-4

Once the RSO or the LCO declare that the range is open, all rockets that are assigned to pads are carried out by their owners and set up for flight. Each rocket is placed on the launch pad and the electronics (if any) are armed. There are usually two alligator clips next to every pad. These clips are connected by wire that runs all the way back to the main control box. The rocketeer hooks up the igniter leads to these alligator clips and then inserts the igniter into the rocket motor (or installs the igniter and then attaches the leads).

When all of the rockets have been set up and the users have cleared the field, the range is closed again, and rockets are launched individually, with countdowns of at least five seconds. Each rocketeer must be prepared to keep track of his or her rocket in flight; no one is allowed to chase a rocket on the range until the range is opened again. No one is allowed to enter or cross the range unless authorized to do so by the RSO or LCO.


7-5

The Launch Field

The launch- field requirements for high-power rocketry are contained in NFPA 1127 Section 4.14-4.18. These sections contain tables for overall launch-site dimensions, launch-pad clearance distances, and minimum distances for spectators and participants.

Minimum Field Size

Installed Total Impulse (N-sec)	Motor	Minimum Site Distance (feet)	Equivalent Distance (miles)
160.01-320.00	H	1,500	.30
320.01-640.00	I	3,000	.60
640.01-1280.00	J	5,280	1.00
1280.01-2560.00	K	5,280	1.00
2560.01-5120.00	L	10,560	2.00
5120.01-10240.00	M	15,480	3.00
10240.01-20480.00	N	21,120	4.00
20480.01-40960.00	O	26,400	5.00

Source: NFPA 1127 (2002)

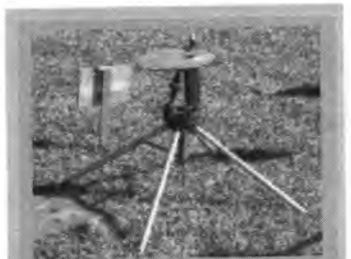
Diagram 7-1

Determining the Size of the Field

The appropriate dimensions for a high-power rocket launch field may be calculated in one of three ways. The first two ways are based on altitude. Section 4.14.2 provides, in pertinent part, that the minimum field size can be no less than one half the maximum expected altitude waiver given by the Federal Aviation Administration (FAA) or other authority having jurisdiction. What does this mean? All high-power rocket launches are held under an altitude waiver granted by the local office of the FAA, discussed below. If the waiver for a particular club is 17,000 feet, the minimum field

The LCO

At most fields the actual launch of each rocket is performed by the Launch Control Officer, also referred to as the LCO. The LCO is usually a Level Two (or Level Three) flyer who operates the club's electronic launch-control system. Each launch pad is numbered and connected by wire or cable to a switch on the main control box. The LCO will call out a countdown of at least five seconds and then hit the switch and launch the rocket. The LCO will also open or close the range and watch out for aircraft or obstacles on the field.

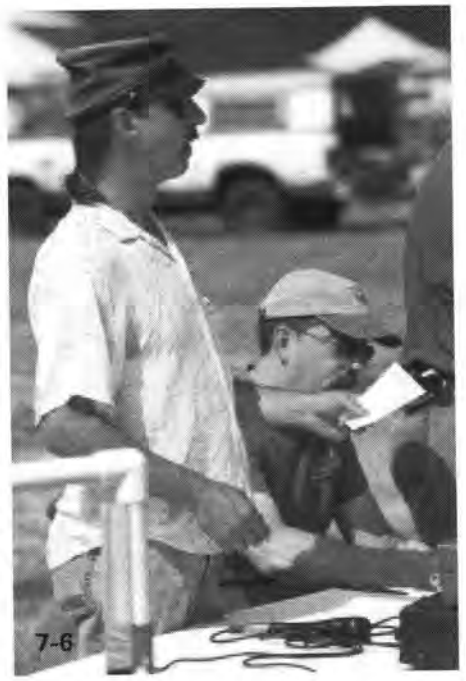


The HOST

The type of field for high-power launching varies all over the country. In some states, launch fields are located on government land. In other locations, launches are held on private property, such as airfields or open land. The most common locations seem to be large farms where the property owner has graciously allowed the local high-power rocketry club to host events one weekend a month, subject to the crop cycles on the property. Such property owners are the unsung heroes of high-power rocketry.

dimension can be 8,500 feet (one half of the FAA waiver of 17,000 feet). In the alternative, if on that same field the highest rocket launch of the day is expected to be only 5,000 feet (as calculated or simulated), the minimum field dimension may be as little as 2,500 feet (one half of the maximum altitude expected).

Another way to determine the appropriate size field for a high-power launch is to use the launch site dimensions table provided by the NFPA. As shown in Diagram 7-1, this measure is based on motor size. The larger the motors to be flown, the bigger the field needed for flight. For example, an H motor requires a minimum field of only 1,500 feet. An M motor, on the other hand, requires a minimum field of 15,840 feet–or three miles.



7-6

LCO Wayne Anthony prepares to launch a rocket at LDRS23 in New York.

How is the field size actually measured? That depends on whether the field is circular or rectangular. Section 4.14.2.1 provides that, for a circular launch field, the minimum launch dimension shall be the diameter of the circle. If the local club has a circular field and is launching motors up to a K, then the diameter of the field must be, at a minimum, 5,280 feet, or one mile.

Section 4.14.2.2 provides that for a rectangular field, the minimum launch dimension is that of the shortest side of the field, which makes sense. If the field is one mile long (5,280 feet) by a half mile wide (2,640 feet), only the shorter side of the field is relevant to the minimum field calculation. In this case, the short side of the field is 2,640 feet. According to the dimensions table, the field may handle an H motor, but not an I or larger.

Launch Pad Location and Minimum Safe Distances

The safety codes of both Tripoli and NAR (and the NFPA) also set forth the locations of the launch pads at a high-power rocket launch. The minimum safe-distance requirements for the average high-power rocket are noted in Diagram 7-2 (NFPA). At most launches there are at least three different launcher locations. The first set of pads– closest to the RSO or LCO table–is usually the model-rocket pads. The next set is typically between 150 and 200 feet from the flight line and can handle high-power motors in the H, I, J, and K range. Beyond those pads, and at least 300 to 500 feet out from the LCO table, are pads reserved for large rocket projects that will be launched on L or M motors, respectively.

Minimum Pad Distance

Installed Total Impulse (N-sec)	Motor	Minimum Safe Distance (feet)	Complex Minimum Safe Distance (feet)
160.01-320.00	H	100	200
320.01-640.00	I	100	200
640.01-1280.00	J	100	200
1280.01-2560.00	K	200	300
2560.01-5120.00	L	300	500
5120.01-10240.00	M	500	1,000
10240.01-20480.00	N	1,000	1,500
20480.01-40960.00	O	1,500	2,000

Source: NFPA 1127 (2002)

Diagram 7-2

Complex rockets have a slightly different set of rules for safe distances. A complex rocket is defined by the Code for High-Power Rocketry as "a rocket that is multi-staged or propelled by two or more rocket motors." The correct distance for complex rockets is also set forth in Diagram 7-2. (Note: Launch-field safety and dimensions tables are also found in the safety codes of Tripoli and NAR. They are very similar to, if not the same as, the NFPA distances.)

The FAA Waiver

Most, if not all, high-power rocketry launches must obtain a waiver from the Federal Aviation Administration (FAA) to launch rockets in the airspace above the United States. The Application for Certificate of Waiver or Authorization is available online from the FAA.

A waiver allows the local rocketry club to launch rockets up to a particular altitude for a specific period of time. For example, the waiver granted by the FAA may be on the third Sunday of every month, to an altitude of 17,000 feet, from 9 A.M. to 6 P.M. During those hours, the club may launch rockets to any altitude not exceeding 17,000 feet. The local FAA office will issue a written bulletin advising pilots of the waiver. Pilots are to avoid that area for the duration of the waiver. Of course, sometimes a plane may wander into the airspace above the launch field. If that occurs, launching stops immediately until the

The WAIVER

The airspace over much of the United States is controlled by the Federal Aviation Administration. Therefore, most high-power rocketry events must be conducted pursuant to a waiver granted by the FAA. The altitude of the waiver depends on the location of the field. The waiver is obtained by the local club and is confirmed for a set period of time. It is renewed on a periodic basis. Applications for a waiver are available online from the FAA. Look for FAA Form number 7711-2. The web site for the National Association of Rocketry has excellent advice for filling out that form. Keep in mind that, regardless of any waiver altitude, all launching stops if any aircraft approach the field.

Setting up the Launch Field

Spectator and launch-preparation areas

There is no single way to configure a high-power launch field. The only requirement is that the launch pads be set up at appropriate distances from the spectator and preparation areas. In this simplified example, the field can handle eight model rockets and 14 high-power rockets at one time, through M motors.

Diagram 7-3

aircraft has cleared the area. The altitude of the waiver varies from club to club. Fields located in rural communities generally have higher waivers granted by the FAA than fields located near urban centers or airports. The waiver at places like Black Rock, Nevada, may exceed 100,000 feet. But most waivers range from 3,000 to 25,000 feet, depending on the location of the field.

To determine the waiver for your field, check with the local NAR or Tripoli officers. Waiver information is often included on a club's web site.

Additional Safety Concerns on the Field

The safety codes also specify a number of common-sense rules pertaining to launch fields and launch operations.

For example, NFPA 1127 requires that all spectators at a high-power launch remain behind the RSO and the person launching the rocket. A high-power rocket shall be launched only in an outdoor area where tall trees, power lines, and buildings do not present a hazard. And all individual launches must be preceded by a countdown of at least five seconds that is audible throughout the launch field, spectator, and parking areas.

No person shall be permitted to launch a high-power rocket horizontally, or at a target, or so that the rocket's flight path goes into the clouds or beyond the launch field, or is hazardous to aircraft. The launch pad cannot be used to launch a high-power rocket at an angle greater than 20 degrees from vertical.

High-power rockets are not to be launched if the surface wind on the field is more than 20 miles per hour. High surface winds can wreak havoc, causing instability in a rocket's flight path. When in doubt, avoid flights on windy days, especially with smaller, lightweight rockets or bigger rockets with very large fins.

For a complete list of all of the safety codes related to a high-power field, review NFPA 1127 and the safety codes of Tripoli and NAR.

7-7

The launch of the Max Q in the Black Rock Desert in 2000 required a special pad and a lot of hands to get the 500-pound rocket in place prior to flight.

The High-Power Launch Pad

The purpose of the launch pad is to provide the rocket with stable and rigid guidance until the rocket attains enough velocity to achieve aerodynamic flight. In most cases, the launch pad will have a rod or rail that keeps the rocket pointing in the right direction prior to flight. A launch lug or a rail button attached to the rocket guides the rocket along the rod or rail after ignition.

NFPA 1127 Section 4.14 provides that any launching device or pad shall have a blast deflector, if necessary, to prevent the rocket motor exhaust from impinging directly on flammable materials. Section 4.15.1 provides that the area around each launch pad shall be free of any easy-to-burn materials (dry weeds, brown grass, etc.) for 50 to 150 feet, depending on the size of the motor in the rocket. The bigger the motor, the larger the distance that must be made safe around the pad.

There are three basic types of launch pads: rod, rail, and tower. The most common pad is probably the rod, although rails are quickly gaining ground.

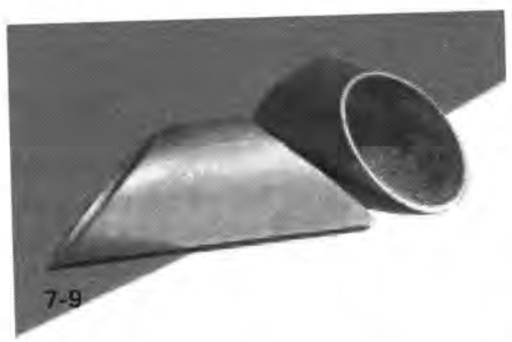
Rod-Type Launch Pads

A rod-type launch pad is used for rockets equipped with launch lugs. Launch lugs are usually nothing more than hollow sleeves of cardboard or metal which are fastened to the rocket, usually with high-strength epoxy. The hollow lugs slide down the steel rod that is fastened to the base plate of the launch pad. The purpose of launch lugs is to guide the rocket along the rod after motor ignition.

High-power rockets typically have at least two well-aligned launch lugs attached to the side of the airframe. When the rocket is brought out to the pad, it is lowered onto the rod so that both lugs slide over the rod and hold the rocket vertical for launch. Ideally, the rod may be unlocked and moved into a horizontal position for mounting the rocket. In other cases, the entire pad assembly is simply tilted over at an angle so the rocket lugs can be aligned and placed on the rod. After the lugs have engaged the rod, the road and rocket are then raised to the vertical position and the rod is locked in place. Launch pad rods come in an assortment of sizes, usually ranging from ¼" to 1 inch in diameter. There are no set rules as to what size launch lugs must be used with a given rocket.

As always, common sense plays a role. The larger and heavier the rocket, the larger the diameter of the lug and rod needed to keep the rocket steady on the pad. *Extreme Rocketry* magazine assistant editor Tim Quigg recommends that a ¼-inch rod be chosen for rockets up to three pounds and suggests 3/8" or ½" lugs are good for rockets up to 20 pounds. On rockets over 20 pounds, Quigg recommends lugs at least ¾" in diameter. These are good guidelines for the average high-power rocket.


7-8


7-9


7-10

There are three types of launch pads: rod, rail, and tower. The purpose of each is the same: To provide the rocket with stable and rigid guidance until it achieves sufficient velocity for aerodynamic flight. Above: Tom Binford (left) and Randy Trotter place Binford's Nike on a rod-type pad. Left, center: A close-up shot of rod-type copper launch lugs. Left, below: A close-up of three unistrut rail guides.

Rail-Type Launch Pads

Rail-type launch pads have gained popularity in the last several years. Rails are made of rigid, extruded aluminum sections that are bolted together to accommodate rockets of almost any size. To use a rail, a rocket must be equipped with rail buttons. A rail button slides down a channel that runs the length of the rail, securing the rocket to the rail for launch. The rail button serves the same basic purpose as a launch lug: It guides the rocket in the first moments after motor ignition.

Rail buttons come in a few different sizes but are similar in appearance. Most rail buttons are made of nylon or hard plastic and have a hole in the middle through which a screw passes. The screw is used to attach the button to the side of the rocket and into a bulkhead, if possible. Usually, at least two rail buttons are used per rocket, although on larger and heavier projects additional buttons may be necessary. Some rail guides are not buttons at all. For example, Acme makes conformal launch lugs for rails which simply attach with epoxy to the side of the rocket's airframe.

There are a couple of distinct advantages in using a rail system over traditional launch lugs and rods. First, rails are usually much sturdier than rods and provide for better overall support for rockets on the pad–especially tall rockets or big, heavy projects. Many Level Three rockets use rails for launch.

Second, because of their sturdy design, rails have almost no flex, or rod whip, at launch. This eliminates the possibility that too much flexibility in the rod will whip the rocket in an unintended direction.

Very large rocket projects often use another form of rail, called the unistrut. Steel unistrut sections are available at home improvement stores in sections up to 12 feet long. They are rigid and strong, and they can easily handle rockets that weigh in the hundreds of pounds. Unistrut launch pads require larger rail buttons than regular, aluminum rail guides.


7-11

Dennis Lappert, right, and a friend load Lappert's M-powered rocket on a unistrut rail at LDRS23. The rail guides must line up with the unistrut channel.

Still, the decision to use a rod or rail usually depends upon personal preference. For the average high-power rocket, either system works well.

Installation of Lugs or Buttons

If you are building a high-power rocket from a kit, follow the kit's instructions as to placement of the launch lugs. Placement of the lugs usually begins with drawing a perfectly straight line up the side of the rocket body. The line should begin at the aft end of the rocket at the mid-point between any two fins. To ensure that the line is straight, use a chalk line, T-square, or door-jamb as a guide. The lugs will be attached at two different points along the line. Generally, epoxy is used. Place the first lug toward the aft end of the rocket between any two fins. The second lug will go forward on the line within a body diameter or two of the center of gravity of the rocket. Slicing the leading edges of the lugs at an angle may help reduce drag.

Placement of rail buttons requires a little more planning because the ideal method of securing the button is to have the screw pass through the airframe and into a bulkhead. On most projects, the aft and forward motor-centering rings are ideal for this purpose. The button should be gently screwed into the bulkhead, with a drop of epoxy for additional strength. On lightweight rockets that are to be retrofitted with buttons, epoxy alone may work for securing the button to the side of the rocket. However, for large and heavy projects, three buttons secured to internal bulkheads are better for securing the rocket at the pad to the rail. In addition, heavy projects may require the use of barrel nuts or T-nuts installed in the bulkhead to receive the rail button screws. (For examples of launch-lug or rail installations, see chapters 11, 12, and 15.)

7-12

A rocket loaded with a Frank Kosdon Q motor awaits launch from a tower at the Black Rock Desert in Nevada in 2004.

When planning your rocket, always keep in mind the type of launch pad that you intend to use. Most clubs now have a full selection of rods and a rail or two. But if your project is large or unusual, do not assume that on launch day the local Tripoli prefecture or NAR section will have a rail or rod for you. Many a certification flight has been cancelled because on launch day the rocketeer showed up unannounced, and the local club did not have a launch pad that would work with the rocket, or the pads available would not accommodate a special rail or lug that was part of the rocket. So always check first–and be prepared to bring your own pad if necessary.

Launch Towers

A launch tower requires neither rail buttons nor launch lugs. Yet towers are an excellent way to provide guidance to a rocket at launch, particularly high-altitude projects. At Tripoli's annual experimental launch held at the Black Rock Desert in 2004 there were several minimum-diameter, high-altitude rockets loaded with N, O, P, and even Q-motors.

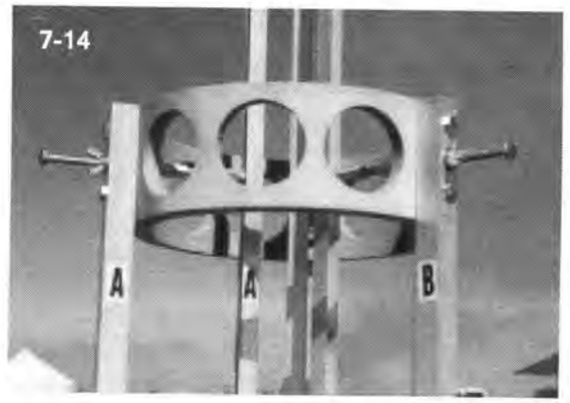
7-13

A tower launcher is popular for rocketeers who want to eliminate lugs or buttons. This helps reduce drag and is useful for rockets built to achieve high altitudes. Here, Tripoli members Bruce Rohn (left), Nathan Montalvo (center), and Larry Friesen load a minimum-diameter rocket built by Friesen into a launch tower in Riverdale, California.

Each of these rockets was launched on a tower. A tower usually has three or more adjustable guides or strips that run vertically the full length of the tower. These guides can be adjusted to fit the diameter of the rocket.

A tower houses the rocket with the aft end of the rocket resting on the blast deflector and the nose cone facing the sky. At launch, the rocket is guided by the adjustable strips into the air. Since the rocket has no lugs or buttons attached to the side, the use of the tower is attractive to extreme- altitude flyers who want to do as much as possible to reduce the effects of drag during flight.

7-14



The upper section of NAR member David Fitch's homemade tower. Fitch constructed the tower using various materials from Home Depot that cost around $75, and by applying his machining skills.

Launch Pad Standoffs

One of the least-appreciated components of any launch system is the importance of a good standoff at the pad. A standoff is anything that provides for some space between the blast deflector (base of the pad) and the bottom of the rocket. Once your rocket is on the pad you will need some working space to install igniters and otherwise ensure that the bottom end of the rocket is ready to go. You do not want the rocket to simply sit flat on the pad, especially heavy rocket projects.

Some clubs have metal standoffs scattered about in the area of the high-power pads, but many do not.

So at the last minute rocketeers are often seen scrambling from pad to pad, looking for anything to use as a standoff. And just about anything can be used–from rocks and pieces of wood (see photo 7-15) to aluminum soft-drink cans. On small-diameter rods, masking tape can be used to accomplish this purpose.

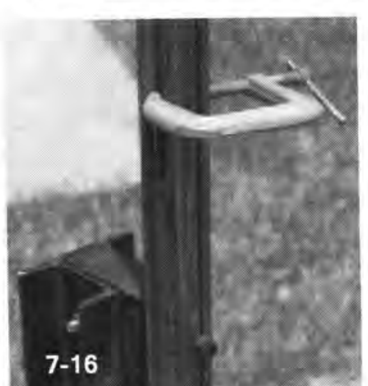
It's better to be prepared. Bring your own standoff, whether it be a piece of metal, a chunk of lumber, or a metal C-clamp. See photo 7-16. Magnum Rockets now sells stainless steel standoff units that attach to rods up to ¾" in diameter for under $20. Giant Leap Rocketry has available "rail stops," which fit in the channel of most rails and will hold in place a rocket up to 200 pounds. The cost is less than $10.

7-15

Commercial Pad Manufacturers

There are many commercial manufacturers of launch pads. Picking the right one for your rocket depends on the rocket's size and weight and whether you choose to launch with a lug or rail system, or with a tower.

Most Tripoli or NAR clubs have a collection of several different types of launch pads that the novice can get acquainted with as they enter high power. Commercial retailers of high-power pads include Magnum Rockets, blacksky, Rocketman, and Yellow Jacket Systems, to name a few.



7-16

Don't forget a standoff. A piece of wood, a C-clamp or some other device is necessary to allow space between the aft end of the rocket and the blast deflector.

Fundamentally, a launch pad provides a stable platform for your rocket. This often depends on the overall size and weight of your project and the footprint of the launch pad. A pad's footprint merely refers to the overall size of the area occupied by the pad's legs as they extend out from the center of the pad. A bigger, heavier rocket needs a larger footprint than a small, lightweight rocket. When purchasing a commercial launch pad, review the manufacturer's description carefully. Most pad makers provide footprint information. Manufacturers also will provide the maximum recommended rocket weight for each particular model.

A launch pad also should have some elevation control. Although it is easy to tilt over entire small pads so that a rocket may be loaded on the rod or rail, larger pads should have an adjustment devise to raise or lower the rod or rail for loading.

Care of Launch Equipment

One of the biggest rocketry club challenges is keeping launch equipment clean. Launch rods and rails take a lot of abuse during a typical weekend launch. Repeated flights leave rods and rails dirty and covered with chemical debris. If this debris is not periodically cleaned off, the equipment can become corroded, and so much debris can build up that the rod will no longer fit through a launch lug, or a rail button will get stuck in the channel of the rail.

At a large regional launch in South Carolina last year, a novice rocketeer placed his H-motor rocket on a rod that had been heavily used throughout the weekend. The owner of the rocket had a little trouble pushing the lugs on the rocket down the

7-17

A launch pad with elevation control is helpful when placing your rocket on the pad. Here, Orangeburg flyers Ed Fenton (left) and Robert Carson have lowered the launch rail to allow for easier alignment of the rail button for insertion into the rail channel. When the buttons are engaged in the channel, the rail is raised to vertical.

rod, but it seemed to fit, and so the rocket was readied for launch. At ignition, the rocket moved about an inch, then spit fire and smoke out the aft end as the motor burned for its full two seconds. After a brief delay of a few more seconds, the ejection charge fired, deploying the parachute over the rocket and the pad. It was entertaining, but not what the rocketeer had in mind.

Upon inspection, it became clear that, not only were the lugs a little on the tight side for this particular rod, but also that the rod itself was caked with debris from a long day of activity.

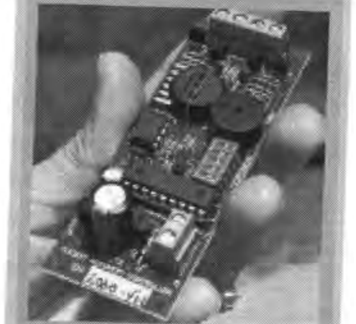
7-18

Rocketeers in Florida carefully place a full-scale Nike Smoke on the pad in anticipation of launch on an experimental motor with a total impulse of 45,000 newton-seconds in 2004.

The obvious lesson here: If the launch lug gets stuck on the rod after ignition, then the rocket won't go anywhere. This may earn you the "closest to the pad" award, but it is a waste of a good motor and can damage your rocket. Fortunately, it is easy to avoid.

Always keep a bit of sandpaper or other coarse material in your rocketry toolbox, or, better yet, in your pocket. When it is your time to load your rocket on the pad, swipe the sandpaper along the length of the rod or rail. This will ensure that your launch will not be affected by debris on the rod and will help keep the system in working order for everyone else.

Do not force the lug over the rod, either. Snug is ok--tight is not. If the fit seems too tight, it probably is. Go back to the RSO or LCO, and ask to be assigned to another pad.



The ALTIMETER

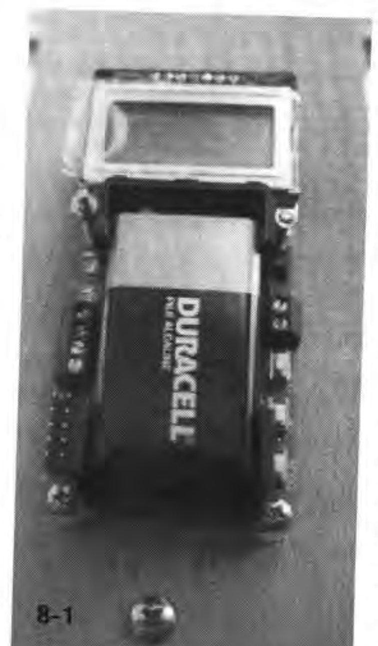
As recently as the early 1990s, there were few commercial suppliers of altimeters for high-power rocketry. And what was available tended to be bulky and expensive. That has all changed. Altimeters are now the most common electronic device used in high power and can be found in rockets at every launch in the country. Altimeters are not only relatively inexpensive, but are available from many makers, including Adept, blacksky, G-Wiz, Loc/Precision, Missile Works, Olsen, and Transolve.

8

High-Power Electronics

Understanding the common electronic components in high-power rocketry

The purpose of this chapter is to provide a general overview of electronics in high-power rocketry. This review will include discussion of altimeters, timers, stagers, beepers, transmitters, and GPS tracking devices. In the following chapter, we'll discuss and illustrate the common ways altimeters and other electronics are mounted in high-power rockets.



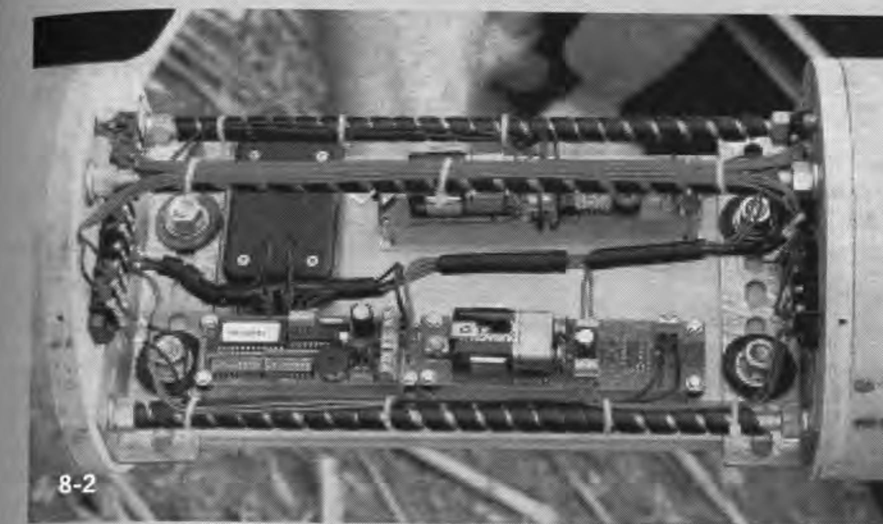
8-1

Altimeters

Altimeters are the most common on-board electronic devices used in high-power rocketry. Altimeters perform at least two functions in high power. First, altimeters are used to activate ejection charges in the airframe of the rocket. The ignition of these charges releases gases that over-pressurize the interior of the rocket. This leads to separation of the airframe and deployment of the recovery harness and parachute.

Second, altimeters also record altitude. Many modern altimeters used in high-power rocketry record not only the rocket's highest altitude, but also track and preserve large amounts of in-flight data, including flight acceleration and the timing of in-flight events (e.g. apogee, mach, burnout, etc.).

There are two basic types of altimeters: pressure altimeters and accelerometers. Pressure altimeters operate on the principle that atmospheric pressure decreases with elevation. These altimeters contain aneroid wafers–



8-2

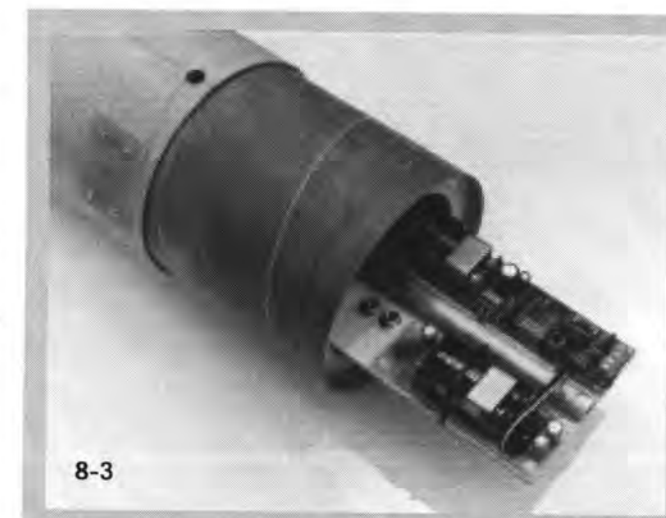
The altimeter bay of Chuck Neff's Level Three certification rocket, which flew successfully at Whitakers in North Carolina in 2004. Back-up altimeters, timers and other electronic devices are now a common sight in high power.

thin metal canisters sealed with a known pressure reference inside. A static or outside air source is connected to the altimeter, exposing the wafers to outside atmospheric pressure. As the rocket climbs or descends, the wafers expand or contract. The altimeter translates these changes in barometric pressure into measurements of altitude in feet.

Accelerometer altimeters analyze changes in the velocity or acceleration of the rocket. An accelerometer analyzes a high-power rocket's velocity, over time, to obtain a measure of distance–or altitude.

To function properly, most accelerometers use a tiny G-switch or similar device, which is triggered by the rocket's acceleration at launch. This G-switch must be placed in the rocket in the proper position and orientation to monitor launch and acceleration. For this reason, accelerometer altimeters offer written orientation instructions such as "THIS END UP" "NOSE END" or "SKY" to help with mounting. The instructions are usually stamped on the face of the altimeter.

Both pressure altimeters and accelerometers work well in high-power rockets. However, they do have their drawbacks. For example, barometric-pressure altimeters must be vented to outside air to work properly. As discussed in detail below, failure to properly vent the altimeter bay can result in false altimeter readings and even early deployment. Pressure altimeters are also susceptible to pressure fluctuations if the rocket's speed exceeds mach one. These fluctuations can lead to early deployment at high speed. However, most barometric altimeters now come with provisions to override problems associated with mach speeds.



8-3

The electronics of Scott McLeod's Level Three rocket. Photo courtesy of Scott McLeod.

Accelerometers, by contrast, do not require a vented altimeter bay, nor are they sensitive to pressure fluctuations or speeds in excess of mach. However, accelerometers may not be as accurate in measuring altitude as barometric pressure altimeters. This is because an accelerometer measures altitude as a function of acceleration and time. In other words, the accelerometer directly measures the rocket's acceleration and from this *calculates* velocity; the velocity, multiplied by the time the rocket is moving, gives the distance traveled, or altitude. As author John Wahlquist noted in his article "Rocket Electronics 101" in *High Power Rocketry* magazine, the distance traveled will only be equal to altitude if the rocket flies in a perfectly vertical trajectory. This does not always occur in high power. Nevertheless, accelerometers provide a pretty good measure of altitude and work well for most high-power rockets.

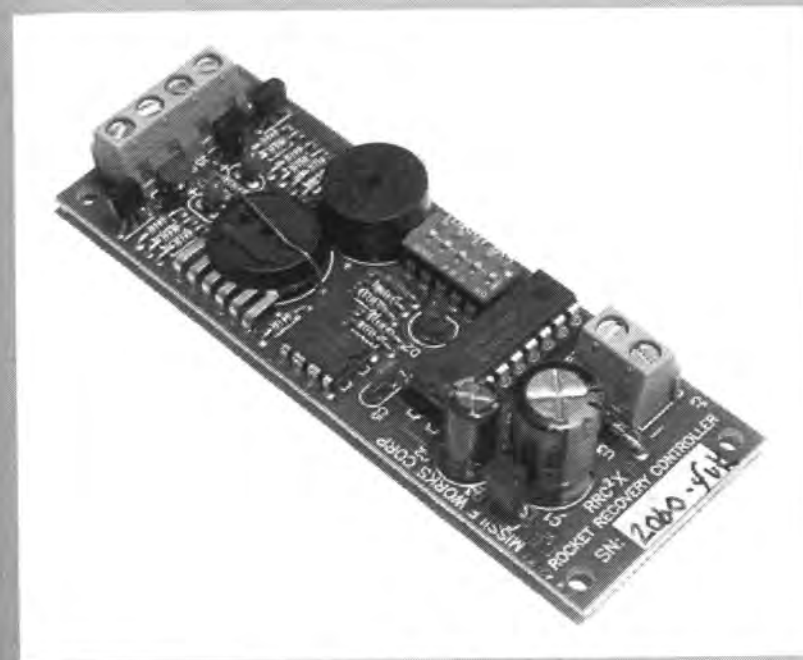
8-4

This 700-pound Black Brant, launched in Northern Nevada in 2004 by Wedge Oldham, carried multiple on-board altimeters to ensure parachute deployment. The rocket reached more than 18,000 feet and was recovered safely.

Buying Your First Altimeter

As recently as a decade ago, there were few commercial altimeters in high-power rocketry. And what was available tended to be bulky and expensive. That has all changed. Altimeters are now the most common electronic device used in high-power rocketry and can be found in rockets at every high-power launch in the country. In fact, altimeters are practically a requirement in rockets that are built for Level Three certification, or for any rocket with a combined total impulse of over 2,560 newton-seconds. Today, the high-power rocketeer can choose an altimeter from any of several reputable manufacturers, including Adept, blacksky, G-Wiz, Missile Works, Olsen, Perfectflite, Public Missiles Systems, and Transolve (to name a few).

Many rocketeers choose altimeters based on the advice of friends or acquaintances. Most, if not all, of the major manufacturers have detailed web sites that discuss all aspects of their altimeters and their use in the field. In addition, rocketry magazines such as *Extreme Rocketry*, *High Power Rocketry*, and *Sport Rocketry* frequently discuss the use of altimeters and provide user



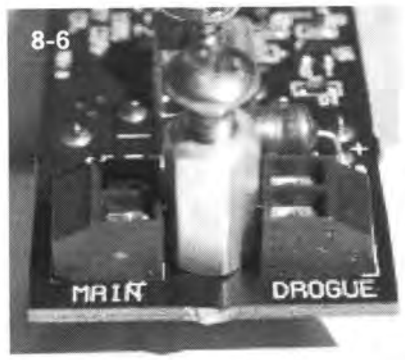
8-5 Missile Works RRC2 Altimeter

reviews of new units. And don't be afraid to ask the manufacturer questions.

No matter how you choose your altimeter, there are a few practical questions to consider.

First, what do you want the altimeter to do? The most basic function of an altimeter is to record altitude. Most commercial units have no problem recording altitudes up to 20,000 feet above ground level (AGL). However, if you are building a high-altitude rocket that you expect will exceed 20,000 feet, be sure to check with the manufacturer prior to purchase to ensure that the altimeter you buy will record and function properly at higher altitudes. Not every altimeter may be up to the job. For example, MissileWorks offers two versions of their popular RRC2 altimeter. One version of the RRC2 is for rockets expected to achieve altitudes up to 25,000 feet, and the other is for rockets capable of reaching 40,000 feet. Either unit works fine for the average high-power rocket. But if you plan on achieving extreme altitudes, the 40k model is for you.

8-6



Most altimeters have provisions for a main and drogue deployment charge. This is a blacksky Altacc.

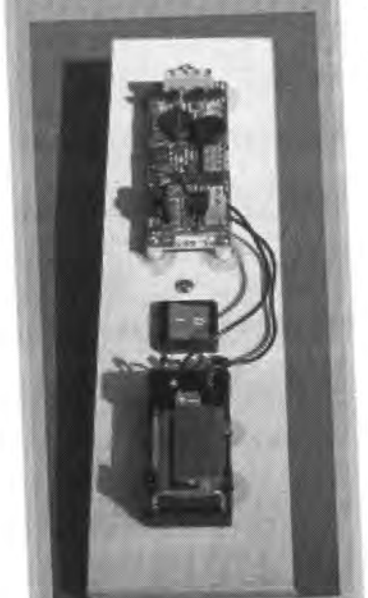
Altimeters are also used to fire on-board ejection charges. Altim-

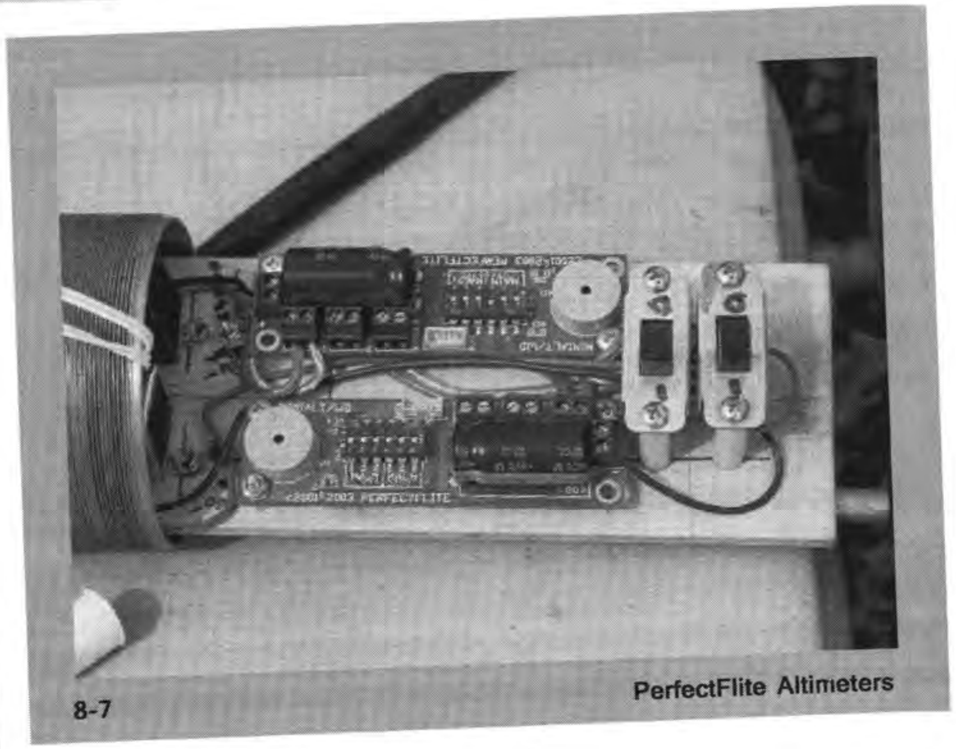
Mach ONE

The speed of sound, also known as mach 1, can play havoc with some altimeters. Barometric altimeters may be subject to pressure fluctuations if the rocket exceeds mach 1. These pressure fluctuations can, in some instances, lead to early deployment because the altimeter senses an increase in air pressure which "should" mean that apogee has been reached. A lightweight rocket with a high-thrust motor can easily exceed mach 1. For such a rocket, look for a barometric altimeter that has a mach-delay feature.

The BEEPS

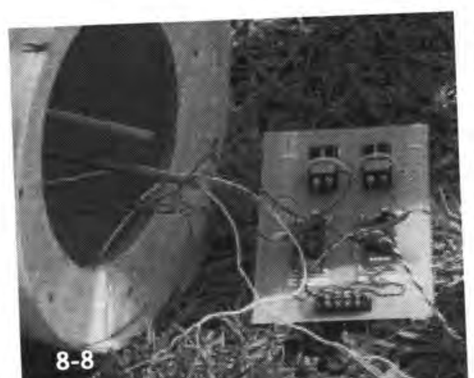
Some altimeters report altitude with a series of beeps that are emitted after the rocket has been recovered. This is true of the popular Missile Works RRC2, pictured below (This one has been mounted to a back board). The altimeter will emit rapid beeps followed by a pause and then more beeps to communicate the peak altitude of the rocket. Simply count the number of beeps between each pause and you will come up with the rocket's altitude.





8-7 PerfectFlite Altimeters

eters usually fire at least two charges–one at apogee for the drogue parachute and one at a lower altitude for the main parachute. This works well for most high-power rockets. However, some altimeters fire only one charge and others, like the G-Wiz LC800, can handle up to three. So consider how many charges you will need before buying your altimeter.



8-8

Most altimeters allow the rocketeer to fine-tune the altitude at which the main charge will fire. This altitude will generally vary, depending on the manufacturer, between 100 and 20,000 feet. For example, the Olsen M2 altimeter can be programmed to fire the main charge in 50-foot increments starting at only 100 feet. The blacksky Altacc 2C can be set to deploy the main chute at intervals of 600, 1200, or 2400 feet. The G-Wiz LC Deluxe model altimeter can be set to fire the main chute at 400 or 800 feet.

Another consideration in choosing an altimeter is whether your rocket is expected to exceed the speed of sound, or mach 1. A lightweight minimum diameter rocket with a powerful motor can exceed mach one. If you are building such a rocket and you are purchasing a barometric altimeter, look for a unit that has a mach-delay timer or similar device or simply use an accelerometer-type altimeter.

Also note the method by which altitude is recorded. Altimeters are not all the same when it comes to reporting altitude in the field. For example, some altimeters report altitude with a series of beeps. This is true of the Missile Works RRC2: The altimeter will emit rapid beeps followed by a pause and then more beeps and pauses to communicate the peak altitude. The Olsen M2, on the other hand, has a digital LED display that reports the altitude on its face. Many altimeters, such as the blacksky Altacc, can be connected to laptop computers so that flight data can be viewed after flight. This information may include launch-site altitude, launch-site pressure, maximum altitude, maximum velocity and acceleration, and graphics describing the performance of the rocket in flight.

Altimeter Cost

An altimeter is one of the more significant purchases you will make in the hobby of high-power rocketry.

8-9

Most altimeters run between $100 and $200. With proper care and handling, an altimeter can be used many times and moved from one rocket to another with minimum effort.

For current pricing information on altimeters, review the web sites of the device manufacturers. Keep in mind that you usually get what you pay for. There are some altimeters that cost much less than $100 and others that may require assembly. If you have experience in assembling electronic components, these kits are fine. But avoid making an altimeter kit your first venture. A well-built and properly functioning altimeter will make the difference between recovering your rocket safely and digging the very expensive remains out of the ground with a shovel.

One final note on purchasing an altimeter: Buy more than one.

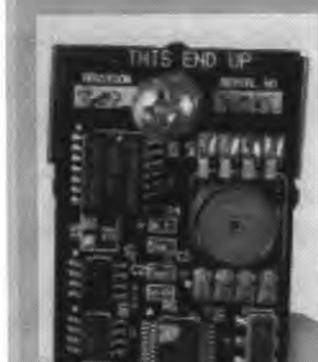
At a Black Rock, Nevada, experimental launch a few years ago,

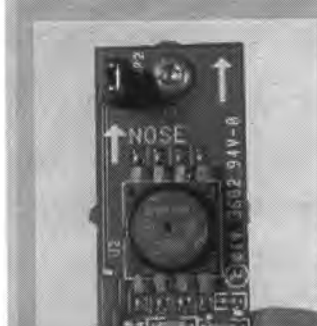
The DISPLAY

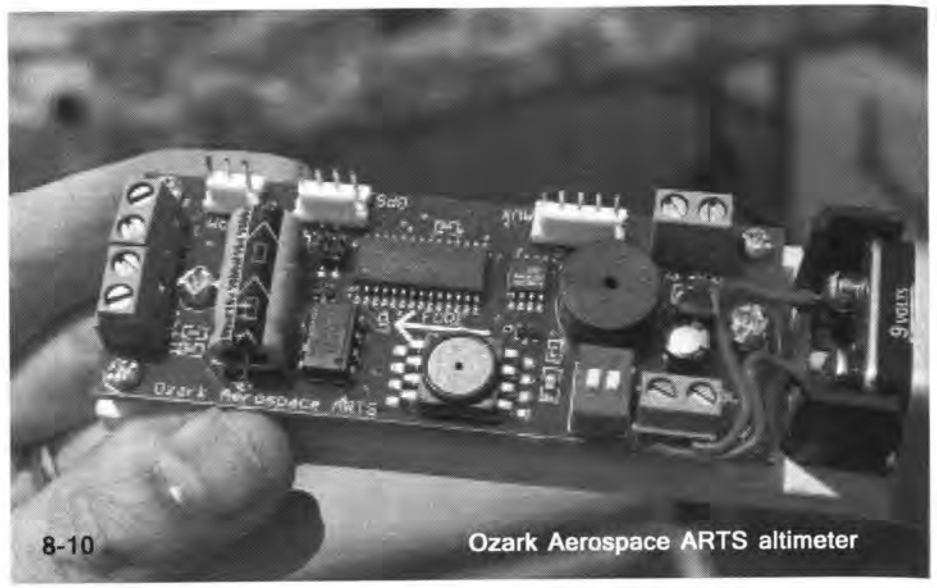
The Olsen M2 altimeter does not report altitude with beeps. The Olsen is one of the few altimeters to report altitude with a built-in LED display. The display can be used to set not only mach delay but also the main parachute deployment altitude. When the M2 is properly armed on the pad, the display will read "Ready." After the flight is over and the rocket is recovered, the display shows the peak altitude of the rocket in feet. The digital display on the M2 will also indicate when the on-board battery is low.

This end UP

All high-power electronic units that operate with a G-switch have an orientation label somewhere on the device. These units must be placed along the correct axis in the rocket, or they will not function. Here are a few examples.







8-10 Ozark Aerospace ARTS altimeter

a European team of high-power rocketeers had made the trek across the Atlantic with a spectacular, minimum-diameter high-altitude flyer. Their rocket, constructed of high-dollar composite materials and the best components money could buy, was powered by an Aerotech N motor and impressed everyone at the launch. At ignition, the N motor lit perfectly, powering the rocket to an estimated 25,000 feet. Then the rocket vanished. Seconds later, a high-pitched whine spread across the desert floor. About a mile away from the launch pad, the rocket could be seen screaming into the ground, nose first, as a lawn dart. The impact threw up a huge cloud of smoke and dust as the entire rocket buried itself several feet under the ground.

Naturally, the rocket was a total loss. Even the Dr. Rocket 98mm N motor casing was torn to shreds. What happened? No one may ever really know, but, unfortunately, this high-performance missile had only one $125 altimeter on board to control deployment. There was no backup to ensure the firing of ejection charges and the release of the parachute.

At LDRS20 in 2001 in Southern California, this scenario was repeated–this time with a beautiful, 10-foot-tall scale model of the V2. This M-powered rocket had a great takeoff and rose in a perfect vertical trajectory several thousand feet. The rocket then turned over at apogee and screamed into the desert floor at high speed not far from its launch pad. There was only one altimeter on board. There was no deployment of the parachute, and the rocket was utterly destroyed.

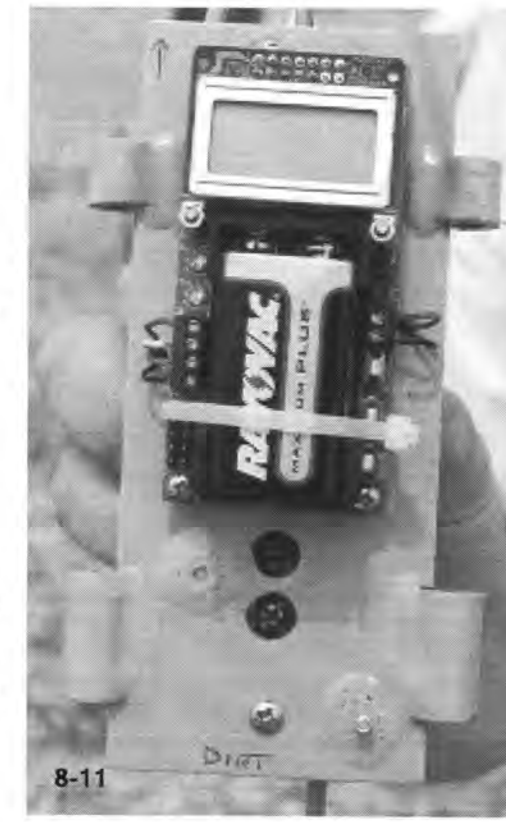
The moral of these stories? Large or complex high-power rockets should always carry more than one on-board altimeter. The term for this is *redundancy*. Altimeters fail from time to time for a variety of reasons, such as low battery power, improper use, wires coming loose, or a host of other

causes. By installing a backup altimeter to fire extra ejection charges both at apogee and at main, you increase the likelihood that your rocket will be recovered safely. In the long run, it is a small price to pay. Also, by installing altimeters from different makers in the same rocket, you decrease the chances that some quirk in that particular brand of altimeter will lead to the failure of both units in flight.

Installation and Use

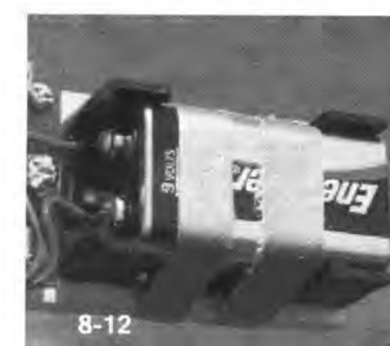
The first rule of altimeter use is always: Read the instructions. With a little patience and a quiet place to read, you will find that the instructions for most altimeters are sufficient to prepare you for field use.

Keep in mind that, although the basic functions of many altimeters are similar, there are differences. Therefore, never assume that if you are familiar with one brand, you can use another brand without instruction. And when in doubt, ask.



8-11

In most local NAR sections and Tripoli prefectures you will be able to find other members who have experience with the type of altimeter you have purchased. Talk to them. In this hobby, as in most things in life, there is no substitute for experience. But it need not be acquired first-hand. It is also a good way to make new friends–most rocketeers will be happy to answer questions about your new altimeter. And if you are still unclear about the instructions, contact the manufacturer. Do not guess.



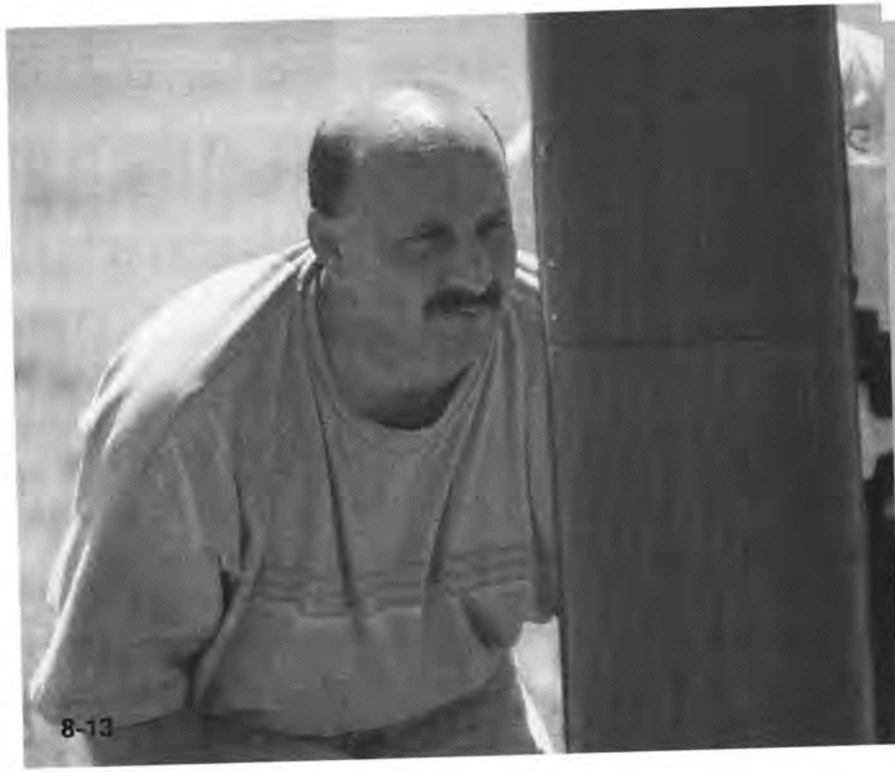
8-12

Tape or plastic tie straps help ensure that the battery does not come loose under thrust or a hard landing.

Next, be sure the unit is mounted properly in the rocket. This applies especially to accelerometer altimeters. An altimeter that is placed in a rocket upside down will not work, and there will be no activation of the ejection charge. If the unit has an orientation arrow or phrase, follow it. For example, the G-Wiz LCD 800 has an arrow at one end that directs the user to point that end toward the NOSE of the rocket. An Olsen altimeter has the word SKY on one end–to denote the end of the altimeter that should be pointed up–and the word DIRT on the other end to indicate the end of the unit that should be pointed toward the bottom of the rocket. Always be sure that you follow the orientation instructions. If there are no instructions on the unit, be sure to read and understand the operating manual for the altimeter prior to flight.

Ejection Gases

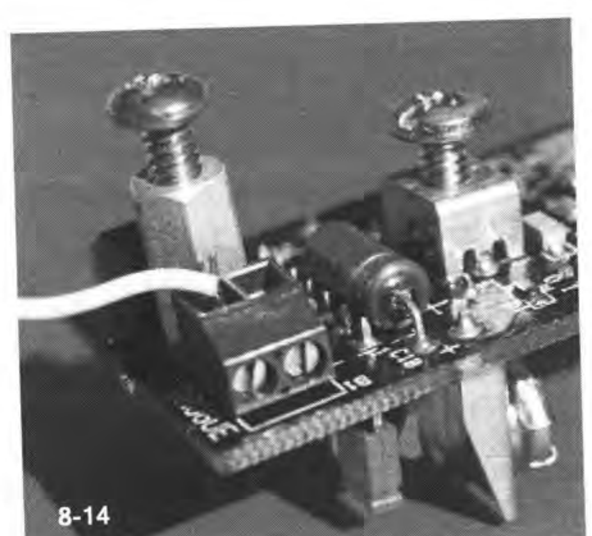
All altimeters must be protected from ejection charge gases. These gases are corrosive and will eventually harm and render inoperable most high-power electronic components. So do not place your electronics and ejection charge holders in the same compartment of the rocket. Furthermore, fully insulate and protect the electronics bay from any leakage of ejection-charge gases from the payload or deployment bay. This is easily accomplished by either sealing off any holes for wires that exit the



8-13

Most altimeters are armed at the pad after the rocket has been placed in the vertical position. Some are armed by the turn of a small screw through a port hole in the airframe. Here, California NAR member Jack Garibaldi looks for the flashing light to indicate his Altacc is armed for his Level Three certification flight in Riverdale.

electronics bay or by using wire-terminal blocks to eliminate the need for holes in the bulkheads to allow wires to pass from one compartment to another. If holes are made in the bulkhead, be sure to fill them with screws, nuts and bolts, epoxy, or some other form of filler that ensures that the valuable electronics in the rocket are fully protected. For information on building an electronics bay, see Chapter 9.



8-14

A Good, Secure Battery is Essential

A low or dead battery is one of the most common causes of altimeter failure in high-power rocketry. The results are usually catastrophic. So always use a new battery on launch day. Many altimeters operate on a single 9-volt battery. These batteries are so inexpensive that there is no reason not to use a new battery for every single launch–even for successive launches on the same day. For altimeters that require more than a 9-volt battery, be sure to have some easy method for testing battery strength on the field. Do not put yourself in the position of having to guess or speculate about the reliability of your battery on launch day. If you are not sure of battery strength, do not launch.

Another cause of altimeter trouble in a high-power rocket is failure to properly secure the battery to the mounting board. At liftoff, any object within the rocket that is not tightly secured to the airframe will come loose. If the battery comes loose, the unit will fail. (A battery can also come loose as a result of a hard landing--causing a loss of data in some altimeters.)

Fortunately, many manufacturers of rocketry electronics now provide solid and reliable battery

holders for their timers or altimeters. But some do not. So carefully assess the means by which the battery is held down in the rocket. Often, you can secure the battery simply and cheaply by attaching a thin plastic tie strap that wraps around the battery and the mounting board. Even some masking tape wrapped around the unit and the mounting board is better than nothing.

Don't Forget a Static Port Hole

Barometric altimeters must have proper venting to the outside air. The vent is referred to as a *static port*. A static port allows the barometric functions of the altimeter to work properly and provides for rapid pressure equalization between the outside air and the air inside the bay during flight.

The location of the static port is important. First, it must be located on the altimeter bay. Second, it should be placed so as to minimize any air turbulence caused by obstructions forward of the vent. Screws, ornamental objects, camera ports, and other items that protrude on the outside of the rocket should not be placed immediately forward of the static port, as these objects may cause air turbulence that will interfere with the function of the altimeter. For similar reasons, keep the static port as far away from the nose cone as possible.

8-15

NAR member Jack Garibaldi's 10-inch-diameter Nike Smoke launches on an M1315 for a successful Level Three certification. The rocket held multiple blacksky altimeters.

Some rocketeers place their electronics in hatch-access bays between the fins on their rocket. If you do this, be sure you consider the effect of turbulance around the fin area and how it might affect your altimeter.

The diameter of the static port also plays a role in the function of the altimeter and timing of the firing of the ejection charges. In an article published some years ago in *High Power Rocketry*, "Why Altimeters Fail," Transolve president John Fliesher and assistant Chris Pearson discussed this issue. They noted that two of the most common trouble spots involve (1) minimum-diameter rockets using I motors or larger and (2) "really big rockets."

Minimum-diameter rockets with high-impulse motors can reach a very high airspeed, with consequent high airflow over the surface of the rocket, which may inhibit air leakage from the airframe. The higher the expected airspeed of the rocket, observed Fliesher and Pearson, the more holes necessary for static port venting. Really big rockets pose a related problem, Fliesher and Pearson found. Since large-diameter rockets often have large altimeter bays, a single static air vent may be insufficient to handle the larger bay volume. This can lead to

Static Port Sizing

First: Altimeter bay radius (inches) **x** bay radius (inches) **x** bay length (inches) **x** 3.14 = bay volume.

Next: Divide the bay volume (from above) by 400. The answer is the size of a single port hole in inches. For multiple ports, see below.

Note: This formula is for altimeter bays up to 100 cubic inches.

Diagram 8-1

Source: Missile Works RRC2 Instructions

delays in altimeter function and thus to late deployment. To counter this problem, Fliesher and Pearson suggest using several larger vent holes in big rocket bays. Another method used to combat this problem is to build a smaller, self-contained altimeter bay that simply slides into the larger bay of the big rocket (see Chapter 9, example 7).

The diameter or size of the static port hole is the subject of many rocketry how-to articles. It is also something discussed in altimeter instruction sheets and in some high-power rocket kits.

For example, Adept recommends that for the use of its popular ALTS25 altimeter, a ¼" diameter porthole should be used for every 100 cubic inches of volume in an altimeter bay.

The instructions for the Missile Works RRC2 contain a similar formula for calculating the proper static-port hole size. According to Missile Works, the sizing of the static port can be determined by first calculating the total volume of the electronics bay. To determine that volume, use the formula: bay radius (inches) x bay radius (inches) x bay length (inches) x 3.14 = bay volume (cubic inches). To determine the size for a single static port, divide the bay volume by 400. The answer will be the static port diameter in inches.

8-16

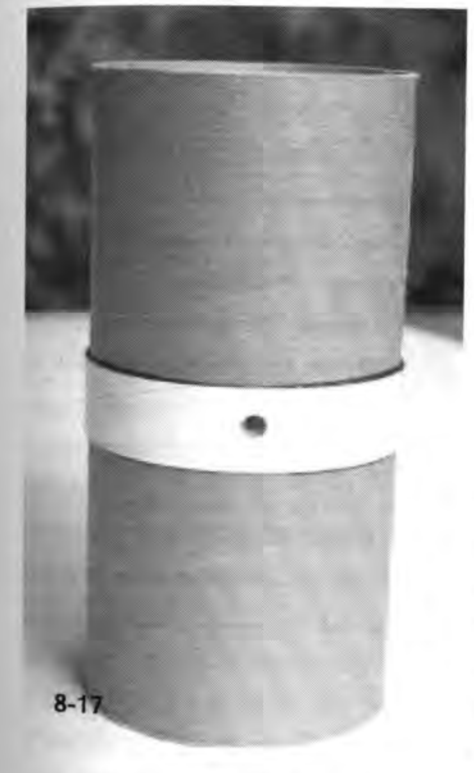
When calculating the static port hole size, be sure you measure the altimeter bay, not the payload bay.

If you are using more than one port, determine the port size for the single port and then apply the following formula: Single port diameter (inches) divided by (the number of ports, divided by 2).

Let's try this with an example.

Our PML Amraam has an altimeter bay that is 3 inches in diameter and 10 inches in length. To obtain the bay volume, we first need the bay radius. The radius is equal to the distance from the outer edge of the bay to the middle of the bay. Since the diameter is 3 inches, the radius is 1.5 inches.

Now, we multiply the bay radius (1.5) by the bay radius (1.5) to reach a product of 2.25. Then we multiply 2.25 by the bay length (10) to get an answer of 22.5. Next, we multiply 22.5 by 3.14. The answer is 70.65.



8-17

A static port hole in an altimeter bay.

The bay volume is 70.65 cubic inches.

Now we move to step two. We divide the bay volume of 70.65 by 400. The answer is 0.17. This is the diameter, in inches, of a single static porthole for this average bay.

It should be noted that Missile Works recommends this equation for altimeter bays up to only 100 cubic inches in volume. It is not clear if this formula will be as precise with larger-volume altimeter bays. So far larger bays, check with the manufacturer of your altimeter (or your rocket, if it is a kit) to see what they recommend. In the alternative, try the formula suggested by Adept.

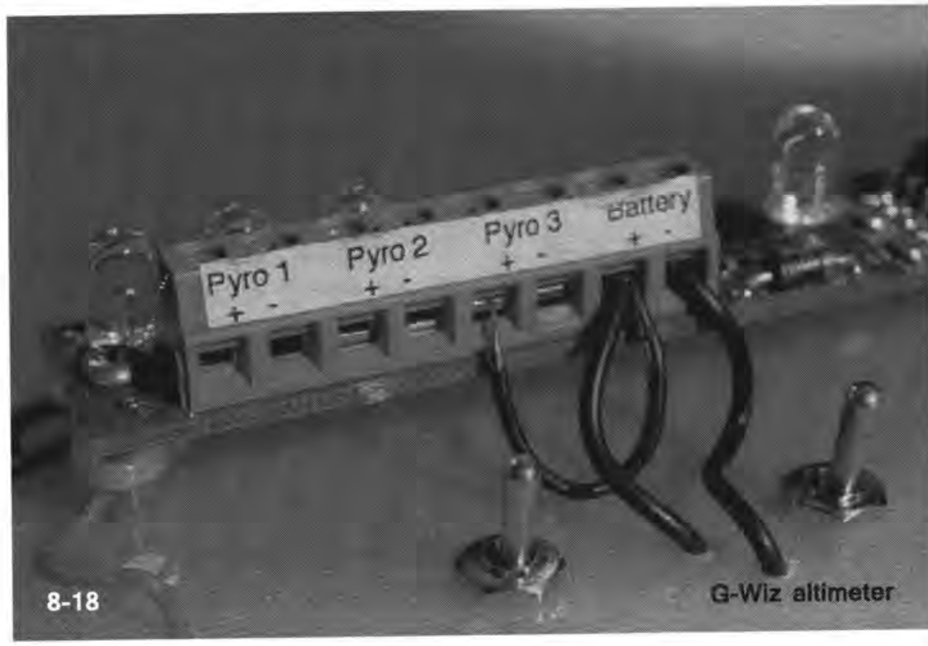
As noted by Missile Works, improper static-port sizing can lead to either early or late deployment. If the port is too small, there may be a pressure equilibrium lag that can cause a delay in firing of the ejection charges. Oversize ports, by contrast, can lead to premature deployment before the rocket reaches apogee.

Is a single port better than multiple ports? Probably not, at least according to those who maintain that multiple ports reduce the likelihood that an unusual wind gust through a single hole might cause the altimeter to misfire. Although this is always possible, most rocket altimeter bays should work fine with a single port. But if more than one port is used, always use at least three, and space the ports equally around the diameter of the airframe, on the same plane.

One final word on portholes: Do not confuse them with vent holes. A vent hole has nothing to do with altimeter function. A static port hole is used in an altimeter bay. A vent hole is used in an ordinary payload bay. A vent hole placed outside the altimeter bay section of the rocket bleeds off excess air pressure as the rocket climbs. As a rocket increases altitude, the air pressure outside the

The BAY

There are two types of bays typically discussed in high-power rocketry: Altimeter bays and payload bays. The altimeter bay houses electronics and must be kept sealed from any and all ejection-charge gases. The payload bay, on the other hand, is where the parachute and other recovery equipment is kept. The ejection charge is usually in the payload bay. For more information on altimeter bays and their construction, see chapters 9, 11, 12, 13, and 15.



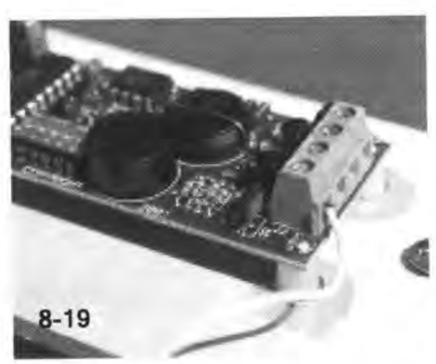
Most high-power electronics, like this G-Wiz altimeter (at left) or the Missile Works altimeter below, have terminal ports that allow you to place a wire into a terminal and then tighten a small screw that secures the wire in place. Always double-check the terminal connections for a good contact.

rocket decreases. Trapped, higher-pressure air inside the airframe of the rocket can prematurely force sections of the rocket apart. Typically, this forces the nose cone off the rocket, which leads to earlier than planned deployment of the recovery harness. If the rocket is traveling upward at a high rate of speed, this can cause a zipper in the airframe.

A vent hole in the payload bay releases this internal pressure naturally as the rocket gains altitude. As a result, there is no early or unplanned deployment. There is no magic formula for the proper size of the vent hole. But the general rule of thumb is the larger the payload bay, the larger the vent hole. A ¼" vent hole (or smaller) will probably suffice for most bays. Be sure that the vent hole is not blocked by components inside the payload bay, such as the shoulder of a nose cone or an internal airframe coupler.

Altimeter Wiring

One of the more common errors made when using altimeters is hooking up the igniter leads to the wrong port on the altimeter. Most altimeters have an apogee terminal block and also a main terminal block. They are usually labeled, and the label is explained in the instruction sheet. However, the labels are small, and it is possible to mix up your igniter leads, causing the main parachute to be deployed at apogee. This can happen easily, especially on a busy launch day in the hustle and bustle of preparing a rocket on the field. Pay attention. Always double-check your leads, not only for a good, solid connection but also to make sure you have not mixed up the apogee and main leads. If you mistakenly deploy the main parachute early on a windy day or on a small field, your rocket may be in for some serious drift–and could be lost.



Also, be careful when bending igniter wire and placing it into the terminal block on the altimeter. Most igniter wire is solid wire (not stranded). Solid wire can, if improperly handled, such as being bent back and forth too often, become brittle and break. If the wire breaks on liftoff, the ejection charge will not go off. If you are doing additional hard-wiring in bulkheads or elsewhere in the rocket, consider

using stranded wire, as it is less likely to break under stress. Finally, when inserting the igniter wire into the altimeter terminal block, try bending the tip of the wire over on itself at least once. This gives the teeth on the terminal block more to bite into–resulting in a strong, solid connection that is unlikely to come apart during flight.

The Danger of Rapid Movement

Avoid moving any high-power rocket in a quick manner during set-up on the launch pad. This is particularly important when raising a rocket with an armed, accelerometer-type altimeter from the horizontal to the vertical position. It is better not to arm, or turn on, the altimeter before the rocket is vertical on the pad. For various reasons, it is not always possible to avoid this. So raise the rocket slowly, and be sure no one is standing in front of the rocket, at any time, in case the altimeter mistakenly fires the ejection charge.

It's Time to Arm the Altimeter

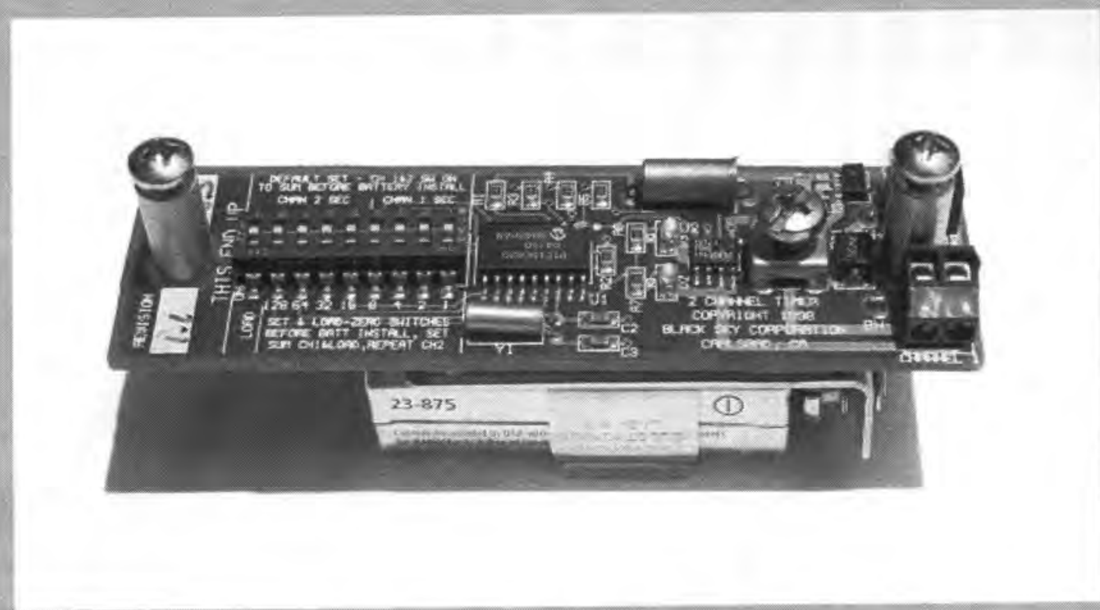
The ideal time to arm an altimeter is after the rocket is vertical on the launch pad. But keep another safety tip in mind: The altimeter should also be armed before the igniter is placed into the rocket motor. Why? A rocket motor will not light without an igniter. Once the igniter is placed into the rocket, all of the components are in place for launch. If, for some unexpected reason, the igniter lights the motor, the rocket will roar off the pad. This can occur if someone mistakenly pushes the wrong button at the LCO table. If you are caught by such a surprise and the electronics are not yet armed, then the rocket will be destroyed on its return from apogee with no deployment. If, on the other hand, you make a habit of arming the electronics first, the rocket will launch, and deployment should occur as expected.

Don't forget a ladder. On large projects a ladder may be necessary to reach and arm electronics on the pad. Here, Dan Michael's Patriot is ready for an M flight at LDRS23 after the altimeters have been armed.

Ejection Charges and Altimeters

It is good practice to construct high-power rockets so that you can externally arm and disarm, or "safe," the ejection charges. Safe ejection charges help prevent accidental deployment when the rocket is being handled prior to launch. Sometimes ejection charges fire unexpectedly. The causes can be many, but the most common cause is that the on-board electronics–for whatever reason–mistakenly fire the charge. This can happen when the rocket is moved suddenly or when the rocket is moved from the horizontal to the vertical position on the pad with the altimeter already turned on. Some altimeters will fire the charge if the unit is turned on and off and on again in rapid sequence. In some situations, the cause is never known.

Many rocketeers take an extra step in making



8-21 blacksky Timer 2

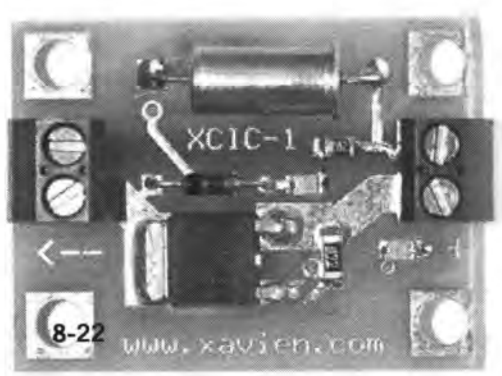
their ejection charges safe by installing an extra switch or shunt in the system that is not turned on or activated until the rocket is vertical on the pad. This extra step is required for Level Three certification by NAR and is, in any event, a pretty good idea. The use of a switch or shunt means that even when the altimeter is turned on, the ejection charge will not accidentally fire–it cannot fire at all until the extra switch is activated. Typically, the switch or shunt is placed between the altimeter and the igniter.

More Safety Issues

In addition to the installation of a safe switch or shunt, there are a few other steps worth keeping in mind to minimize the chance of an accidental ejection charge, and injury to you or others in the area.

First, forego turning on any electronics until the rocket is vertical on the pad. If the altimeter is off, then chances of an accidental firing is low. If for some reason the electronics in the rocket must be armed prior to raising the rocket on the pad, be sure not to point the rocket in the direction of any person. Indeed, once ejection charges are placed in the rocket, the rocket should not be pointed in the direction of anyone, even if the electronics are turned off.

Next, if the electronics must be turned on before the rocket is raised, lift the rocket slowly and gently from the horizontal to the vertical position. This is especially important with altimeters or timers that use a G-switch to trigger unit function. Also, get in the habit of warning everyone in the vicinity that the electronics are being armed, even when the rocket is vertical on the pad. Since charges do occasionally go off accidentally, it is good practice to wear eye protection when arming the rocket.



8-22

Xavien makes several timers for high power, like the tiny XCIC, above. Photo courtesy of Xavien.

Many times the arming of the altimeter cannot be accomplished without the use of a ladder. This is common when the electronics are housed in a large or tall rocket. Again, since unexpected firing of the charges can occur, always pay close attention when arming the rocket and keep a firm grip on the ladder in case you are surprised.

8-23

A safe switch is sometimes used to ensure that the ejection charges in the rocket cannot be armed until the rocket is vertical and on the pad.

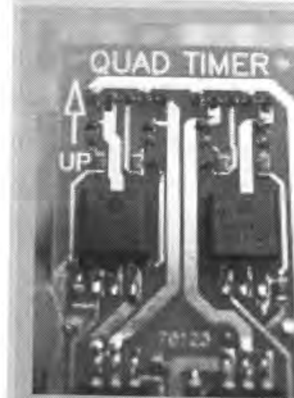
Timers

Timers (sometimes also called stagers) are common electronic devices used in high-power rocketry. The most common function of a timer is to airstart motors. However, timers are also used for staging, parachute deployment, and even the operation of on-board camera equipment.

Like altimeters, timers are sensitive to ejection charges and must be placed in a location in the rocket that is sealed from any ejection charges. Timers also have orientation arrows, or other indicators to advise the user which end of the timer needs to be pointed toward the nose of the rocket. An improperly mounted timer will not work.

The average timer used in high-power rocketry measures time, in seconds, from a given event. At a preset interval, the timer will then fire an ejection charge or perform any other desired electrical function. Some timers have more than one channel and can therefore handle multiple igniters at the same or even different time intervals. The "event" discussed with timers is usually the liftoff of the rocket (although some timers function with a pull pin or break wire). A tiny G-switch in the timer senses the initial movement of the rocket ,and the clock starts ticking.

For example, in a rocket that has motors that are to be airstarted, the timer will sense the initial launch of the rocket and will then fire the igniters of the remaining motors while the rocket is in the air. Prior to launch, the timer is set to fire the igniters at whatever time interval the rocketeer chooses for the airstarted motors.



The TIMER

Timers are used to fire ejection charges, operate camera equipment, or ignite motors for airstarts or multiple stages. Like altimeters, timers should be kept in special bays isolated from ejection-charge gases. The battery of the timer should be tightly secured. Timers also have orientation arrows that must be followed for the electronics to function properly. An Adept Quad timer is shown above.
Below: A blacksky Timer 2N.

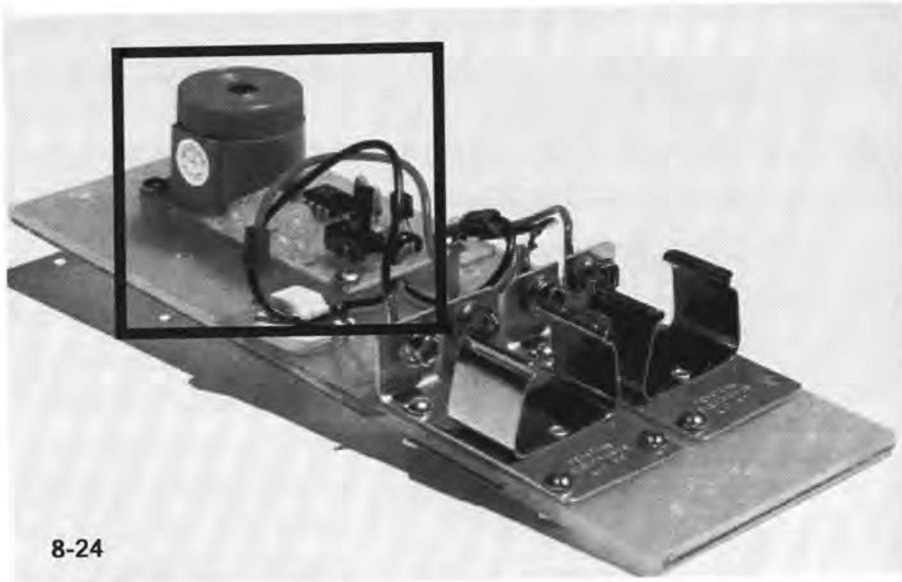
Likewise, in a staged rocket, a timer can be used to light the sustainer motor at a preset time after the launch of the rocket. The most simple timers fire their charges immediately after launch is detected. There is no delay time.

Some timers may need up to a second of constant acceleration from liftoff to activate. For example, Adept's PST440 Quad Timer needs the acceleration switch to be closed for at least one half second to trigger the timing function. This will work on almost any high-power rocket motor. However, it may not work for low-thrust experimental motors or for rockets designed for slow liftoff.

Timers generally cost a little less than altimeters. Although many timers operate on one 9-volt battery, some timers require different voltage amounts. The same safety rules for batteries apply to timers: Install a fresh battery for every launch, and be sure the battery is securely mounted. If the battery is weak or if it comes loose, the timer will not function. And as with all electronics, read the instructions carefully before using a timer. If in doubt about any aspect of the timer's function, ask for help.

Beepers

An audio beeper is a recovery device. Beepers may be constructed from hand-held personal alarms available from retailers such as Radio Shack, or they may be purchased specifically for high-power from rocketry outlets. The purpose of a beeper is to help locate a rocket after deployment. The beeper is packed into the rocket and is not activated until the rocket separates and the parachute is unfurled. Beepers available from electronics stores are usually activated by pulling out a small pin from the main unit. Once activated, the beeper gives off a loud alarm that cannot be turned off until the pin is reinserted. In high-power rockets, the pin is usually attached to the recovery cord in such a fashion as to



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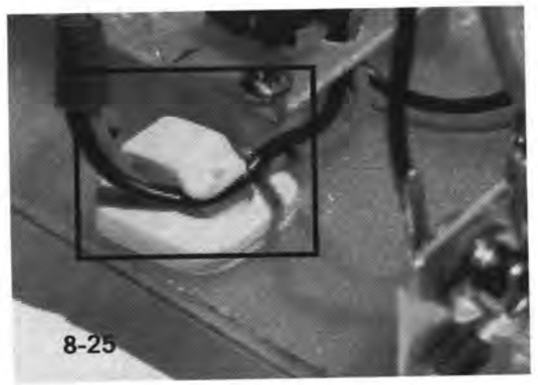

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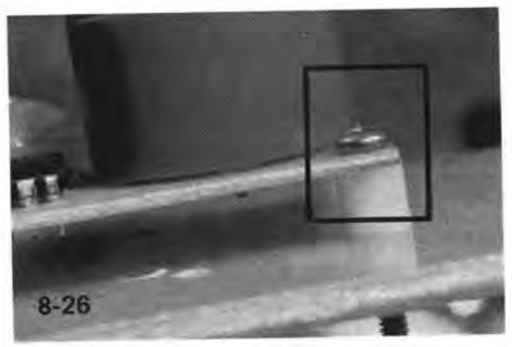


8-26

Above: A Transolve beeper (inside box) is mounted to a piece of G-10 fiberglass. Battery holders are available from electronic supply stores. Left: Adhesive clips secure wiring in high-power rockets. Below: Nylon standoffs are used for altimeters, timers, and electronic parts that are mounted to boards. The standoffs can be obtained at hardware or home improvement stores.

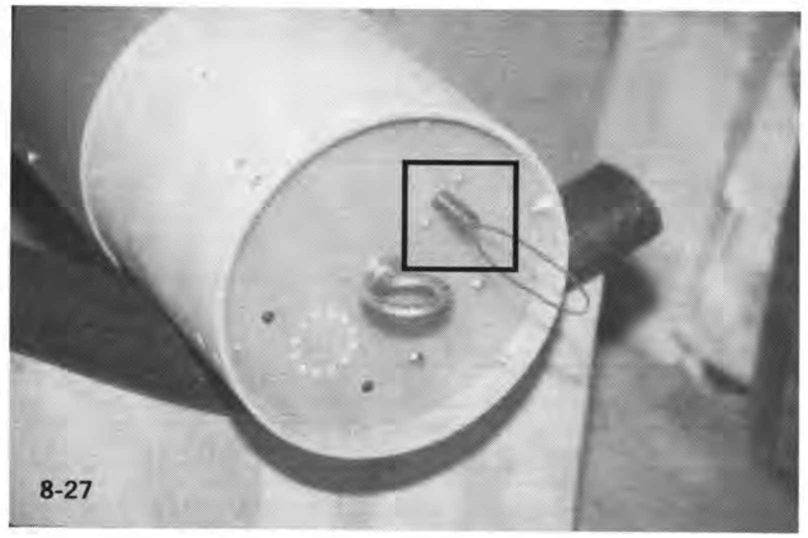
Beepers are an important and often overlooked aspect of recovery in high power. Even a large rocket can be virtually invisible to searchers if it lands in plants or grass more than a foot high. A beeper helps recover rockets that land in grass, cornfields, or forests. Beepers also alert rocketeers and spectators to a descending rocket in their vicinity. Beepers are simple to install and can be moved from rocket to rocket easily. They are also inexpensive, ranging from only a few dollars for the personal-alarm variety to only $20 to $30 for units specifically designed for high-power rockets.

Locating Transmitters

Transmitters are an excellent investment for the serious high-power rocketeer. They drastically reduce the chance that a rocket will be lost even at very high altitudes or when it descends into woods or pastures.

There are several transmitter manufacturers in high-power rocketry. Among these are Adept, Rocket Hunter, and Walston. These transmitters work on radio frequencies and, when properly installed in a high-power rocket, allow the user to track down a rocket for several miles. The basic transmitter installation actually involves at least three different components: a transmitter, an antenna, and a receiver. The transmitter and the antenna are mounted in the rocket. The receiver stays with the rocketeer. After the rocket is launched and returns to the earth safely, the receiver will receive a signal indicating the direction of the downed rocket.

Radio-frequency trackers are sold at different price ranges, and it is best to shop around for the unit that will work best for your rocket. Generally, the antenna and transmitter are the least expensive



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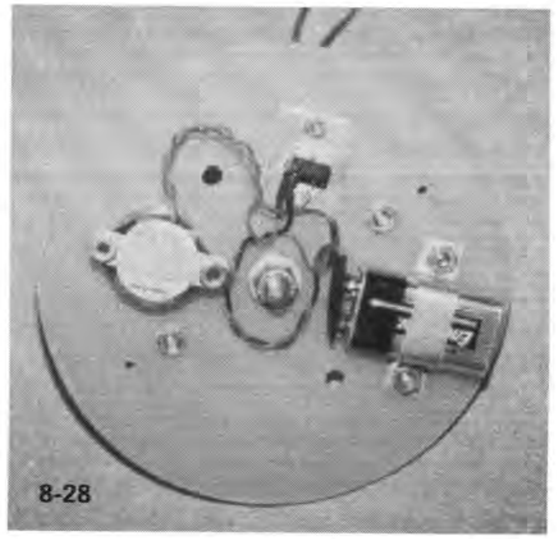

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8-29

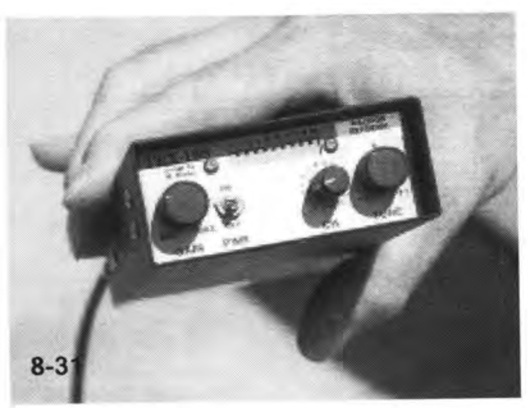
Level Three flyer Stephen Roberson placed a 100-decibel miniature siren into the aft bulkhead of his payload bay. The photo at left (center) shows the back view of the bulkhead and the siren assembly. The circuit is activated when a headphone plug is pulled out of the jack upon ejection and separation of the body tubes. Note that the simple system is powered by a regular 9-volt battery. The photo below shows the plate installed with the ejection charge canisters (made of copper) empty. Photos courtesy of Stephen Roberson.

8-30

The total cost of a transmitter system may run several hundred dollars. But the price can be shared by club members and a good system will pay for itself over and over again through the recovery of rockets that would otherwise be lost.

of the three main components, usually running between $100 and $150. The receiver is more expensive. A tracking receiver can cost hundreds of dollars, depending on the number of channels available and other features. However, this investment is a good one, especially if you are building rockets that will reach altitudes of more than 10,000 feet or if you are flying on small fields or in the vicinity of trees or other obstacles. A good tracking unit can mean the difference between finding your valuable rocket and losing it forever.

And don't forget to turn the equipment on. At a recent LDRS event, a multiple-motor, 200-pound rocket equipped with on-board altimeters, expensive motor cases, video equipment, and other valuable parts was lost in a nearby forest for several days because the on-board transmitter was not turned on prior to flight. This can happen on a busy launch day, especially with a complex rocket. Luckily, the rocket was eventually spotted from the air by an airplane after three days of ground searching had turned up nothing.



8-31

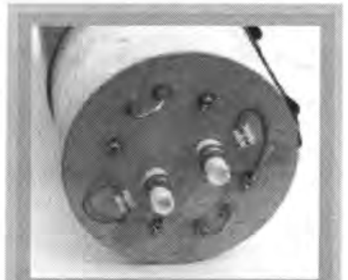
Radio transmitters are an excellent investment for the serious high-power flyer. Shown above is a Walston unit.

Recently, GPS transmitters have seen more use in high-power rocketry. An on-board GPS device not only reports back data during the flight of the rocket, but also pinpoints the rocket's landing location. GPS units run on batteries, and so most of the other rules for rocketry electronics apply. The unit must also be protected from harmful ejection-charge gases. But when mounted properly in the rocket, these units are an excellent way to track a rocket, especially high-altitude flyers or rockets launched from smaller fields.

8-32

8-33

A sturdy table and a quiet place to work on the field is essential to hooking up your electronics correctly. Here, Tripoli member Harold Sasloe of Fort Meyers, Florida, carefully prepares the altimeter bay for his Level Three certification flight at the Florida Winter Nationals in January 2005. Sasloe's "Horizon Rizon" was 5.5" in diameter and weighed 32 pounds loaded on the pad. The 11-foot-tall rocket carried altimeters from Missile Works and G-Wiz. It featured dual deployment. The rocket successfully launched on an Aerotech 75mm M1297, and reached an altitude of more than 6,000 feet, before landing just a couple of hundred feet from the launch pad.



The BASICS

An altimeter bay in any high-power rocket must keep the electronics inside the bay isolated from any ejection charges in the rocket. Ejection charges contain corrosive gases that will harm or even destroy a typical timer or altimeter. So the bay must be sealed. At the same time, the bay must allow for the passage of wires to the ejection charges placed outside the bay. This is not difficult in most rockets, but it does require a little planning before construction.

9

Altimeter Bays

A look at some of the most popular designs for high-power altimeter bays

There are two basic methods of parachute deployment in high-power rocketry: single and dual deployment.

Mechanically, single deployment in high power operates just like it does for model rocketry. One ejection charge event deploys the recovery system of the rocket. At or near apogee, an ejection charge is fired and the rocket separates into two pieces connected by a single tether or shock cord.

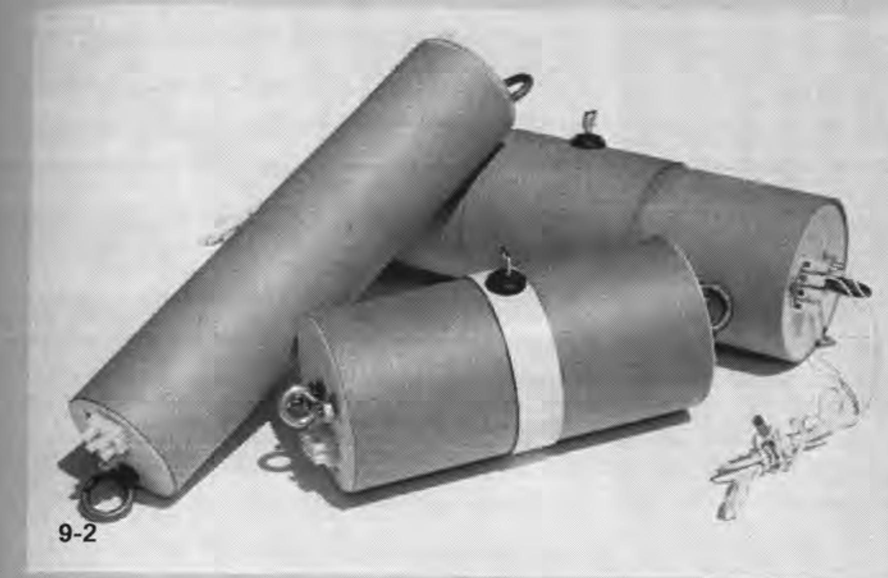
Attached to the cord is the main parachute. As the two rocket pieces travel away from each other, the cord and parachute are pulled out of the rocket. The parachute unfurls and the rocket descends to the ground.


9-1

A removable altimeter bay built by NAR member Keith Gaillard for his Level Three rocket.

In dual deployment there are two distinct ejection-charge events. The first takes place at or near apogee. As the rocket turns over and the first charge fires, the rocket splits into at least two pieces, connected by the recovery harness. However, the main parachute does not deploy; Instead, a small drogue parachute is *ejected* from the rocket. The drogue is only a fraction of the size of the main parachute. It allows the rocket to descend quickly–but not too quickly–with a minimum of drift.

In some rockets, not even a


9-2

Removable altimeter bays come in several different sizes, but most have the same general appearance. The bays must be self-contained and sealed off from ejection charges. Shown here are two four-inch bays and a three-inch bay.

drogue is used. The rocket simply separates and falls. The rate of descent is still slow–especially compared to a rocket that does not separate at all.

At a lower altitude–usually 1,500 feet or less–another ejection charge fires. The rocket separates again. It is now in at least three separate pieces–all still attached to each other by separate recovery harnesses. This last event pulls out the main parachute, and the rocket slowly descends for a soft and gentle landing.

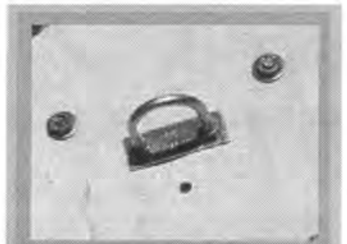

9-3

Altimeter bays may be located in many places in the rocket. Here, the bay was placed just forward of the fins in this beautiful wooden rocket.

Deployment systems for most single and virtually all dual-deployment rockets are controlled from a single, sealed, altimeter-equipped payload bay. This bay is usually referred to as the altimeter bay.

The altimeter bay in a high-power rocket may be a permanent part of the rocket or it may be completely removable–allowing it to be moved from one rocket to another. The bay may contain up to three or four altimeters or other electronics (timers, beepers, etc.), or it may hold just one altimeter. In some rockets, the only way to access the altimeter bay is through disassembly of the rocket. In such a rocket, the electronics within the bay are turned on at the pad with an external switch mounted in the rocket's airframe. In other rockets, the inside of the altimeter bay may be accessed with the removal of a hatch that allows the user to arm his or her electronics directly.

There is a great deal of variation in the construction of an altimeter bay. But all bays have at least one thing in common. An altimeter bay must be completely sealed from ejection-charge gases. For this reason, most bays



The BOLT

Anyone who has been in high-power rocketry for very long knows that open-ended eyebolts used for altimeter-bay attachments are a bad idea. Yet we have all used them. The truth of the matter is that you can use open eyebolts on lightweight rockets and medium-weight rockets and get away with it–for a while. But why take the risk? Sooner or later, that open-ended eyebolt is going to encounter a freak deployment that will rip it wide open. Be smart. Use closed eyebolts or U-bolts on all your high-power projects.

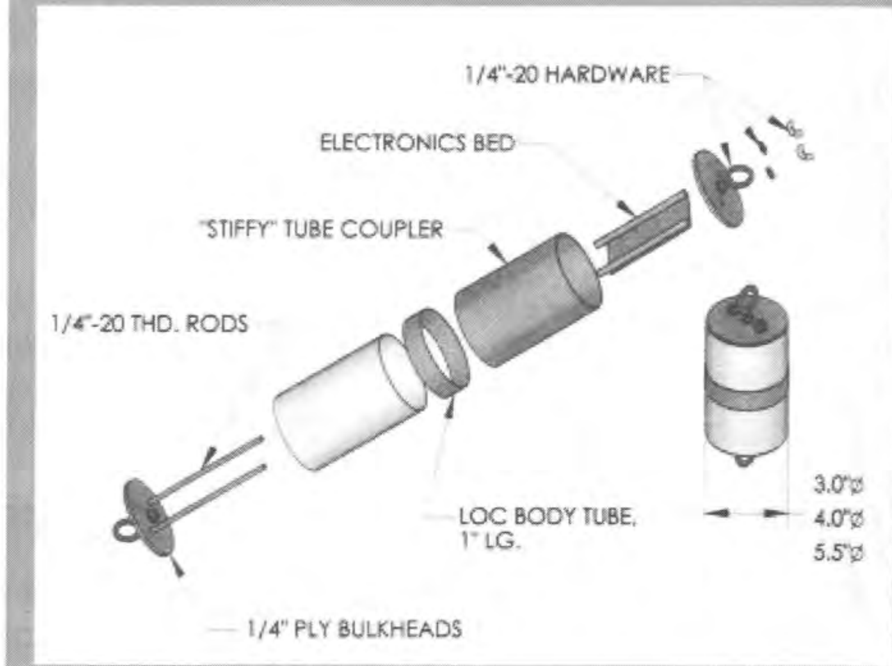


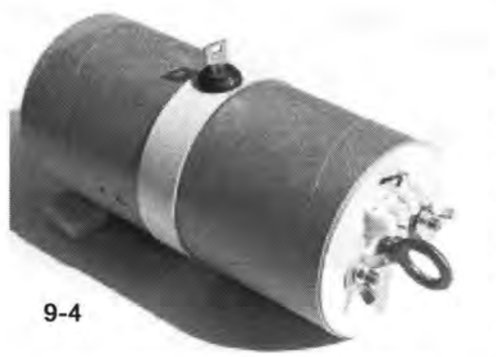
Diagram 9-1 **Diagram courtesy of LOC/Precision**

contain only the electronics of the rocket. Ejection charges are always outside of the bay, connected to the electronics inside by wire that passes through bulkheads, switches, or terminal strips. Most altimeter bays also have one other thing in common. They are vented to outside air. Since many altimeters have a barometric function (see Chapter 8), the altimeter bay must have a static-air port to allow outside air to vent into the bay. (For information on the size of the port, see Chapter 8.)

The purpose of this chapter is to compare and contrast the construction and use of both hatch-access and closed-access altimeter bays in modern high-power rocketry.

Altimeter Bay 1

Altimeter bay No. 1 is a commercial bay that is completely removable and may be transferred from one rocket to another with a minimum of effort.



9-4

Altimeter bay 1

This eight-inch-long bay fits rockets that are four inches in diameter and is built from a kit available through LOC/Precision. It can be either a single or dual deployment bay, with ejection charges mounted at both ends. In its dual-deployment mode, the bay can be configured for forward and rear deployment. Ejection charges at either end are activated by an altimeter that is mounted on a board that slides in and out of the bay. An external switch (not included in the kit) allows the user to arm the altimeter and ejection charges when the rocket is vertical and on the launch pad. As illustrated below (photos 9-22 to 9-24), this altimeter bay also acts as the main coupler between the upper and lower airframe of the rocket.

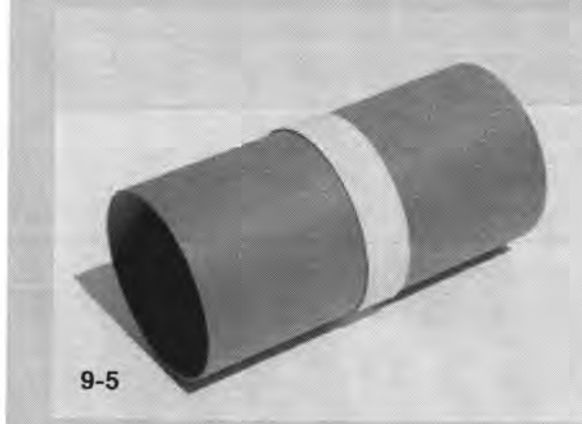
The LOC illustration in Diagram 9-1 shows a breakdown of the altimeter bay and all of its components. As you can see, the design and construction of the bay are simple. The main parts are a section of coupler tube and a smaller section of body tube. This type of bay can be built for almost any rocket. A photograph of the completed bay is shown in photo 9-4.

The main body of the altimeter bay is nothing more than eight inches of LOC four-inch-diameter coupler tube. The kit also comes with a one-inch-wide section of four-inch LOC body tube that can be placed in the middle of the coupler tube so that the entire bay can be used as a coupler for the rocket. Without the small strip of body tube, this altimeter bay would simply slide into the rocket and be invisible.

The first step in construction was to epoxy the small section of body tube over the altimeter bay, as shown in photo 9-5. Next, two sections of LOC "Stiffy" tube were placed inside the bay with epoxy. See photo 9-6. The Stiffy tube is slightly smaller in diameter than the main bay and is also shorter in length. As a result, and as can be seen in photo 9-7, the stiffy tube provides a shoulder inside the main tube at both ends. This shoulder functions as a stop or rest for the wooden end plates supplied in the kit. The plates fit into the altimeter bay at either end. They are flush with the edges of the main bay, and they are stopped by the stiffy tube from going into the bay any further. See photo 9-8.

The next step was to install an external switch in the bay.

The purpose of the switch is to turn the altim-



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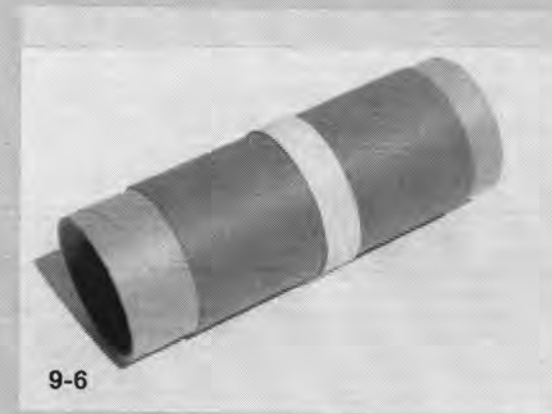

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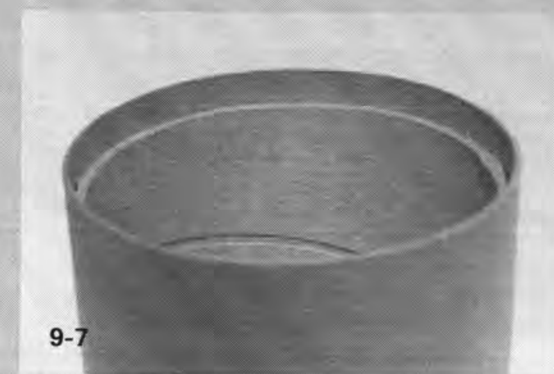

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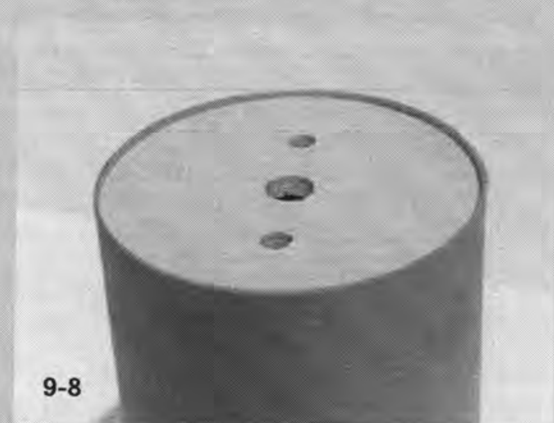

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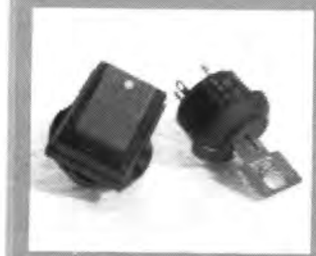


The Switch

The selection of an external switch for an altimeter bay varies greatly among rocketeers. Some people use key switches with a small flag attached to serve as a reminder to arm the altimeter before leaving the launch pad (at which time the key and the flag are removed). Others prefer a keyless switch, often on the grounds that a keyless switch can be turned off by anyone if the rocket is lost and recovered by strangers.

eter on or off from outside the altimeter bay once the rocket is on the launch pad. There are a number of different switches available for this application. Hardware stores, home-improvement stores, and electrical-supply houses carry switches that will work for rocketry altimeters. Radio Shack is a good place to hunt for switches. Make sure the switch you choose is sturdy in design and will be strong enough to withstand the stress of a high-power launch.

For our bay, we chose a key switch from a rocketry retailer, Aerocon Systems, in San Jose, California. Aerocon has a wide variety of both keyless and key switches. The switch has a large nut that threads over the base to secure the switch in place. A photo of the switch with a section of wiring attached is shown in photo 9-10.

9-9

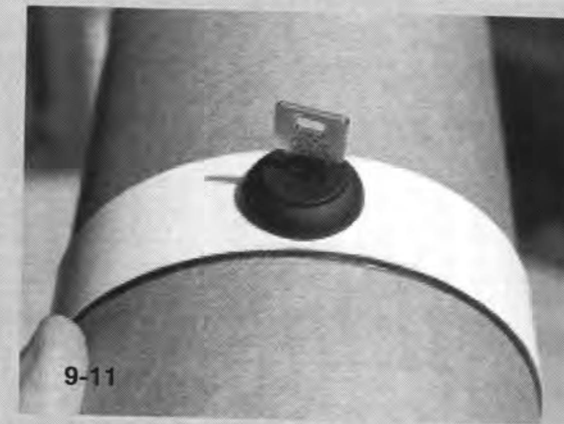
Terminal strips like this one, available at electronics stores, are useful for altimeter bays.

To mount the switch in the bay, a hole was drilled through the one-inch outer strip and through the coupler. The switch is shown in place in photo 9-11. The switch was secured with the mounting nut, and two wires were soldered to the switch for connection to an altimeter on/off port later. Be sure your solder joints are good, and after every launch inspect them to make sure the terminals are in good condition. Also, it is a good idea to attach heat-shrink tubing or some other insulation to the switch terminal (or contact) points to prevent the wires from shorting out each other.

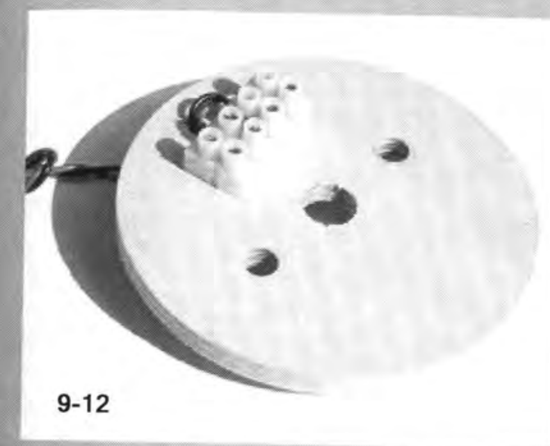
The next step in construction was to modify the two end plates of the bay. The plates came with three drilled holes. The center hole was for the eyebolt, and the outer two holes would pass two pieces of all-thread rod from one end of the bay to the other. We drilled one additional small hole in each plate to allow wire to pass from inside the bay (and the altimeter) to a terminal strip outside the bay. The terminal strip, purchased at Radio Shack, was screwed into the bulkhead plate and then epoxy was used around the edges to hold it firmly in place. This was repeated for both bulkheads. As discussed below, the igniters would be connected to the terminal strip on launch day. One of the end plates with the terminal strip attached is shown in photos 9-12 and 9-13. Note how the wire from the strip passes through the small hole drilled in the bulkhead. That hole should be completely sealed prior to use in the rocket.

The LOC kit came with two open eyebolts. These eyebolts would

9-10



9-11



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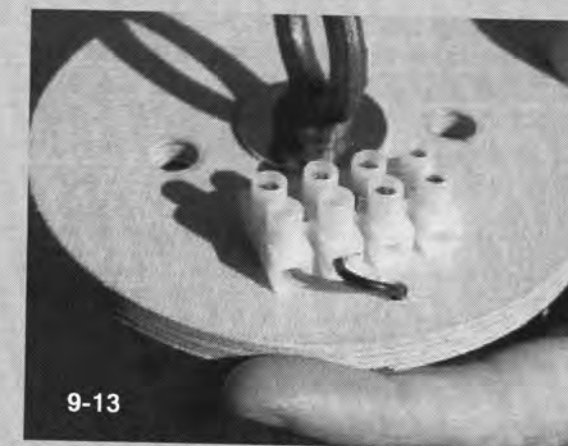

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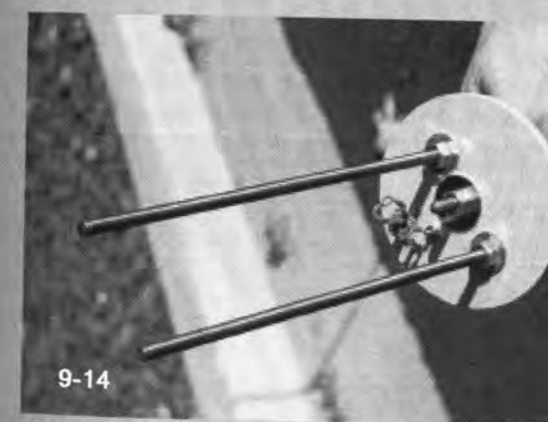

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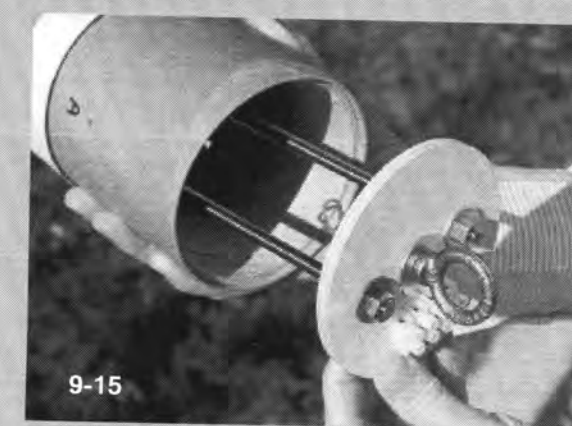

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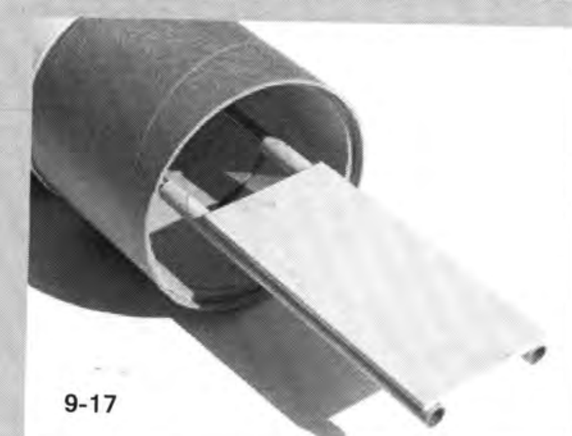
9-16



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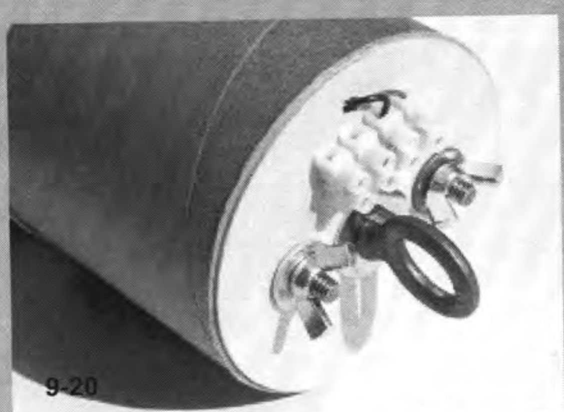
9-19


9-20


9-21


9-22


9-23

be used to secure the recovery harness at either end of the altimeter bay. The open eyebolts were discarded and replaced with closed forged eyebolts. The eyebolts were secured with a washer and nut, and a small dab of epoxy was placed on the threads of the bolt to hold it securely in place.

The next step in building this bay was to permanently attach the two pieces of all-thread rod to one of the end plates. To do this, we used the lock nuts and washers supplied in the kit. With approximately ¼" of the rods protruding through the outside end of the bulkhead, the rods were locked in place. A dab of epoxy was added to keep the assembly from moving in the future. The rods were now permanently affixed to this end plate, or bulkhead. See photo 9-14.

The bulkhead with the all-thread rods was placed into the bay, rod end first. We pushed the bulkhead in as far as it would go, so it was seated against the inner shoulder of the bay, as shown in photos 9-15 and 9-16.

It was time to work on the plywood board that would hold the altimeter. Two cardboard mounting lugs supplied in the kit were secured to the back of the board with epoxy. The mounting board could now slide over the all-thread rods, as shown in photos 9-17 and 9-18.

The bay was now ready for final assembly. We placed the


9-24

Altimeter bay 1 installed in a LOC four-inch rocket. The bay serves not only as a housing for delicate electronics, but also as the coupler for the booster and upper airframe sections. The bay is easy to build and can hold many types of altimeters, or timers.

The Location

As can be seen from the examples in this chapter, most altimeter or electronics bays are located near the middle of the rocket. But it does not have to be that way. Many NAR and Tripoli members have found all kinds of unique ways to mount their electronics. For example, some people, like NAR member Jeff Proschold, build their bays into the aft end of the rocket. In the photograph below, Proschold has installed a bay to hold a timer to airstart outboard motors on a LOC Bruiser EXP. Other flyers, like Tripoli member Scott Lemm, locate their bay between the fins (see top photo). This allows for easy access on the pad without any need for a ladder to reach altimeters or timers. Altimeters can even be mounted in the nose cone, as seen in the middle photo of Tripoli member Richard King's rocket, which contained a blacksky Altacc mounted directly to the inside of the cone. Be aware, however, that turbulent air flow near the tip of the rocket, or near the fins, can inadvertently trigger the altimeter early.

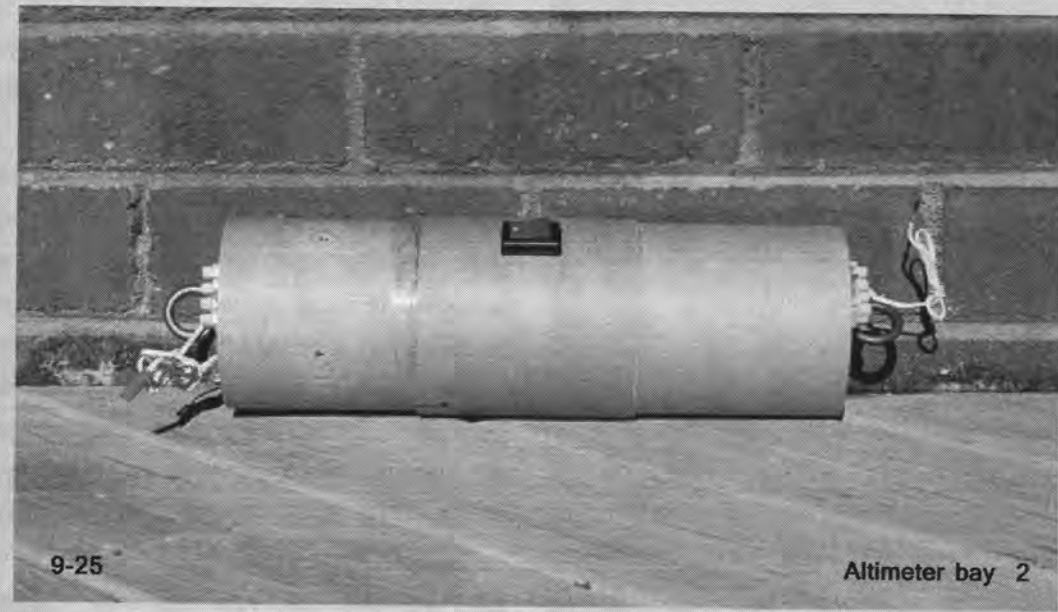
remaining end plate over the rods until it was seated against the shoulder, as shown in photo 9-19. We attached the two wingnuts, as seen in photos 9-20 and 9-21. The nuts pulled the end plates together, making the unit tight and secure.

The bay was almost done, but another important step remained. A static porthole needed to be placed into the bay. Without a static port, the altimeter (if it is barometric) will not function.

Using one of the equations from Chapter 8, it was determined that the correct port would be ¼" diameter. So a single porthole was drilled into the bay. When drilling static portholes, be sure the hole is not directly below any obstructions on the rocket (screws, switches, fins, etc) as this can lead to airflow disturbances that may influence the altimeter. Also, clean out the hole after it is drilled to make it uniform and as round as possible. A dab of CA around the edges of the hole will help keep it clean, smooth, and uniform.

Photo 9-21 illustrates the bay with an electric match secured in the terminal strip at one end of the bay. If this were a dual deployment rocket, there would be igniters or electric matches at both ends of the bay.

The entire altimeter assembly was then fitted into the airframe of the rocket, as shown in photos 9-22 and 9-23. The bay



9-25 Altimeter bay 2

was secured to the upper airframe with two blind nuts. The blind nuts were attached with a clamp and epoxy, 180 degrees apart, on the inside of the altimeter bay. The other end of the bay functioned as a simple coupler for the lower airframe.

At launch, the upper payload bay will hold a small drogue parachute. The main parachute will be contained in the lower bay. At apogee, the forward ejection charge will force off the nose cone, deploying the drogue.

At a lower altitude, the rear ejection charge will separate the altimeter bay from the lower airframe, deploying the main parachute. This arrangement can be reversed, too (the drogue can be in the lower bay and the main in the upper bay). With either configuration, the rocket can be recovered close to the launch pad.

9-26

The stop for this bay's bulkhead is a simple centering ring.

Altimeter Bay 2

The second altimeter bay is also four inches in diameter. It is scratch-built from a four-inch coupler tube that is twelve inches in length.

As illustrated in photo 9-25, the completed altimeter bay has a center section of four-inch-diameter airframe tube that fits over the coupler tube.

The parts list for this bay are as follows: (1) one section of four-inch coupler tube, 12 inches long; (2) one section of four-inch airframe tube, 4 inches long; (3) two 5/16" closed eyebolts; (4) two terminal blocks; (5) one 13-inch piece of 5/16" all-thread; (6) two ½" thick coupler centering rings; (7) two coupler bulkhead plates; (8) one altimeter mounting board and brass hobby rod; (9)two to three feet of 22-gauge color-coded wire; (10) one external switch; (11)

9-27

9-28

9-29

miscellaneous 5/16" washers, nuts, and wingnuts; (12) four 4-40 blind nuts.

The bay is longer than the LOC tube but it is similar in overall appearance to the LOC bay. But there are some significant differences.

For example, the end plates do not seat against an inner stiffy tube. Instead, the plates are seated against a centering ring on either end. The centering rings are placed 3/16" from either end of the bay, as illustrated in photo 9-26. The rings serve the same basic purpose as the stiffy tube in the LOC example, but they are an alternative design that is used in high power.

Another difference is the mounting board. In the LOC example, two pieces of all-thread were used to mount the altimeter board. Here, only one piece of all-thread is used. Prior to actual construction, you need to decide whether the all-thread rod will run through the center of the bay or whether it will be offset. In our case, we will be using an Olsen M2 altimeter. By test-fitting the altimeter into the bay, we learned that if the rod went straight down the center, the M2 would barely fit, if it fit at all. Therefore, we chose to offset the rod–moving it ½" away from the center of the bulkhead (at both ends) to allow the Olsen to fit easily into the chamber. As illustrated in photo 9-28, a closed eyebolt was still placed in the center of each end plate. Only with this design, the wingnut is off to the side. As illustrated in photo 9-29, each end plate also had a section of terminal strip attached to accept wire from the inside of the bay that would be connected to the altimeter.

9-30

The switch in this altimeter bay is also different. See photo 9-30. It is a keyless switch purchased from Radio Shack. It is secured by drilling a hole through the two tubes (the airframe tube and the coupler tube), inserting the threaded portion of the switch into the hole, and then securing the unit with the plastic nut supplied with the switch. The switch will activate the on-board electronics when the rocket is vertical and on the pad.

The choice of wire in any altimeter bay is important. The wire should be color-coded. Color-coded wire will help you correctly identify which wire goes where on launch day. It will prevent you from mistakenly hooking up the main ejection charge to the wrong port on the altimeter. The wire should also be stranded, if possible. Although solid wire works fine, stranded wire has less tendency to completely break with repeated manipulation.

This altimeter bay, like the LOC kit, will also be secured to the upper airframe of the rocket. To accomplish this, we used four blind nuts. To drill the pilot holes, place the bay into the upper airframe of the rocket and drill through the airframe and the altimeter bay. Make a mark on the tubes to keep the holes aligned. Next, insert the blind nuts, and epoxy them in place. attach each nut to the inside of the tube with a clamp, and then epoxy.

The completed bay is shown in photo 9-25.

Altimeter Bay 3

This is a three-inch-diameter altimeter bay, 12 inches long. It is similar to the first two examples and is a variation of the three-inch bay available from Giant Leap Rocketry. This bay is all coupler tube. It fits inside the airframe of a three-inch rocket, although it can also be used in larger diameter rockets when an appropriate size hole is drilled in a large bulkhead.

This altimeter bay has a different seat, or shoulder, for the two bulkheads at either end. The arrangement works because the two bulkheads are slightly different in size. The aft end of the bay has a three-inch coupler-tube centering ring that is attached with epoxy to the inside of the coupler, as shown in photo 9-31. This is the same type of design as found in the centering ring in example No. 2. However, the opposite end of the tube coupler has no centering ring at all. Instead, a larger bulkhead is used. The bulkhead is the same diameter as the

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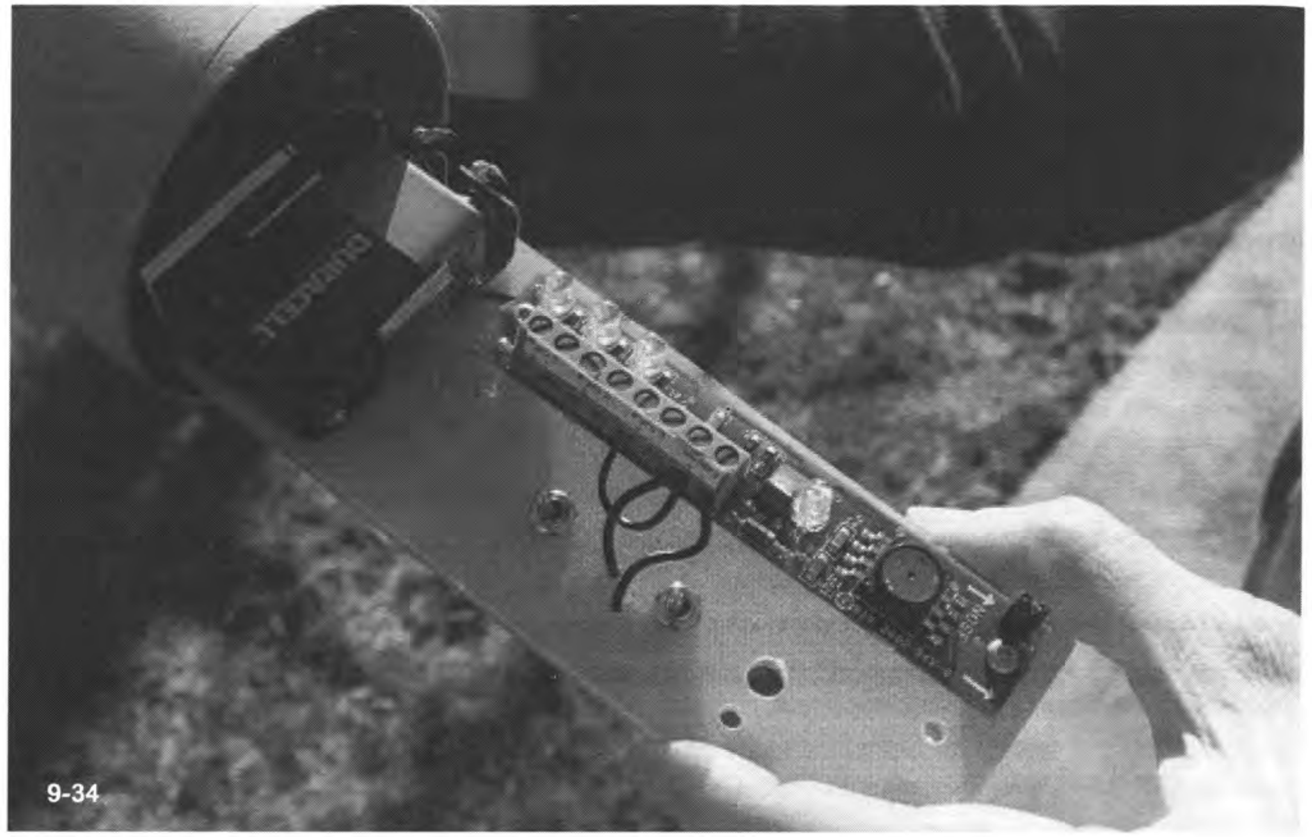
9-33

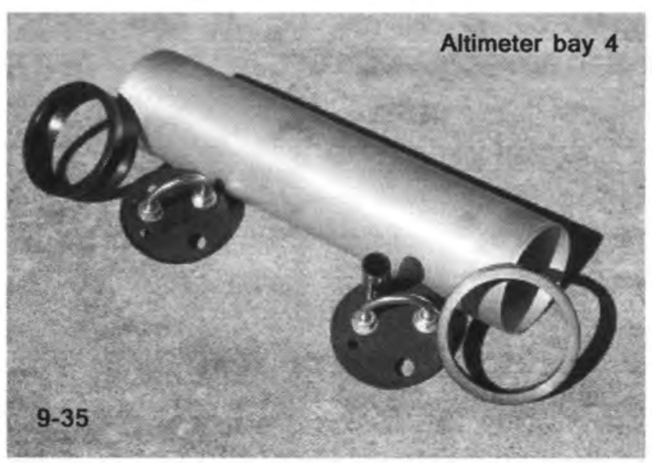


9-34

coupler tube. It sits on the end of the tube and when the all-thread and the wingnut are added, the bulkhead tightens against the coupler tube itself.

The advantage of this arrangement is that it allows for a larger altimeter board (and altimeter) to be squeezed into the three-inch coupler tube through the end without the centering ring. As shown in photo 9-32, the closed eyebolts that are placed at either end of the bay are offset from, rather than in the center of the end plates.

The G-10 fiberglass board in this bay is 11 inches long. The 5/16" brass tube that is attached to the reverse side for the all-thread is shorter than the mounting board at either end of the tube. This provides clearance for the nuts on the all- thread on the inside of the bay. The board slides into the bay with the electronics mounted directly to the board. See photo 9-34.



9-35

Giant Leap Rocketry's all-metal Slimline altimeter bay. This is a heavy-duty bay that is fully machined.

There is no external switch for this altimeter. Instead, there is an access hole drilled through both the upper airframe of the rocket and the coupler tube. This access hole is placed so the altimeter can be turned on at the pad.

This hole also functions as a static porthole when barometric-style altimeters are used in the bay. This bay also acts as a coupler tube and is attached to the upper airframe with blind nuts.

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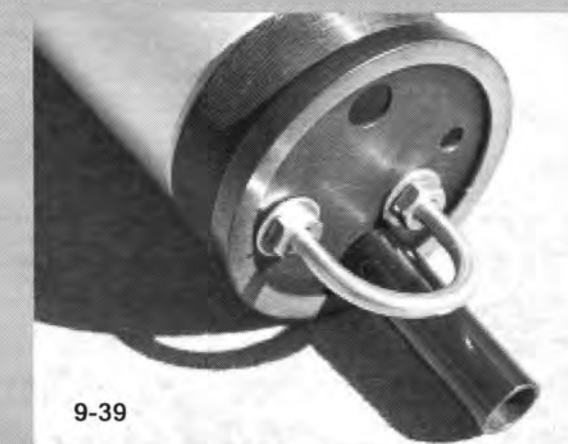
9-38



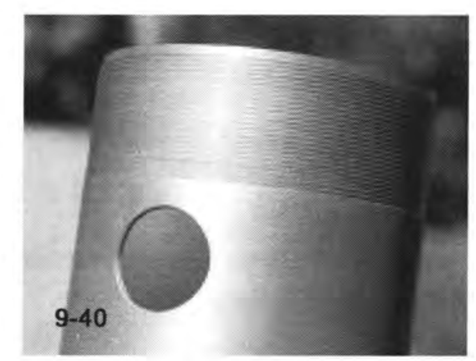
9-39

The bay is anchored at only one end, much like the bays in the first two examples.

Altimeter Bay 4

Example 4 is the Slimline Avionics Bay available through Giant Leap Rocketry. This bay is approximately 2.75 inches in diameter and is one foot long.

This is truly a heavy-duty altimeter bay. It is machined from aircraft-grade aluminum and has metal end caps that thread onto either end of the bay. See photos 9-36 and 9-37. The metal end caps retain a flat mounting plate at either end of the bay. This mounting plate secures U-bolts and ejection-charge holders. See photos 9-38 and 9-39.



9-40

A hole in the side of the Slimline provides for on-off access at the pad.

The complete kit for the Avionics Bay is supplied with a number of parts, including the metal bay, end caps, ejection charge holders, U-bolts, a section of three-inch coupler tube, and a mounting board. The bay also comes with inner and outer o-rings to ensure that the electronics inside the bay are fully sealed from any ejection charge gases.

This bay fits inside the airframe of the rocket. It does not use an external switch. Instead, the Slimline bay has a hole near one end through which electronics can be armed when the rocket is vertical on the pad. See photo 9-40. This hole also

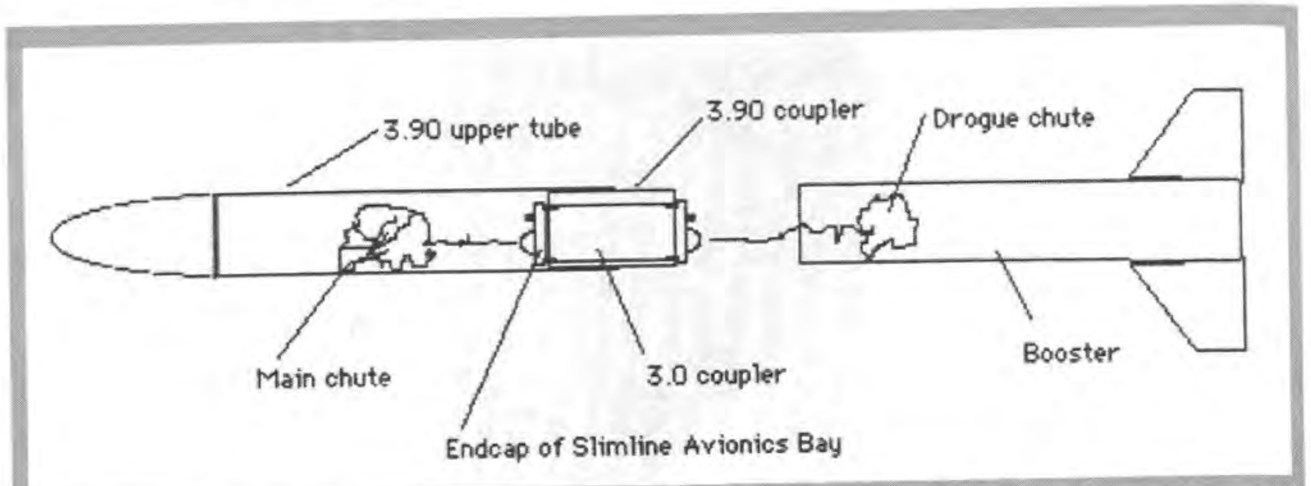
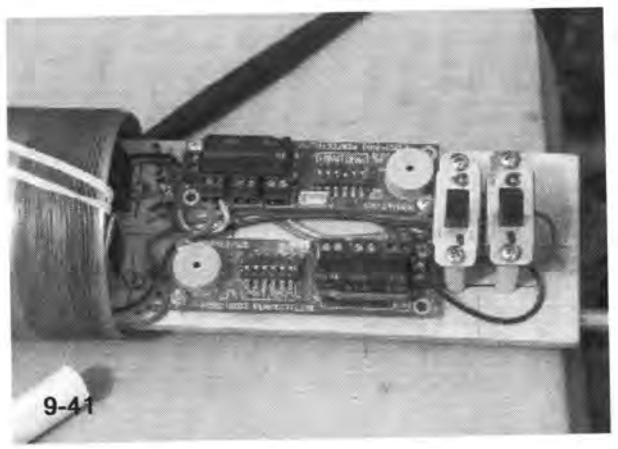


Diagram 9-2 Diagram courtesy of Giant Leap Rocketry

functions as a static port hole for barometric altimeters.

The kit comes with a mounting board that can be drilled to the specifications of the electronics you are using for your rocket. The board mount is similar to the designs discussed in the previous altimeter bay examples. In photo 9-41, two PerfectFlite altimeters are mounted in the bay.


9-41

There are several ways to mount the altimeter bay in your rocket. The most common method is noted by Giant Leap Rocketry in its directions for the bay. In their example, the bay is mounted in the aft end of the upper airframe. In this position, the forward ejection charge deploys the main parachute. The aft charge deploys the drogue. See Diagram 9-2.

In the diagram, one of the threaded end caps is permanently affixed to one end of the eight-inch-long phenolic coupler tube supplied in the kit. . This coupler assembly is then installed in the rocket with an offset "centering" ring. The ring is offset to ensure that the hole in the metal Avionics Bay is flush against the outside of the rocket's airframe, where a corresponding hole is drilled to allow access to the inside of the bay to activate a switch.

The coupler assembly is a permanent part of the rocket. Epoxy is used to secure it in the offset centering rings at either end.

To install the bay into the rocket, the Slimline unit is inserted into the coupler tube until the machined threads on the outside of the metal bay connect with the inner threads of the end cap that is affixed to the forward end of the coupler. The bay is then simply threaded in place. See photo 9-42.

Altimeter Bay 5

The next example is an altimeter bay for a large-diameter rocket. In this case, the example used is from a 10-inch- diameter Nike Smoke available from Skunk Works Rocketry and Andy Woerner of Southern California. The bay is also a coupler, connecting the upper airframe of the rocket to the booster section. The bay is permanently affixed to the upper airframe but has removable upper and lower bulkheads that allow access to the huge interior of the bay.

The basic parts for the bay are similar to the prior examples--but on a much larger scale. The bay has two bulkheads, two U-bolts for recovery points


9-42

The Slimline Avionics Bay is inserted into a Bumper-WAC rocket before being flown in Battle Park, Virginia, in 2004. The rocket was built by Dave and Bill Alewine of Virginia. The altimeter bay held two PerfectFlite altimeters, shown on the opposite page just prior to loading.

of attachment, and bolts, washers, and all-thread rod for mounting electronics. Instead of one or two pieces of all-thread, this bay has four sections of threaded rod. The lower bulkhead has a machined lip that fits into the 10-inch coupler.


Altimeter bay 5

9-43

The box area shows the location of the entire altimeter bay in the payload section of the rocket, a 10-inch Nike Smoke.

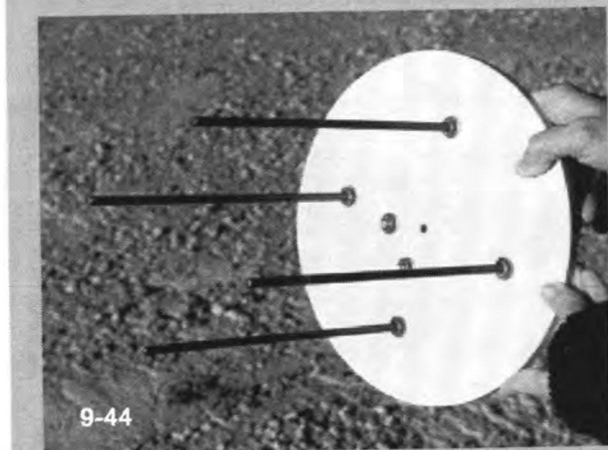
To illustrate installation and use of this bay, we will first put together the basic components before permanently affixing the bay housing in the rocket.

The initial step is to affix the four sections of all-thread rod into the upper bulkhead. As can be seen in photos 9-44 and 9-45, flat washers and nuts are used on both sides of the bulkhead for each of the four rods.

Note also that the U-bolts for parachute-recovery points have already been attached.

Once the rods are in place, take the upper bulkhead assembly and place it onto the 10-inch coupler bay. Now, invert the bay, as seen in photo 9-46.

The lower bulkhead plate has a machined edge or lip around its circumference that fits into the coupler bay. See photos 9-47 and 9-48. Pick up the lower bulkhead plate, and carefully place it over the coupler. As you do, align the four rods with the corresponding holes in the bulkhead plate. Press the plate in place. The rods should protrude far enough so as to allow enough thread on each rod to accept a washer and a wing nut. See photos 9-49 through 9-51.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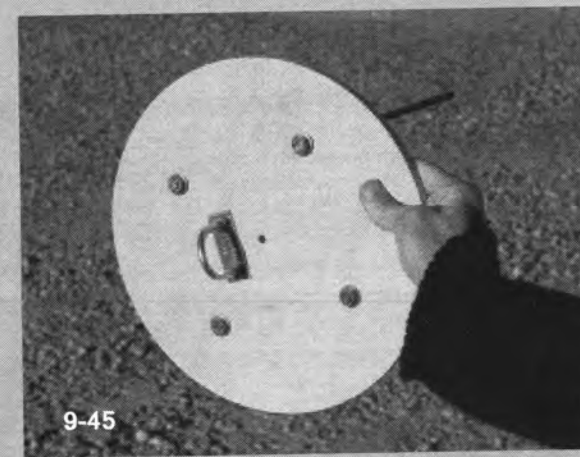
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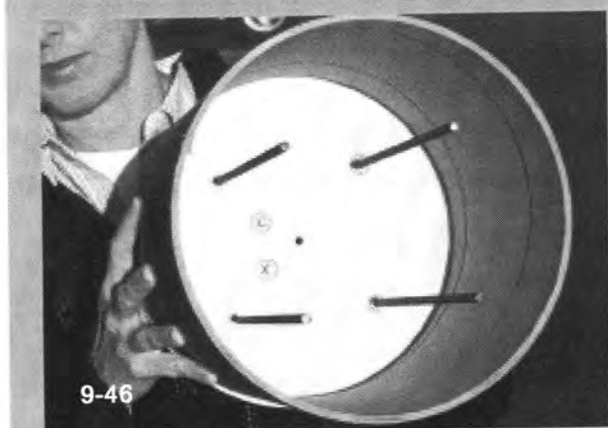
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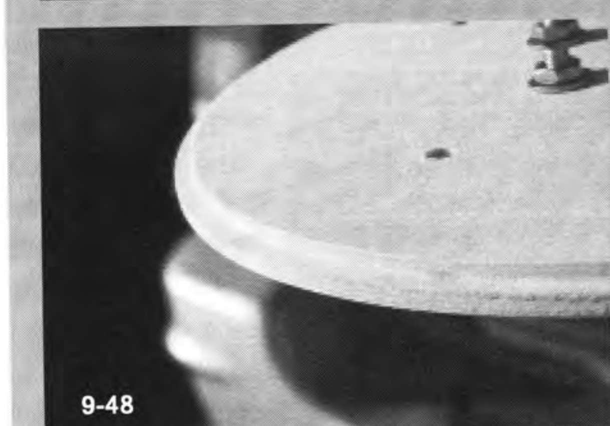
9-47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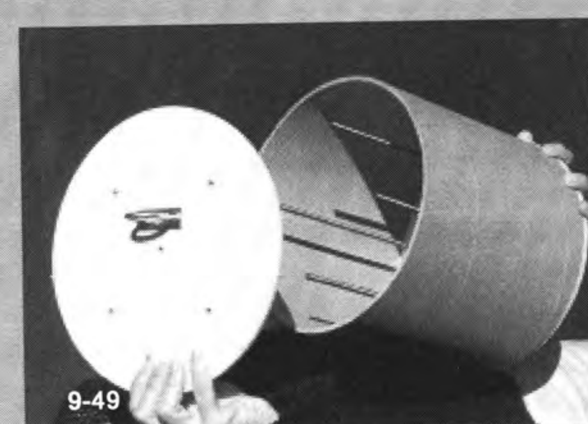
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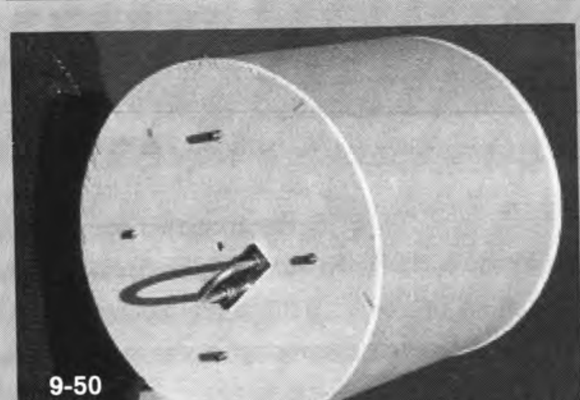
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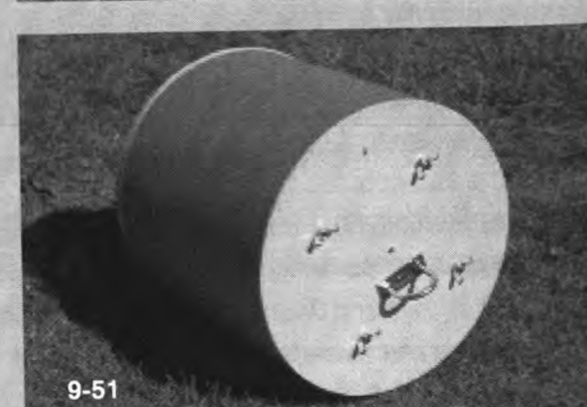
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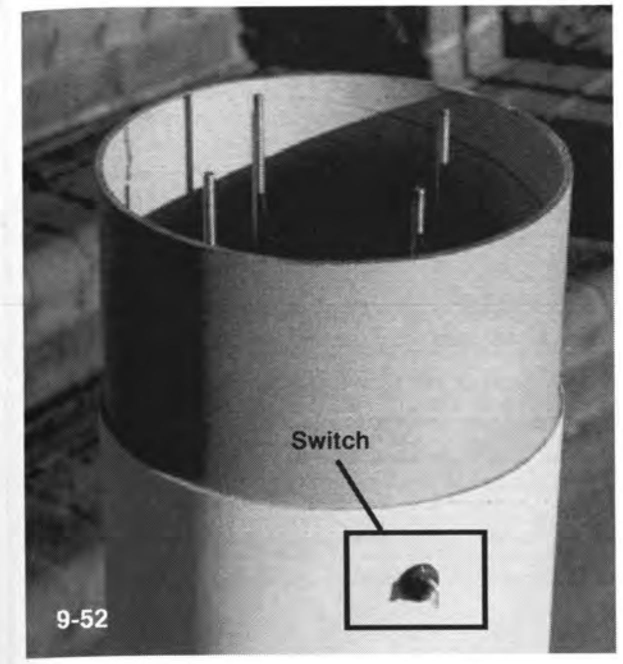


9-52

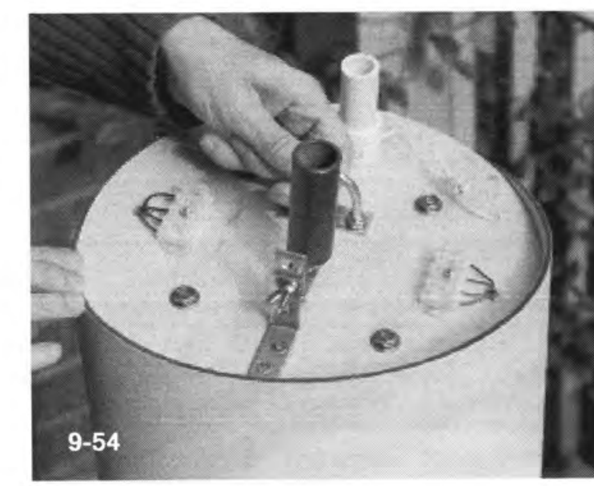

9-53

If the thread is not long enough, go back to the other end of the upper plate, and adjust the nuts and washers. Once you have completed the test- fitting, tighten the nuts on the upper bulkhead, and place epoxy over them to keep them permanently in place.

Once the nuts have been tightened, you can epoxy the upper bulkhead plate to the coupler. However, in our example we will not attach the plate with epoxy. It will be left to float freely in the air-frame until it is tightened into place.

It is time to mount the bay into the upper airframe of the rocket. Remove the two bulkheads from the coupler. Then, install the altimeter bay coupler in the upper airframe with epoxy. Test-fit the coupler a couple of times first. You should leave six inches of the bay exposed from the lower end of the airframe. See photo 9-52 (note that a switch for one of the altimeters has already been installed). Then, coat the inside of the upper airframe with epoxy for about four inches from the aft end of the airframe. With the epoxy still wet, slide in the altimeter bay coupler with a gentle twisting motion to fully engage the epoxy. Set this assembly aside to dry thor-oughly.

Photos 9-53 through 9-58 illustrate the use of the bay on launch day. First, the upper bulkhead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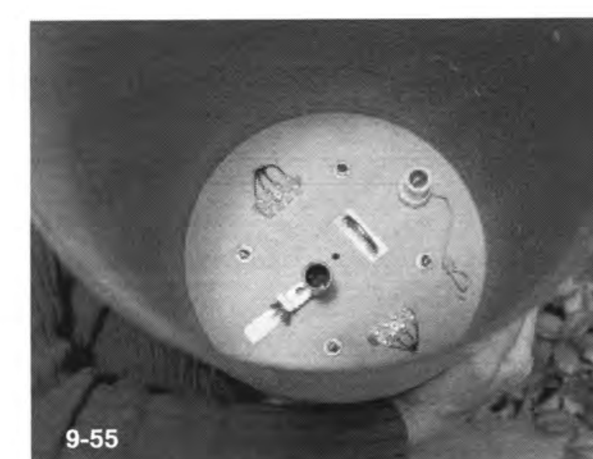

9-55


9-56


9-57


9-58

plate is placed into the top of the upper airframe and pushed down through the airframe until it seats fully against the top of the coupler tube. Note that the ejection-charge canisters and terminal blocks have been mounted to the bulkhead.

Now, as seen in photo 9-56, the upper airframe is inverted, exposing the four all-thread rods. To place our electronics in the bay, a mounting board slides down over any two of the four threaded rods, as shown in photo 9-57.

With the boards in place, the remaining bulkhead plate is pressed into position by lining up the four holes on the bulkhead with the four all-thread rods. The entire bay is then tightened with washers and wingnuts, as seen in photo 9-58.

To turn on the electronics inside the bay remotely, a hole is drilled into the side of the airframe and through the coupler. A switch can then be installed for operation on the pad.

Altimeter Bay 6

This is a hatch-accessed altimeter bay. See photo 9-59. (Photographs of this and a similar bay are also found in chapters 12 and 15.)

This bay is not removable from the rocket. It is built into the rocket and allows the user to access the interior of the rocket even after the rocket is vertical and on the pad. The basic construction requires the builder to insert a coupler or similar-sized tube within the main airframe. This interior tube "double walls" the airframe and provides the support and mounting area necessary for the hatch.

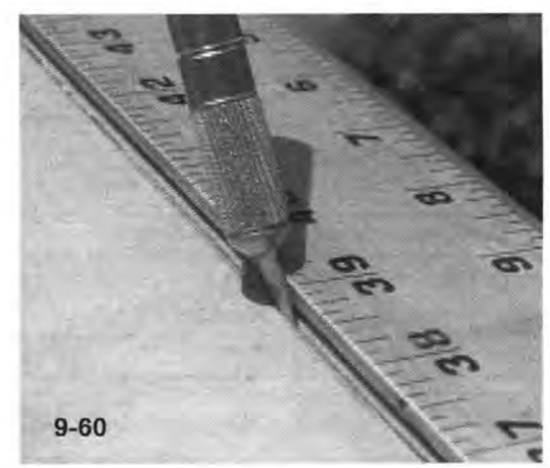
The rocket in this example is 7.51 inches in diameter. It will carry at least two and as many as four separate electronic components. All of these components will be flush-mounted against the interior of the airframe. The removable hatch allows the user to open a door at the pad and directly arm the electronics inside. This also allows the user to visually inspect his or her electronics to ensure that they have been properly armed.

The first step in this project is to decide on the location of the altimeter bay and hatch. A hatch-accessed bay can be located anywhere on a rocket.


9-59 Altimeter bay 6

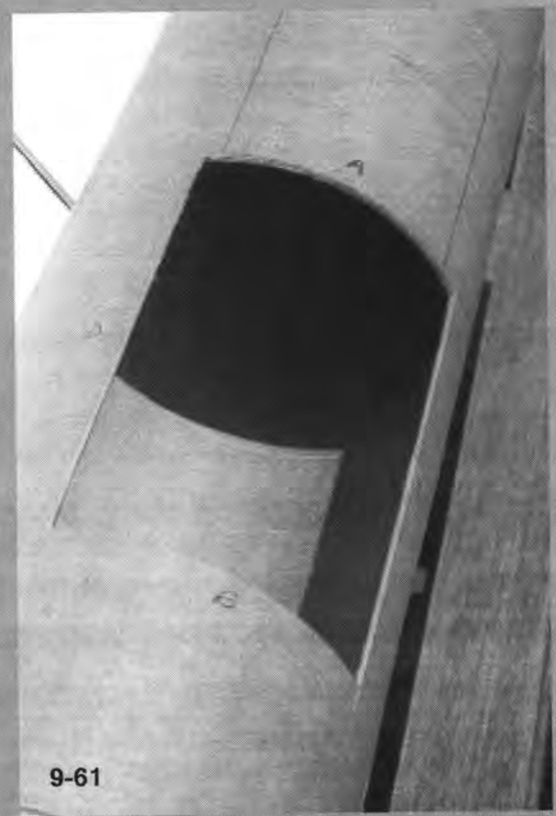
Our bay will be near the middle. But it is not uncommon for people to place the hatch adjacent to the fins on the rocket. If you do place the hatch near the fins, be aware that the turbulence or movement of air near the fins can cause altimeters to fire their ejection charges too early or too late. You may want to consider additional static portholes or a larger porthole than you would normally use, to minimize the impact of the fins on the airflow.

The altimeter-bay chamber must be sealed at both ends to protect the altimeters inside from ejection charges, so one of the most convenient places to locate the bay is directly above the main bulkhead in the upper airframe of the rocket. This provides the bay with a bulkhead at the aft end of the bay. But it must also have a forward bulkhead. The location of the forward bulkhead depends on the rocket's length and how large the chamber will be. Ideally, the hatch is located at the midpoint between the forward and aft bulkheads.

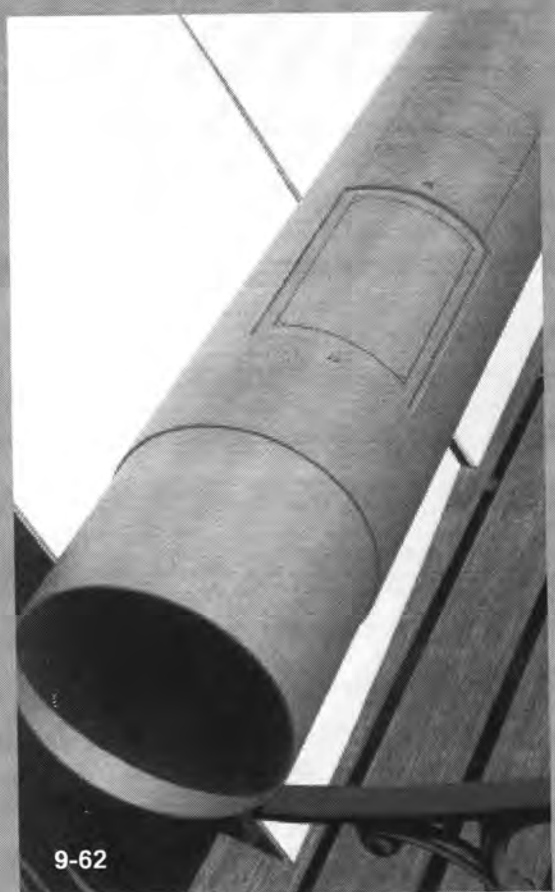

9-60

After the location of the bay is chosen, the builder needs to decide on the size of the hatch. This is a two-step process because, as a practical matter, two hatches will be cut–the outer hatch, which will become the removable hatch door, and the inner hatch, which will be the actual space through which the electronics (and your hands or tools) will pass. For this project, the outer hatch is 9 inches long (or tall) and 5.5 inches wide. The inside hatch will be 7.5 inches long (or tall) and 4 inches wide. The size of this hatch was based in part on hand size, or the ability to reach into the bay easily to install and arm any electronics placed inside.

The outer hatch may be cut with any sharp instrument, including a Dremel or hand power tool or even a simple hobby knife. As illustrated in photo 9-



9-61

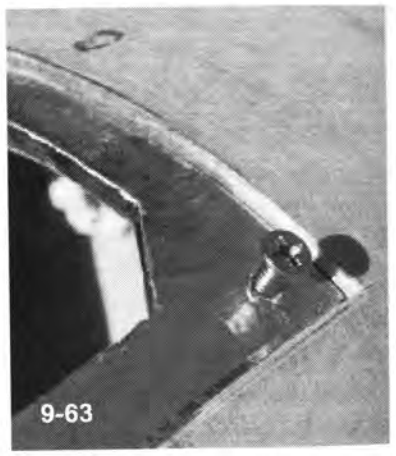


9-62

60, a hobby knife was used in this case to cut through the airframe tubing. Use a straightedge to draw an outline of the door and to make the first few passes with the hobby knife. This is a slow and steady process. Do not rush, as this increases the chance you will make a bad cut. Run the blade gently along the straightedge, increasing the pressure very slowly with every few passes. Use a new blade, and let the blade do the work.

You should notice that after the first few passes a small valley will be created in the airframe and you may then remove the straightedge and make pass after pass through the valley. In this example, the first 9-inch-long incision took less than 10 minutes. The entire door was cut in about half an hour. See photo 9-61.

The next step is to cut the inner hatch. In this case a 7.51-inch coupler tube was used for the inner door. (In the alternative, ordinary construction-style sono tube works well, too. See chapter 18.) The coupler was two feet long. It was placed into the airframe so that 6.5 inches of the coupler was left exposed. This would be the actual coupler between the upper and lower airframes.

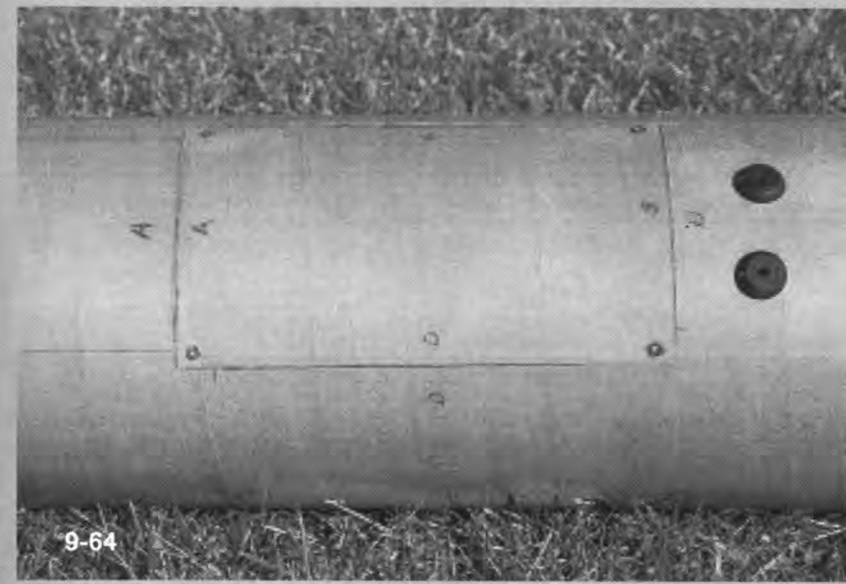


9-63

When placed into the rocket, this coupler tube blocks the hole that was cut for the removable door. See photo 9-62. With this space blocked, you can now outline the diagram for the inner hatch.

As alluded to above, the size of the inner cut is dependent on a several factors. First, how wide do you want and need the opening to be?

Second, how much space will you need to secure blind nuts in the shoulder that will be created after the inner door is cut out?

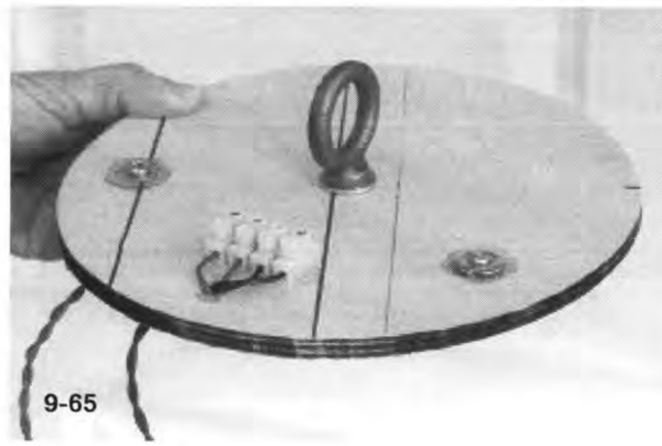


9-64

The altimeter bay after completion. The internal bay is accessed by a simple hatch that is secured at the four corners with machine screws. Just below the hatch on the airframe are two surface-mounted switches for arming the altimeters or ejection charges.

Third, how many and what type of electronics will be placed inside?

In this case, 6-32 blind nuts would be used to secure the outer door. To allow enough space to mount the nuts securely, the inner door was cut at 7.5 inches by 4 inches. This gave the blind nuts plenty of shoulder space and enough airframe material to provide for strong attachment of the outer door. Once the measurement of the inner door was made, the coupler was removed, and the door was cut in the same manner as the first door. The coupler was then reinserted into the airframe to check the fit and alignment and was later attached in place with epoxy. Be sure to place plenty of epoxy where the inner coupler meets the edges of the outer door.



9-65

To install the blind nuts, place the outer door over the hatch. Measure carefully at each corner and drill pilot holes for the blind nuts, one at a time. Remove the hatch each time, and be sure the pilot holes are centered in each corner. See photo 9-63. In this case, four pilot holes were drilled. Once the blind nuts were installed, small dabs of epoxy were placed around each nut to hold them permanently in place.

The hatch is now complete. The door is attached with machine screws and is easily removable at the pad. See photo 9-64.

To attach a forward bulkhead, create a 7.51" coupler bulkhead that has provisions for terminal blocks and ejection-charge holders. See photo 9-65.

To install the bulkhead, place it into the forward end of the airframe until it is stopped by the upper end of the coupler tube. Epoxy the bulkhead

The aft end of altimeter bay 6 has locations for multiple ejection charges and electronic terminal blocks. Holes for any wiring that passes from the outside of the bulkhead to the inside of the bay should be sealed with epoxy or some other sealer.

in place, and the chamber is sealed. In the alternative, the upper bulkhead can be secured with a piece of 3/8" all-thread that runs through the center of the altimeter bay and attaches to the lower bulkhead. This method allows for removal of the upper bulkhead and installation of terminal blocks and ejection charges that can be changed from time to time. See also Chapter 15.

The aft bulkhead is the normal bulkhead used for the coupler tube. This bulkhead, like the forward bulkhead, will be used to attach terminal blocks, an eyebolt, ejection-charge canisters, and other devices normally included in the bulkhead.

This bulkhead is permanently attached to the coupler with epoxy and epoxy fillets on both sides of the bulkhead. See photo 9-66 for the completed at end of the bay.

Altimeter Bay 7

This final example is a simple bay that can be switched from one rocket to another with very little effort. The bay is nothing more than a 2.5-inch piece of coupler tube that houses a single altimeter and is held in place by a stop at one end and a motor clamp at the other. In photo 9-67, the bay sits in the coupler section of a 5.5" rocket.

This small and removable bay fits into rockets of several different diameters. Here, the bay slides into a 5.5" airframe. Photos 9-68 through 9-71 show the bay in a four-inch rocket. The bay also fits in a 7.51" rocket.

To create this bay, you need a section of coupler tubing and a section of 2.5" airframe tubing. The section can be as long or short as necessary for your own altimeter.

As shown in photo 9-68 (the bay is being installed this time in a four-inch rocket), the bay housing is the length of regular airframe tubing that is set in the coupler tube bulkhead. The four-inch coupler tube bulkhead has

been cut to allow placement of the bay housing flush against one side of the larger coupler. This location allows a hole to be drilled through the main rocket airframe, the coupler tube, and then the altimeter bay, so as to allow access for arming the altimeter on the pad. (A remote switch could be used for the same purpose.)

The bulkheads for the altimeter bay can be created using one of the designs from other bays in this chapter. The forward bulkhead is fixed. The forward end of the altimeter bay is placed into the housing, as shown in photo 9-69. It slides all the way in until it rests against a stop and is flush with the four-inch bulkhead. See photos 9-70 and 9-71.

Photo 9-71 shows the end cap removed. The end cap has a terminal block permanently affixed for igniter wiring for the ejection charge.

This example, used by flyer Mike Scicchitano of South Carolina, works well in several of his rockets. In this rocket, the offset hole is in a four-inch-diameter rocket. The same bay fits into an offset hole in a 7.5-inch bulkhead as well. It is very inexpensive to build and simple to move from one rocket to another. Although this small bay will hold only one altimeter, larger bays based on the same design could easily handle multiple altimeters.

Conclusion

There is no one way to build an altimeter bay for all high-power rockets. Attend a few launches and look around. You will find that rocketeers use variations of the altimeter bays discussed in this chapter, as well as entirely different bays that also work fine.

No matter which type of bay you build, be sure to keep a few fundamental rules in mind: Keep the bay well sealed from the ejection charges, and be sure that the bay has an adequate static port if you plan on using an altimeter. (See Chapter 8 for more information on static-port sizing.) Also, try to make your altimeter bay easy to use on launch day. Test-fit your altimeter-bay components at home several times to make sure they fit well and will work well under actual launch-day conditions. And don't forget to ask questions along the way.

The Trouble

Recovery problems are common for both the novice and the experienced rocketeer. For the newcomer, recovery issues are often overlooked. The entry-level rocketeer spends too much time worried about the "up" part of the flight and neglects recovery. For the experienced flyer, the big problem is complacency or human error. Even Level Three flyers have forgotten to attach a quick-link, or turn on altimeters.

10

Deployment and Recovery

Bringing your high-power rocket home safely for another flight

The No. 1 cause of mishaps in high-power rocketry is a failure of some component of the deployment-and-recovery system. The anecdotal evidence can be found at any local, regional, or national launch. Rockets are lost or destroyed from time to time, and the trouble most often occurs when the parachute fails to deploy on time, or fails to deploy at all.


10-1

The most common causes of deployment failure are: (1) failure of onboard electronics due to operator error; (2) improper activation of ejection charges, resulting in deployment that occurs too early or too late; (3) failure of the recovery harness (shock cord) or its points of attachment; (4) an improperly packed parachute.

The purpose of this chapter is to review the basics of deployment and recovery and to provide examples of systems that work–and don't work–while discussing the causes of deployment failures.

Basic Principles

The safety codes of both NAR and Tripoli (and the NFPA) require that a high-power rocket may be flown only if it contains a recovery system that will return all parts of the rocket safely to the ground so that it may fly again. For most high-power rockets, this goal is achieved through a parachute that is deployed when ejection charges in the rocket separate the rocket into multiple parts.

Recovery systems in high-power rocketry are either single


10-2

If you focus on the fundamentals of simplicity and strength, deployment will not be a problem. Here, the booster section of Wedge Oldham's 700-pound Black Brandt rests on the desert floor in Black Rock after returning from an altitude of more than 18,000 feet. The booster landed gently beneath a 47-foot-diameter military-surplus parachute. See also photo 10-13.

deployment or dual deployment. In a single-deployment system, the rocket typically separates at or near apogee, and a parachute is deployed. (See Introduction.) In a dual-deployment system, the rocket still separates at apogee, but instead of deploying a large main parachute, a smaller drogue parachute–or no parachute at all–deploys. The rocket then falls to a preset altitude, much closer to the ground, where the main parachute is deployed by the separation of another part of the rocket. See Diagram 10-1.


10-3

Florida flyer Robb Haskins prepares his X-form parachute for packing into a high-power rocket.

The advantage of dual deployment is that it minimizes drift of the rocket as it returns to the ground, which is helpful on small launch fields or under windy conditions. Dual deployment is also beneficial in rockets that will reach very high altitudes. This method of deployment is popular in the eastern and southern United States, where launch fields are often bordered by forests, cornfields, irrigation canals, or other obstacles. In the wide-open rocket ranges of the western United States, single deployment can be used for most rockets, even those reaching altitudes of 10,000 feet or more.

Separation of the rocket is usually triggered by black-powder ejection charges, activated by an onboard electronics system, usually altimeters. (Under NFPA rules, an electronic-activated recovery system is mandatory in any high-power rocket launched with an installed total impulse greater than 2,560 newton-seconds.)

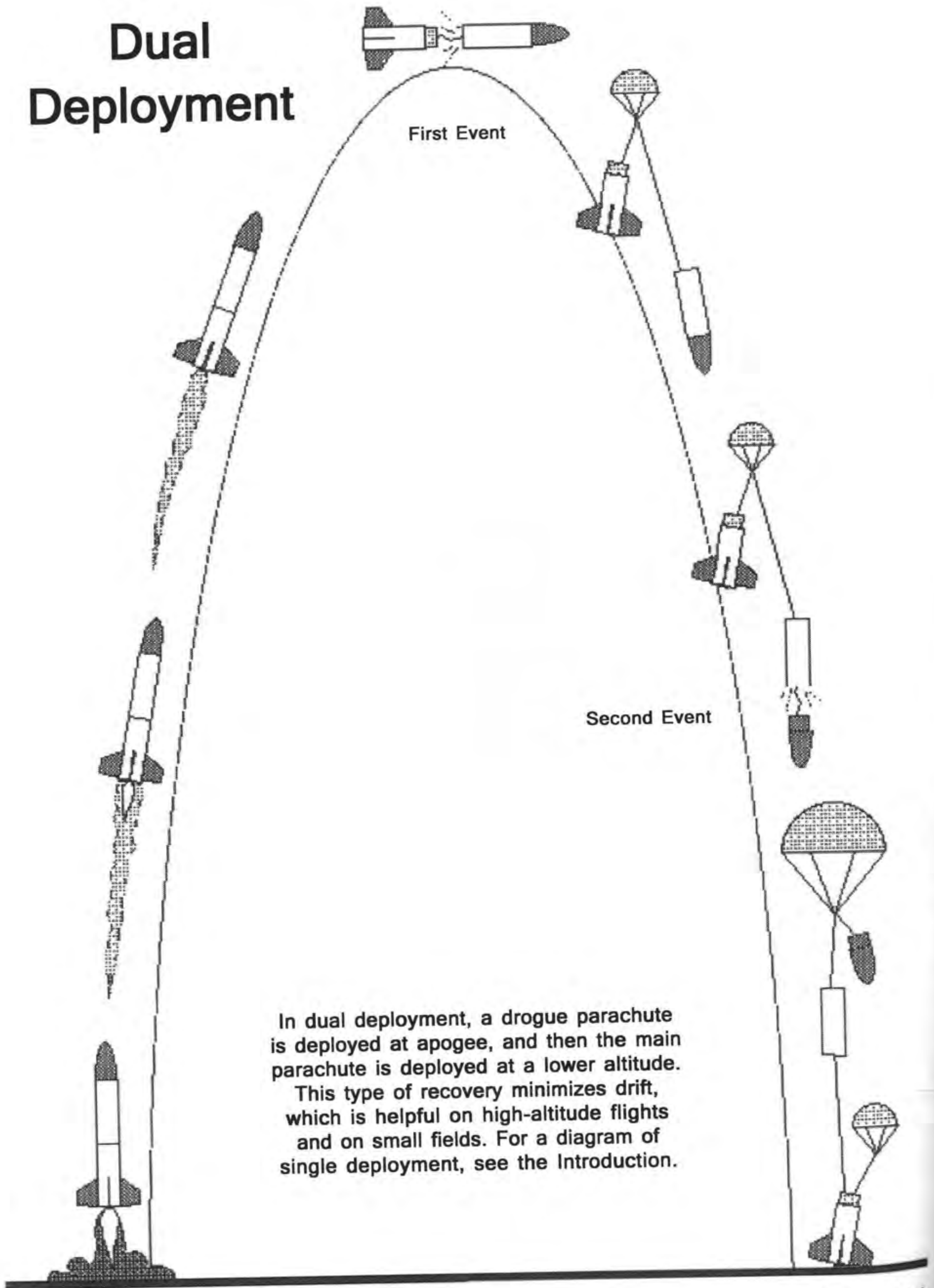
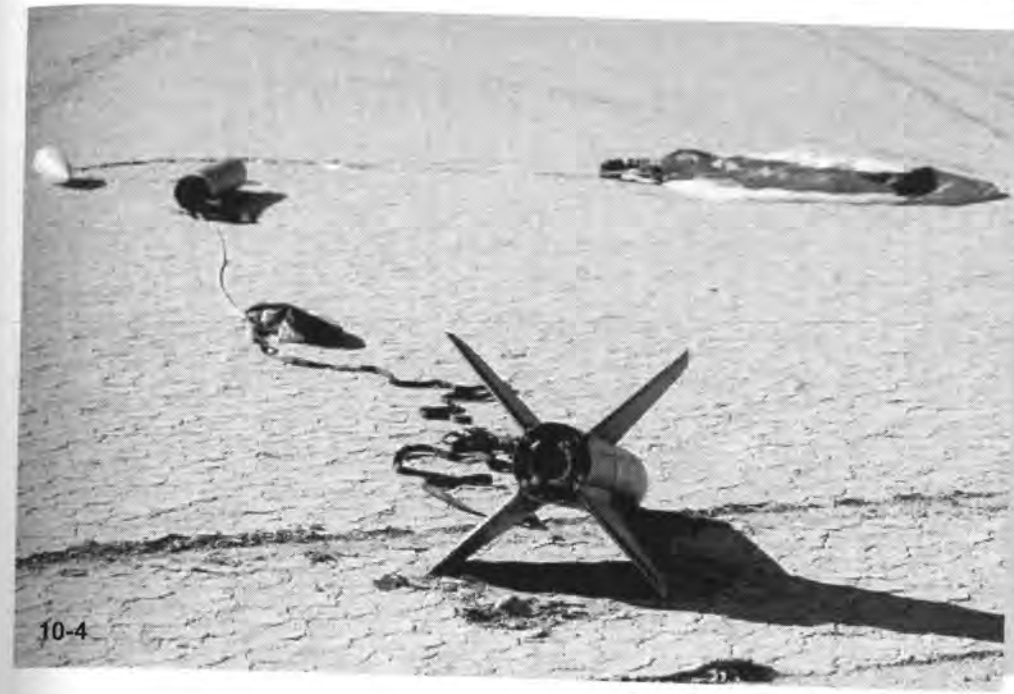


Illustration by Ray Dunakin

Diagram 10-1



This rocket landed safely from several thousand feet thanks to a well-designed recovery system. Note two parachutes: A drogue between the booster and the altimeter bay and a main parachute at the top right corner. The entire rocket is connected by a recovery harness.

In smaller rockets, motor ejection may be (but does not have to be) used for deployment. This means that a small charge is either built into the motor (in the case of single-use motors) or added to the motor's forward closure prior to flight. Some rockets may even combine motor ejection charges and altimeter ejection charges in the same vehicle. In any case, the ejection charges must function to deploy the recovery system.

Once an ejection charge is fired, the interior of the rocket fills with gas. This gas over-pressurizes the rocket's internal airframe. When this occurs, the rocket separates into two pieces. In the typical high-power rocket, these pieces are the booster (or motor end) of the rocket and the upper (or payload) section. These two halves move apart at the moment the charges are fired, but they are eventually restrained by a tether or cord that connects them. This cord is called a recovery harness, also known as a shock cord.

A single-deployment rocket after a good flight. There is one parachute.

In a single-deployment rocket, there is one recovery harness, deployed at or near apogee. In a dual-deployment rocket, there are usually two recovery harnesses. The first harness deploys at apogee. A small drogue parachute attached to this harness deploys as the rocket begins its descent.

Some rockets with dual deployment use no drogue parachute. Instead, the increased drag of the separated rocket slow the rocket's descent.

Once the rocket reaches the preset altitude, usually under 2,000 feet, another recovery harness is deployed by the firing of a second ejection charge.

The main parachute is attached to this harness. When it deploys, the overall descent of the rocket is slowed to between 15 and 25 feet per second. This usually allows for a good touchdown, depending on the field.

Basic Components of Recovery

The basic elements of a recovery system are the

The Recovery System

In this dual-deployment rocket there are two parachutes. The drogue parachute is deployed at apogee, and it is connected to the recovery harness between the booster and the altimeter bay. The main parachute is deployed at a lower altitude. The main is connected to the recovery harness that links the altimeter bay and the nose cone.

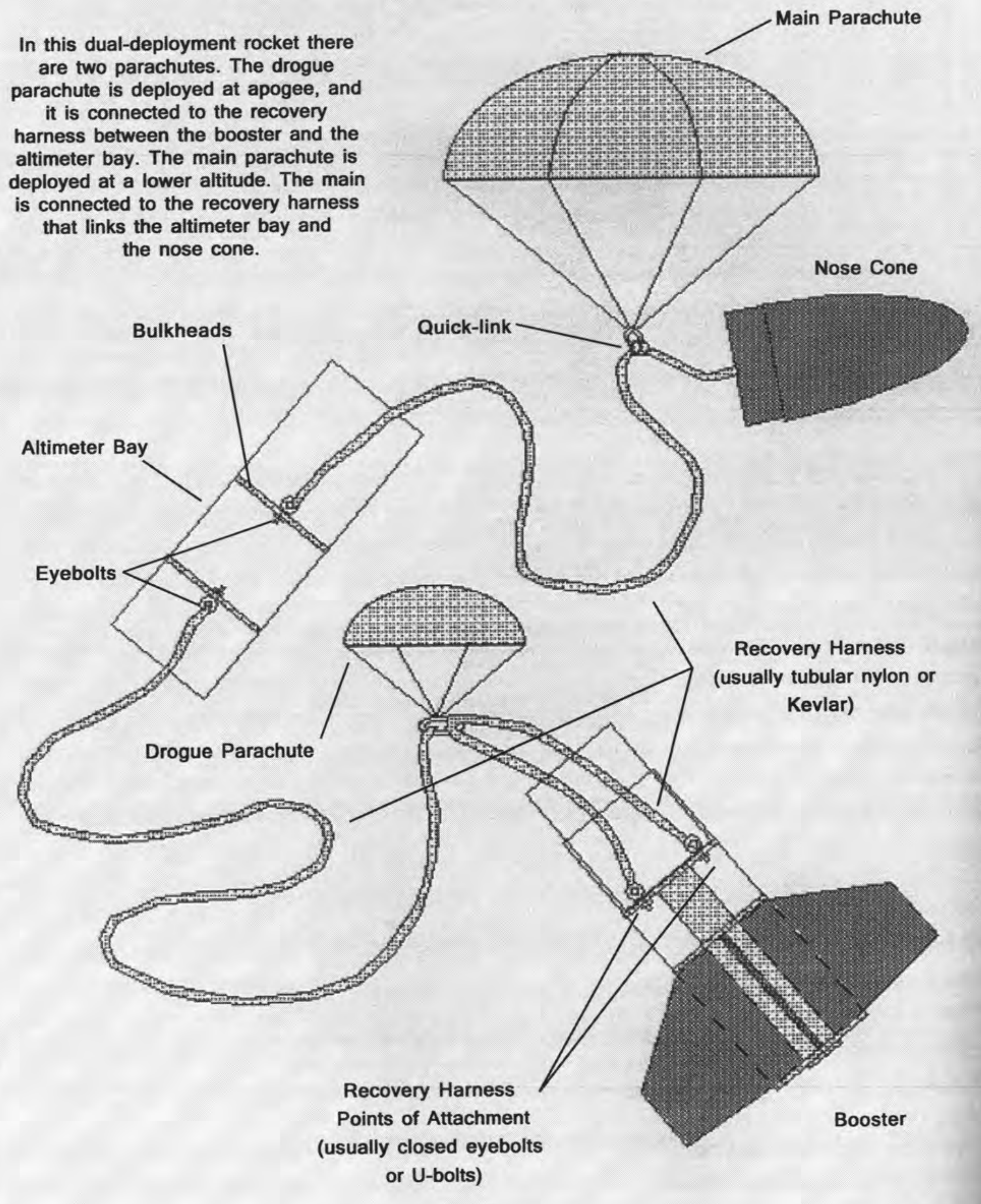


Illustration by Ray Dunakin

Diagram 10-2

Tubular nylon is excellent material for a recovery harness in high-power rocketry. The loop was made to hold a quick-link to attach to an eyebolt. To create the loop, several inches of the cord were folded back and then secured with fishing line and a thin coat of 30-minute Devcon epoxy.

shock cord or recovery harness, the points of attachment, and the parachute.

The Recovery Harness

The recovery harness helps absorb the energy of the rocket parts as they move apart during separation. The cord must also keep the rocket tethered together. A weak shock cord is a well-known cause of recovery failure. If the cord is not strong, then it will break during deployment, and at least one part of the rocket will return to the ground without a parachute.

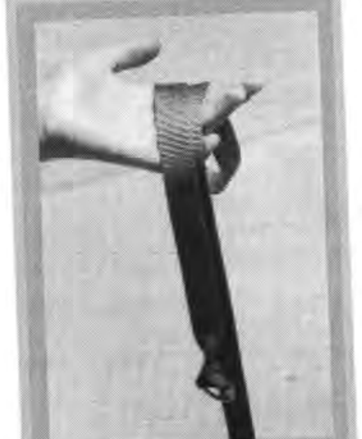
Many entry-level rocket kits come with an elastic or bungee-style shock cord. Although this kind of cord works fine in model rockets (and very lightweight high-power rockets), they are not sturdy enough for most high-power rockets. A recovery harness in high-power rocketry should be made from tubular nylon, Kevlar, or similar materials. Tubular nylon is used by hikers and mountain climbers. It is relatively inexpensive and can be purchased at most mountaineering stores. Use tubular nylon that is "man-rated," which means the cord is strong enough to be used by people in climbing situations. Kevlar cord can be obtained from rocketry retailers.

Elastic shock cords are fine for model rockets and very lightweight high-power rockets. But most high-power rockets need something stronger.

Opinions vary on the proper length for a shock cord in a high-power rocket. However, there is at least one rule of thumb that seems to work well: The cord or harness should be at least two to three times (and as much as four to five times) the total length of the rocket body. This is because the rocket halves tend to slow down as they move further apart. The longer the recovery harness, the slower the parts will be traveling when the harness reaches its maximum extension. This minimizes the chance that the harness will fail.

A long recovery harness can also be used to minimize the effects of larger-than-normal ejection charges. The extra length of cord allows the rocket halves to decelerate as they move toward the limits of the cord length.

Using this rule of thumb, if the rocket is 14 feet tall, then the cord should be at least 28-42 feet in



How LONG?

A good rule of thumb to use in determining the length of your recovery harness is to make the cord at least two to three times the length of the rocket. The longer length lessens the chance that, when the cord reaches maximum extension, there will be a failure of your points of attachment, since the rocket should be traveling slower by then. Some rocketeers make the cord as long as four to five times the rocket's length. This is fine, too–as long as you have room for the extra length of cord in your payload bay. Be sure to test fit all of your recovery parts prior to launch day.

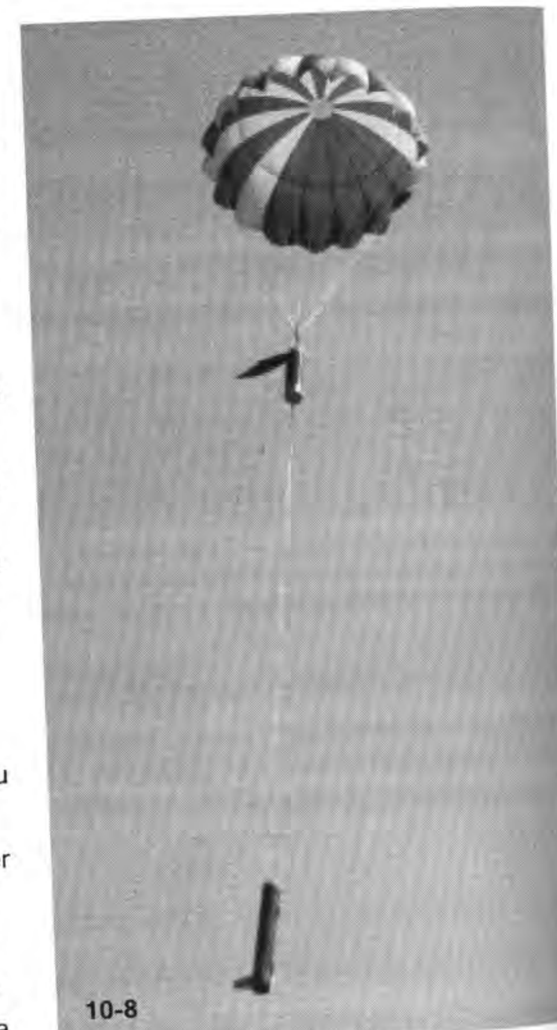
length. Some people use a cord that is even longer. It is not unusual at regional launches to see cords that are 60, 70, or even 80 feet long. This is probably longer than necessary, but it is better to err in having too long a recovery harness than one that is too short.

Points of Attachment

In the average single-deployment rocket, both ends of the recovery harness are attached to the rocket. One end is attached to the rocket booster, or lower end, and the other is connected to the payload, or upper end, or to the nose cone. The point of attachment at either end is usually an eyebolt or a closed U-bolt that is set in a rocket bulkhead, centering ring, or a removable altimeter bay. The eyebolt or U-bolt is secured with a nut and epoxy. Eyebolts are available in either open configuration or closed. If you use an eyebolt, always use closed eyebolts in high-power rocketry.

In the late 1990s, engineering students at Cal Poly San Luis Obispo in California received grants from NASA to experiment with the construction of high-power rocket designs that might replace the space shuttle. The students created the Cal Poly Star Booster, a beautiful, large-scale, high-power rocket that was flown on L and M motors. The Star Booster stood more than ten feet tall with a wingspan of over eight feet. The rocket was designed to launch on a motor but return as a glider via radio control. Depending on the configuration, the rocket weighed 70 pounds, or more.

On one of its early flights with an L motor, the Star Booster roared off the pad, climbed several thou-



10-8

A high-power rocket descends under parachute. Note the long recovery harness.

sand feet, turned over at apogee, and started its descent. Unfortunately, the radio control failed to operate. The nose-heavy rocket picked up speed as it hurtled toward the ground. But the students from

10-9

A bullet-proof point of attachment involves three separate components: The recovery harness, the Quick-link and the eyebolt (or U-bolt).

Cal Poly were not worried. As a back-up plan, they had prepared a rear-ejecting parachute that was attached to a sturdy metal centering ring in the aft end of the rocket. Moments before impact, an ejection charge (also activated by radio) blew the parachute out the back end of the rocket. Then, in the blink of an eye, the parachute opened and was ripped instantly away, leaving the rocket to plunge into the ground, where it was utterly destroyed.

An inspection of the crash site quickly revealed the cause: Although the all-metal centering ring survived, two open eyebolts used to connect the recovery harness and parachute to the aft ring had been ripped completely open by the force of deployment. The obvious lesson: Do not use open eyebolts in high power.

Some excellent high-power rocketry kits come with open eyebolts. The best practice is to discard them or weld them closed. If you are going to overbuild your rocket anywhere, do it at the points of attachment. Closed eyebolts or U-bolts cost a few dollars each, or less. Making that small extra investment in your high-power rocket is insurance that the rocket will stay together on the way down.

Attaching the eyebolt or U-bolt to the rocket is simple. The point of attachment is usually a bulkhead. See photos 10-9 and 10-10. The threaded eyebolt goes through the bulkhead and is secured with a washer and nut. Some people add extra security by applying epoxy to the threads of the eyebolt after the nut is tightened. The method of attaching a U-bolt is the same. Keep in mind that as a rocket gets larger and heavier, the points of attachment should get larger, too. Do not use the same size eyebolt for your 5-pound rocket and your 65-pound Level Three rocket.

10-10

A simple U-bolt attached to the center of this nose cone bulkhead provides a good attachment point.

On minimum-diameter rockets, placing a point of attachment in the booster section is often difficult. However, the forward closure or forward bulkhead

The EYEBOLT

An open eyebolt, like the one shown above, works fine in model rockets and lightweight high-power rockets. But for most high-power applications, a U-bolt or closed eyebolt is preferred. The point of attachment should be bolted firmly to the bulkhead or centering ring. After the nut is tightened, place some epoxy on the threads of the bolt to ensure that the assembly does not come loose later. Two eyebolts can also be used.

10-11

on some reloadable motors has a threaded slot that will accept an eyebolt. See photo 10-11. This works fine as a point of attachment for a sturdy eyebolt.

The parachute is usually attached to the shock cord or recovery harness with a knot or with a quick-link (through a loop in the harness). The recovery harness is then attached to the eyebolt or U-bolt in the rocket's bulkhead with a quick-link.

10-12

Do not forget to attach all the links as you finish preparing your rocket. In fact, include that step in your pre-flight checklist, especially in large projects.

A couple of years ago at our local launch in California, one of our Level Three flyers forgot to attach his recovery-harness quick-link to a nose-cone bulkhead. It was a busy morning of launching, and arming the altimeters and timers in the 80-pound M-powered rocket took some time. The upper payload bay was filled with a military-style parachute attached to the harness, but somehow the rocketeer placed the nose cone into the upper payload bay without attaching the quick-link from the harness to the cone.

The rocket launched on an Aerotech M1939 and air-started additional motors. It was a great flight up. But at apogee, the ejection charge fired, and the nose cone was literally launched out of the upper payload bay. It was attached to nothing on the rocket, so it hurtled to the ground and was severely damaged.

The rest of the rocket fared even worse. Since the cone was not attached to the recovery harness, there was nothing to pull the parachute out of the payload bay (the ejection charge was on the nose cone, forward of the recovery harness). The rocket simply tumbled in a flat spin, and it was destroyed on impact. A simple error–made by an experienced flyer–might have been avoided with a pre-flight checklist on a busy day.

The Parachute

There are many high-quality parachute makers, and it is easy to obtain excellent parachutes for rockets of all sizes–from small, lightweight rockets to rockets weighing 75, 100, 150 pounds, or more.

There are several styles of parachutes. These include X-style, conical, cross-form, canopy-style, and drogue.

As discussed in Chapter 1, a drogue parachute is a small parachute that is opened at apogee to help slow down a rocket's descent and minimize drift, so that at a lower altitude, the main parachute can be deployed. The main parachute is a much larger parachute.

10-13

A perfect descent rate: A military surplus parachute gently drops the 400-pound booster section of this Black Brandt in the Nevada desert at Tripoli's annual experimental launch in 2004. The rocket returned safely from more than 18,000 feet.

High-power rockets may be flown with a drogue and a main chute, or just a main. See photo 10-14. Main parachutes may be deployed at apogee–or at a lower altitude when used in a dual-deployment recovery system.

Parachutes are made of different materials, the most common in high power being rip-stop nylon. Military surplus parachutes–made of either nylon or silk–are also popular. See photo 10-13.

In the *Handbook of Model Rocketry*, G. Harry Stine observed: "The heavier the model, the bigger the parachute. And the bigger the parachute, the longer the model rocket will stay aloft." The observation is true in high-power rockets as well. What's more, the bigger the parachute, the longer the rocket will stay in the air–and the farther away it may drift.

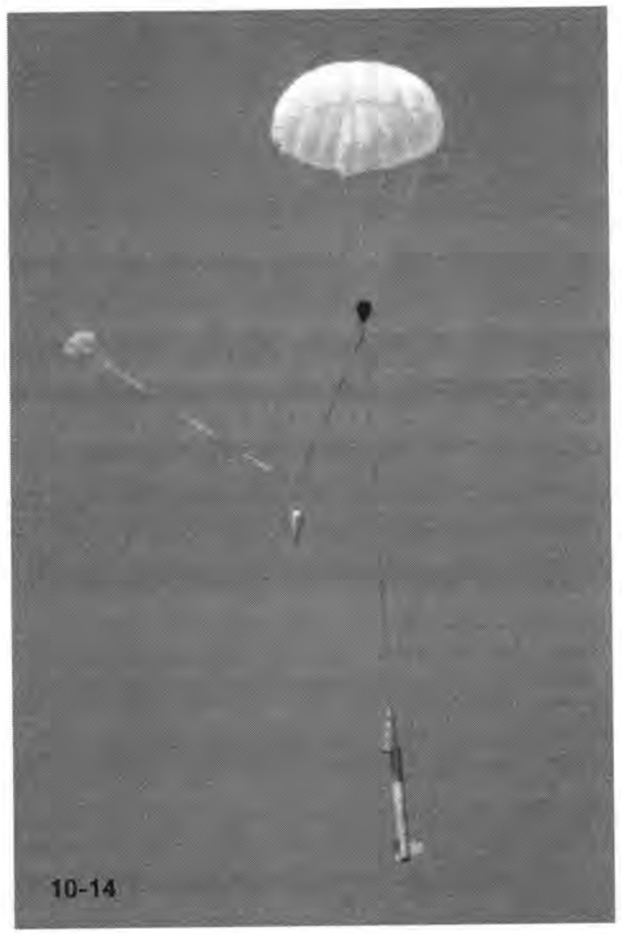
The Descent Rate

In high-power rocketry, parachute size can be determined by calculating the descent rate of the rocket. There are no set rules in the NAR or Tripoli safety codes as to a precise rate of descent for high-power rockets. But it should be noted that for Level Three certification, NAR requires a descent rate not greater than 20 feet per second. Generally, most high-power parachute makers design their parachutes to allow for an overall descent rate of 15-25 feet per second, when fitted to the rocket's correct weight.

There are some differences in opinion among parachute companies as to which rate is best, but this appears to be the general range.

There are several tables, charts, and calculators available online to help high-power rocket builders determine the descent rate for their rocket and the appropriate parachute size. Most of these tables can be found on the web sites of the commercial parachute makers.

For example, Rocketman provides charts that allow you to match descent rates with Rocketman parachutes based upon the total weight of the rocket and the target descent rate (within the 15-25 foot per second range). Similar information is available from the web pages of other parachute makers, such as SkyAngle and Top Flight Recovery.


10-14

A descent rate calculator can also be found at www.onlinetesting.net/cgi-bin/descent3.3.cgi. This calculator, maintained and designed by Jordan Hiller, will help you pick the right size parachute for almost any rocket. Another useful calculator, submitted by Dean Roth, can be found at www.info-central.

Descent-rate calcualtors are great for giving you an idea of how fast your rocket will fall from apogee. But do not leave your common sense at home when picking a parachute.

The ground you fly on plays a role in parachute selection. Is it hard and dense, like the desert playa in Black Rock, Nevada? Or is it soft and lush, like the sod farms in Orangeburg, South Carolina, or West Palm Beach County, Florida? Is it the middle of the summer in the West (where even farm land can be hard and dry)? Or is it November, (when the same land is now soft with moisture)? If you have a heavy rocket, give these and related questions a minute or two of your pre-flight planning time. For harder ground, use a larger-than-normal parachute to slow down your rocket's descent rate. On softer ground, a smaller parachute will usually suffice.

Attaching the Parachute to the Harness

The payload/altimeter bay/nose cone section of the rocket should land last in the average dual-deployment rocket. This allows the most damage-sensitive portion of the rocket to take full advantage of the main parachute. As the rocket approaches the ground, the heavier booster section should land first. This momentarily relieves the main parachute of the heavier weight and allows the rest of the rocket to land gently.

To accomplish this, attach or tie the main parachute as close to the nose cone or forward end of the rocket as possible. The use of quick-links allows you to easily vary the position of the parachute and to move the parachute from one rocket to another.

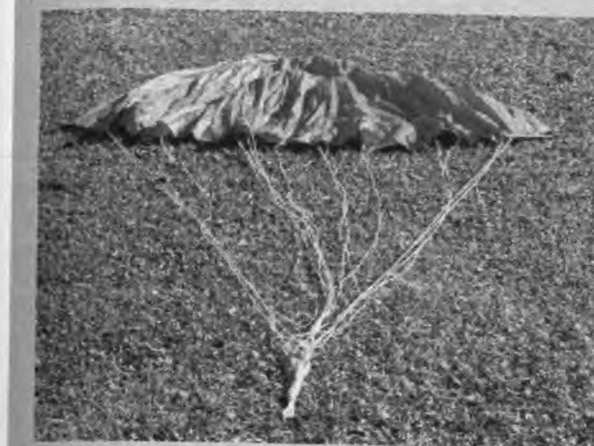
Packing the Parachute

There are many ways to pack a parachute. One of the most common methods is illustrated in photos 10-15 through 10-20.

First, detangle all the shroud lines, and then lay the parachute flat on the ground. See photo 10-15. Next, fold the parachute panels over each other as illustrated in photo 10-16. Then take the shroud lines and place them in the center of the folded parachute as shown in photo 10-17.

Leave some of the shroud line extended

Packing the Parachute


10-15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10-18


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10-20

10-20

10-21

beyond the parachute so you may attach the line to the recovery harness.

After you have placed the shroud lines in the middle of the canopy, you can fold the parachute over again (lengthwise), covering the the lines, or simply roll the parachute up, as shown in photos 10-18 through 10-21.

Once the parachute has been rolled up, a loop of the gathered shroud lines at the base of the lines will be used to attach a quick-link. That link, in turn, can be connected to the recovery harness.

Placing the parachute into the rocket is pretty easy. Keep in mind that there should always be protection between the parachute and the ejection charge canisters. (As shown in photo 10-20, a large section of Nomex can be placed in the rocket prior to insertion of the recovery harness and parachute.) The recovery harness goes in first, and then the parachute is placed in on top of the harness. See photos 10-20 and 10-21 (rocketeer Terry Baucom preparing his Level Two rocket). This helps ensure that when the rocket halves separate, the act of the harness coming out of the rocket must force the parachute out, too. The parachute can be snug in the airframe--even tight. But prior to actual launch, be sure to test your ejection charges to ensure that you have sufficient charge to force the rocket apart (see Chapter 6).

Photos 10-22 through 10-27 demonstrate a similar method of packing a parachute for a high-power rocket. This method allows the parachute to snap open and was suggested by Christopher Lam in his April 2002 article in *Extreme Rocketry* magazine.

Lam's method begins with the shroud lines detangled and the parachute on a flat surface. As illustrated in photos 10-23 and 10-24, fold each parachute *panel* in half (lengthwise), with all of the shroud lines held together and the folded panels stacked on top of each other. Next, carefully take the shroud lines, and fold them so most of the lines fit on top of the folded parachute panels, as shown in photos 10-25 and 10-26. Now, fold the parachute

Packing the Parachute

10-22

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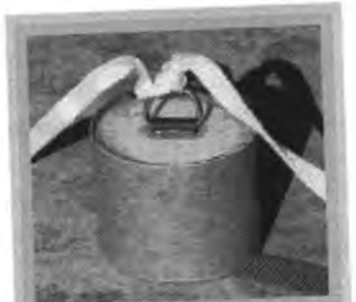
10-26

10-27



The PISTON

Piston-style ejection charge protection comes standard in many Public Missiles Systems kits and can be custom-built for almost any rocket. The advantage of the piston is that it protects the parachute from ejection gases. The ejection-charge gas forces the piston out of the rocket. The parachute is placed above the piston. The gas never comes in contact with the parachute. But it is important to keep the piston clean and in good working order. Small particles of dirt can become lodged between the piston and the airframe wall. This can lead to ejection failure. Inspect the piston after each flight to be sure it still moves up and down smoothly.

panels again, beginning at the top of the panel (the end opposite of the shroud lines) until the folds conceal all but the leading length of the shroud lines. See photo 10-27. The parachute is now ready to be attached to the recovery harness and inserted into the rocket's payload bay.

Parachute protection

The parachute and the recovery harness must be protected from the hot gases of the ejection charge. These gases will melt or burn holes in most parachutes and can damage even the toughest shock cords over time. The most common means of protecting recovery devices from ejection charges is to place fire-retardant material between the charge and the recovery system.

The most popular material used for this purpose in high-power rocketry is Nomex cloth. Nomex is available from rocketry retailers and comes in rectangular, hexagonal, or circular sheets that can be slipped over a shock cord or recovery line to rest between the ejection charge and the parachute. See photo 10-28. Nomex is inexpensive, provides good protection, and will extend the lifetime of all of your recovery system. Nomex also comes in long narrow sleeves that fit over the harness itself to protect the cord from damage. See photo 10-29.

Another way to protect the recovery system is with piston-style ejection. A piston-ejection system will completely insulate the recovery harness and parachute from any ejection charges. Piston-style systems come standard in several Public Missiles Systems kits and can be built from scratch and installed in almost any rocket.

The piston, which is the size of an airframe coupler, is located between the parachute and the

10-28

10-29

A Nomex sleeve is placed over the first foot or so of this recovery harness to protect the harness from ejection charge gases. This is the area closest to the ejection charge when the charge is fired. These sleeves are available from many rocketry outlets.

ejection charge. The piston is secured by a recovery cord that allows the piston to move inside the rocket. When the charge fires, the hot gases force the piston up through the airframe and then out of the tube. This forces the parachute and recovery harness out of the rocket first. See generally photo 10-30.

The drawback, if any, to piston-style ejection is the tendency of the piston periodically to get lodged or stuck in the airframe and then fail to fully eject the recovery harness and parachute. To guard against this, always inspect your piston system after each launch to keep it free of dirt or debris. Be sure the piston slides smoothly and easily before subsequent flights.

For more discussion on piston-style ejection, see Chapter 6.

Another way to protect the parachute is with loose wadding. This type of wadding is sold by rocketry retailers in plastic bags (and can be found in bulk at home-improvement stores in the form of insulation). It is usually a gray-colored, cellulose-type material that is crumbly and loose when dropped in the rocket's airframe. But it does work, and it is inexpensive. It is particularly beneficial when used in conjunction with a Nomex pad.

10-30

A Public Missiles piston-ejection system in a three-inch airframe. The piston protects the parachute from ejection charges.

Yet another method of protecting the recovery harness and parachute is to eliminate the use of black powder as the ejection charge.

As discussed in Chapter 6, some rocketeers are now utilizing systems that use carbon dioxide to pressurize the airframe and cause separation and deployment. With these systems, the need for Nomex cloth or other protection for the recovery system is reduced, if not completely eliminated. These systems are especially helpful in high-altitude rockets when the

The ZIPPER

A zipper is a tear along the length of the airframe caused by the recovery harness. It occurs when the harness deploys while the rocket is traveling too fast. This can happen when the ejection charges fire either too early or too late. With a little construction planning and flight simulations, most zippers can be avoided.

ignition of black powder charges is less-than-optimal.

Common Causes of Recovery Failures: Electronics

One of the most common causes of recovery failure in high-power rocketry has to do with errors in operating on-board electronics. An electronics-based error usually means the altimeter fails to fire the ejection charge, which results in a total failure of recovery and the destruction of the rocket.

Altimeters used in high-power rocketry are easy to operate and come with detailed instructions. Read them. If you do not understand the instructions, ask someone for help. Be familiar with the methods of turning the altimeter on and off. Be sure the correct electrical ports are used for ejection-charge igniters. Make sure the battery is fresh (new) and is secure. And always use some type of checklist on launch day to ensure that you do not forget to arm the altimeter on the pad. Believe it or not, this is a common error. It happens even to experienced Level Three flyers.

Common Causes of Recovery Failures: Construction Defects

Another common cause of recovery trouble is failure of the points of attachment. This is a construction issue. Avoid using elastic or bungee-type shock cords. These cords do not make for a good recovery harness, unless your rocket is very light. They have a tendency to snap or break under stress. Use Kevlar or tubular nylon or other strong material, and attach the harness to your rocket with sturdy quick-links. This way, the harness can easily be moved from rocket to rocket. Also avoid using open eyebolts. The best recovery harness in the world is no good if the

10-31

A lawn dart (or in this case a desert dart) occurs when there is a total failure of recovery. Lawn darts are usually caused by a problem with on-board electronics. Back-up altimeters usually solve the problem. The fin canister on this rocket slid over the airframe and into the ground.

eyebolt to which it attaches is stripped open during separation or when the parachute deploys. Closed eyebolts or U-bolts should be used for all points of attachment.

Zippers

A zipper is an unfortunate slice in a rocket's airframe caused by the recovery harness during deployment. It typically occurs in the booster section of the rocket.

As noted in previous chapters, the best time for the recovery harness and parachute to be deployed is at or near apogee, when the rocket is moving slowly. A zipper is caused by deployment that takes place too early or too late. In either case, the rocket is moving too fast, which causes the shock cord to slice through the airframe as the rocket separates and the booster tumbles from side to side.

10-32

10-33

Tom Thompson, at Battle Park, Virginia, with his anti-zipper device built from a swimming pool float and some duct tape.

A zipper rarely results in a total failure of deployment. But zippers can cause serious damage to the rocket and may even prevent an otherwise successful high-power certification flight.

In a rocket equipped with a motor-based ejection charge, a zipper may occur if the delay element for the charge is too short or too long. As discussed in Chapter 6, delay elements are variable between 6 and 16 seconds. To pick the right delay time for your rocket, run flight simulations with programs such as RockSim to see when apogee will be reached with your rocket's anticipated flight weight/motor configuration. The delay time you choose should be as near to the moment of apogee as possible.

If you do not have access to a computer program, ask your local motor vendor what delay time they would recommend–again, based on your particular rocket and the motor chosen for the flight. Motor vendors and other experienced flyers can usually make a pretty good guess, based on experience, as to the proper delay element, so that the ejection charge fires when the rocket has reached apogee.

If you cannot get exactly the right delay, opt for a delay element that is a little longer, rather than shorter. A short delay time between motor burnout and the firing of the ejection charge may result in a rocket that is still traveling too fast for safe deployment. This is particularly true for high-impulse motors in lightweight rockets.

If, on the other hand, you are launching a heavy rocket or a rocket that will not go very high, be careful not to choose a long delay time. If the delay element is too long, the charge may not fire until the rocket has returned to the ground. In the alternative, the charge may fire just in time to force the nose cone off the rocket before it hits the ground. The result is that the airframe plows into the dirt--an outcome known as a *core sample*. Either way, the rocket is damaged or destroyed.

Zippers can also occur in rockets equipped with on-board altimeters. Electronics may be tricked into sensing apogee too early or too late. This condition can occur if the altimeter portholes are improperly sized (by a lot). It may also occur if the altimeter bay is located between the rocket's fins or near the nose cone, where turbulence can cause the altimeter to fire charges early or late. To calculate static-hole sizes, see Chapter 8.

The results of a zipper can be minimized. A wide recovery harness cord–at least one inch in diameter–may decrease the chance of a zipper, while a narrow cord might present more of a risk of slicing through the airframe. Another anti-zipper device is illustrated in photos 10-32 and 10-33. In this rocket, a "bubble" is attached to the cord where it exits the airframe. The bubble is actually a float commonly used in swimming pools. It is taped to the cord line and, in theory, will lessen the chance that the cord will cut through the airframe in a violent deployment.


10-34

The nose cone of this rocket ejected too late. The result is what veteran rocketeers call a core sample, because the airframe digs into the ground a foot or so, bringing dirt with it when it comes out.

Some rocketeers also add an extra layer of fiberglass or Kevlar to the lip of the booster section (on the outside of the airframe) to strengthen the airframe against the impact of a zipper.

Yet another method of minimizing a zipper was presented by Brad Vatsaas in the January 2004 issue of *Extreme Rocketry* magazine. Vatsaas suggests moving the tube opening to the front payload section instead of the booster section. This reduces the chance that the tumbling booster section will be cut by the recovery harness. For additional discussion on zippers, see Chapter 6.

Other Causes of Failure

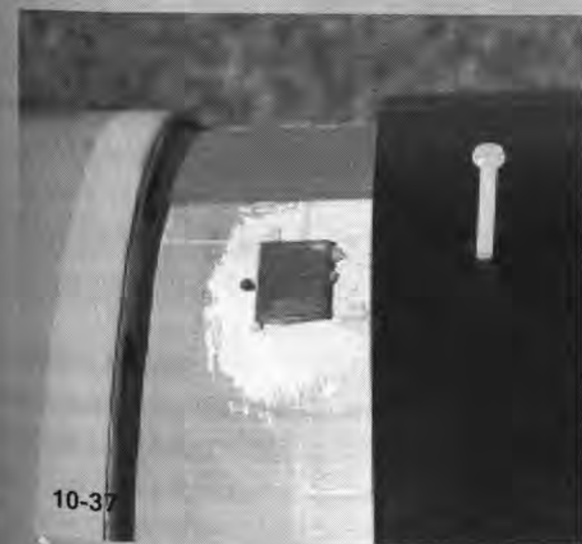
Insufficient black-powder charge is another cause of recovery failure. As explained in more detail in Chapter 6, it is essential that the rocketeer do testing on the ground for any new rocket, particularly large projects, prior to flight. When in doubt, use a little more black powder. A *little* too much powder rarely results in any damage to the rocket. Not enough powder, on the other hand, may lead to a lawn dart. Remember the old rocketry adage: "Blow them apart or blow them up."

A related recovery failure occurs when the nose cone or the body halves of the rocket are too tight and the ejection charge simply fails to separate them (this occurs more often as the result of an insufficient charge). There is no hard-and fast-rule as to how tight a nose cone should fit in the airframe. Most rocketeers use masking tape wrapped around the shoulder of the nose cone to get a good firm fit prior to launch (and to prevent the cone from coming off early).

Several years ago, Tim Quigg of *Extreme Rocketry* magazine suggested that rocketeers use just enough masking tape so that you can pick up the rocket by the nose without the rocket coming apart. This is a good rule of thumb. Quigg also suggested that if you can shake the rocket's nose vigorously without anything coming apart, perhaps


10-35


10-36


10-37

the pieces are too tight. These same principles also can be applied to the fit or connection between the booster and upper airframe on most rockets.

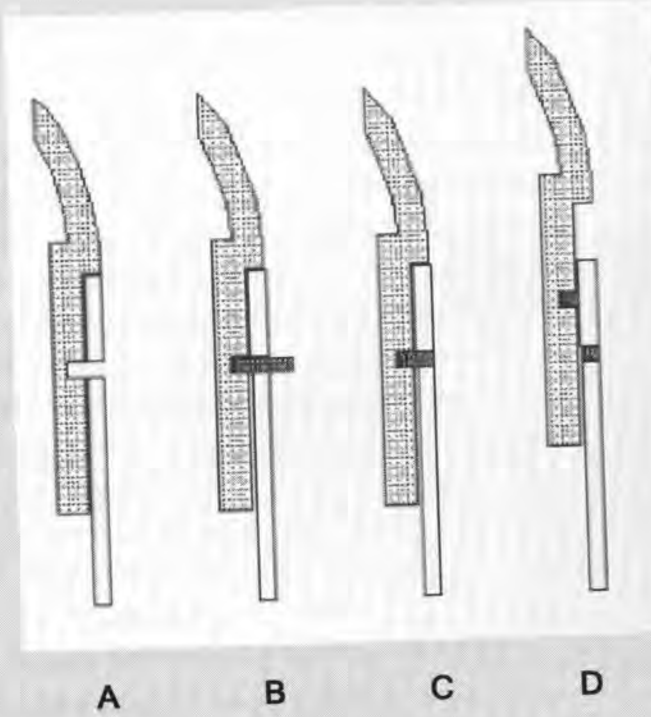
Shear Pins

In dual-deployment rockets, there are two separate ejection-charge events. Typically, the rocket separates at its midpoint at apogee, deploying the drogue parachute. Sometimes, the force of the initial charge is enough to knock off the nose cone, too. If the nose cone comes off at apogee, it will probably pull out the main parachute as well. This can lead to a lost rocket, especially on a windy day or on a small field.

To prevent this problem, rocketeers use shear pins. A shear pin runs through the airframe and the shoulder of the nose cone and holds the cone firmly in place until the ejection charge for that compartment is ignited. The shear pins are usually made of plastic or nylon screws. They provide enough strength to hold the cone in place during normal flight, but they easily shear when the appropriate charge fires.

Shear pins are also used to prevent drag separation of rocket components during flight. Drag separation happens when the drag of the rocket's booster (for example) becomes higher than the drag of the forward airframe. This can occur after the single or primary motor burns out but while the rocket is still moving up. The difference in drag can cause the booster to fall behind and then separate from the rest of the rocket. This can lead to an early deployment of the recovery harness. Shear pins prevent this from occurring.

There are on-line calculators available to assist rocketeers in determining the correct number of pins to use in a rocket of a given size. One calculator can be found on Rocketry Online in the Info Central section. Photos 10-35 through 10-37 show the placement of a shear pin (one of several) in the upper payload bay and nose cone of a 10-inch rocket. The payload bay and the nose cone have a hole drilled at the same location. After the rocket is assembled, the pin is placed in the hole and forced



Shear Pins

Shear pins are helpful in preventing drag separation and early deployment of the main parachute. As seen in this diagram, (A) a hole is drilled through the airframe and into the nose cone. (B) A pin (often a piece of styrene rod) is then placed and trimmed off (if you are using nylon screws there is no trimming required). (C) The pin will hold the nose cone on the airframe during the deployment of the drogue parachute. (D) But when the ejection charges for the main parachute fire, the force of the ejection charge gases will break or shear the pin, allowing the nose cone to separate and the recovery harness to be pulled out of the payload bay. Illustration by Ray Dunakin.

Diagram 10-3

all the way through both pieces. When the charge fires, the pin is sheared. See Diagram 10-3.

In this example, NAR member Mike Scicchitano has attached with epoxy a small rectangular piece of copper sheeting to the nose cone shoulder and the inside of the payload bay (not shown). This helps ensure that when the charge fires, the pin will be cleanly cut in two.

Lost Rockets

Recovery is not complete until you have tracked down your rocket and found it in the field. This may seem like a no-brainer, but often in the thrill of the launch rocketeers take their eyes off the rocket or fail to note exactly where it touched down. This happens when the owner of the rocket is taking pictures of the flight or is busy celebrating an apparent certification. And new rocketeers sometimes incorrectly assume that the LCO or other club members are carefully watching where every rocket lands. This can lead to big trouble. If you do not find the rocket, there will be no certification.

10-38

No matter how large your rocket is, if the rocket drifts beyond the immediate landing field, keep your eyes focused on the rocket until it lands or disappears. Be sure to note where the rocket landed in relation to some distant landmark, such as a tree or utility pole. When you set off to search for the landing area, keep that distant object in sight. And bring help, if you can. Rockets often land a lot farther away than you think

As discussed in Chapter 8, consider investing in some type of locater device for your rocket. This can be as inexpensive as a $10 audio beeper from Radio Shack (see photo 10-38) or a full-scale transmitter system or GPS unit. A beeper can be attached to your recovery harness and turned on when you arm your altimeter, or it can be activated by placing the pin in such a location as to cause it to be pulled out when the harness deploys.

Even a large, Level Three rocket can completely disappear in only two or three feet of corn or weeds. See photo 10-39. A small beeper will help bring you to the right spot quickly and safely.

Additional Safety Issues

A high-power rocket that has launched, successfully deployed, and returned to the ground should never be touched by anyone without the express consent of the owner. This is common etiquette in high-power rocketry, and it's also a good safety rule. Many rockets are equipped with multiple ejection charges. Sometimes, not all of the charges go off during flight. So a rocket that has landed may still have live charges on board. The owner of the rocket is the only person who should initially pick up and handle the rocket after flight. That person is in the best position to determine whether all of the charges have been ignited.

10-39

Searchers Scott Canepa (left) and Loren Eakins recover a large rocket that landed on farmland. This 8" diameter, 10-foot-tall rocket was hard to spot in crops that were only two feet high. Beepers, GPS units, and transmitters help make recovery a success.

Leaving a rocket alone is also a courtesy to the owner. Some rocketeers like to take photographs or otherwise analyze the rocket's landing site for future reference. So if you find a high-power rocket in the field, do not touch it. Mark its location and notify the RSO so he or she can find the rocket's owner.

The safety codes also provide for additional rules related to recovery.

NFPA 1127 section 4.10.4 (and the NAR and Tripoli codes) provides that no attempt shall be made to catch a high-power rocket as it approaches the ground. This common-sense rule is followed by most adults, but occasionally an excited child or teen will run up to a rocket as it approaches the ground. If you see this happen, warn them away.

Another safety issue that arises at a high-power launch is the problem of utility or power lines. Rockets that drift a long way sometimes find themselves hanging by their parachutes in high-power lines.

NFPA sections 4.10.4 and 4.10.5 make clear that no attempt is to be made to recover any rocket from a power line. If a rocket becomes tangled in such a line, the power company or other appropriate authority must be contacted.

Under no circumstances should the rocket be touched–serious injury or even death can result from any contact with materials suspended from power lines. Call the power company and wait. Some utility companies will remove the rocket at no cost. Others may charge a fee. Whatever the cost, leave it to professionals to pull your rocket out of the wires and warn all persons to stay away from any dangling rocket until the power company arrives.

The ROCKET

To obtain Level One certification you should construct your own rocket. However, this does not mean that it has to be scratch-built. The majority of Level One certifications are with kits made by rocket makers such as Aerotech, Binder Design, PML, and others. Level One rockets are typically lightweight, but strong. They are often flown first on F or G motors. On an H or I motor, some of these rockets can reach altitudes of 4,000 feet or more. They can be flown with or without electronics on board.

11

Building the Level One Rocket

The selection and construction of your first high-power rocket

There are many commercial rocket kits suitable for a Level One certification flight. Manufacturers such as Aerospace Specialty Products, Aerotech, Binder Design, LOC/Precision, and Public Missiles Systems produce quality kits that require a minimum of model-building skills.

11-1

A scale model of a Nike Smoke takes off on I power.

The purpose of this chapter is to acquaint new rocketeers with the basic skills and techniques used in the construction of a simple and reliable high-power rocket.

To help illustrate the construction of a typical Level One rocket, we have chosen the Hi-Tech H45, produced by LOC/Precision. The H45 is an affordable and reliable high-power rocket that provides the builder with hours of enjoyment and multiple high-power launches. It is moderately priced (less than $75), easy to construct, and a good rocket for a Level One certification flight, as it can easily handle most H and I high-power motors.

Get Things Started

As with all high-power rockets, it is important to follow the instructions

11-2

Ed Fenton, left, and Alan Whitmore stand by their Level One certification rockets at the field in Orangeburg, South Carolina. Level One rockets are readily available in kits and can also be made from scratch. They are true high-power rockets and must be built strong enough to sustain the thrust of an H or I motor.

from the manufacturer, especially if this is your first kit. Before construction begins, make sure you have received all the parts with your kit. Carefully match up the parts list with the instruction sheet. If anything is missing, contact LOC. As with most major rocket companies, LOC will probably put any missing parts in the mail right away.

LOC recommends using high-strength epoxy in the construction of the H45. Do not skimp here. Glues or adhesives weaker than epoxy will not withstand the stresses of a high-power rocket launch. The adhesives that you may have used in model rocketry will not work in high power. A Level One motor packs more than enough punch to tear poorly constructed rockets apart. So heed the instructions of LOC, and pick up quality epoxy.

11-3

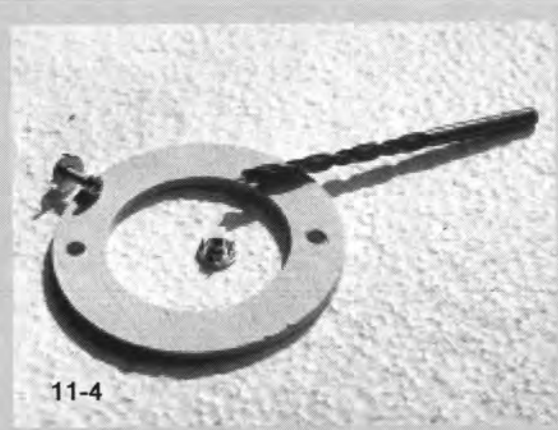
NAR member Todd Haring certified Level One on his Der Red Max.

For this rocket, we used Devcon 30-minute epoxy, which is slow to set up and very forgiving. If you make a mistake, it can be wiped away and cleaned up quickly, and you can begin again. However, once it dries, 30-minute epoxy forms a rock-solid bond that works well for almost any high-power need.

Positive Motor Retention

The first step in putting this rocket together is to provide for some means of motor retention. Although there are several methods available, we chose to use two blind nuts set in the rocket's aft centering ring. This is an inexpensive yet sturdy and reliable, means of keeping the high-power motor in the rocket body–where it belongs–at all times. Blind nuts are available at hobby and hardware stores and usually cost less than $1 per package of two.

Since the aft centering ring on this rocket is so thin, use care when drilling the two pilot holes for the blind nuts. If you have access to a drill press, use it for this part of the construction. Be sure to use a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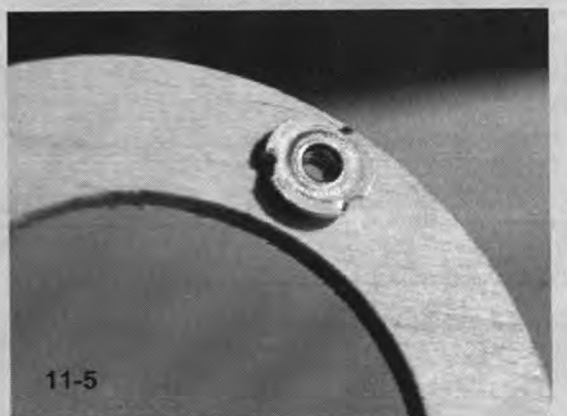
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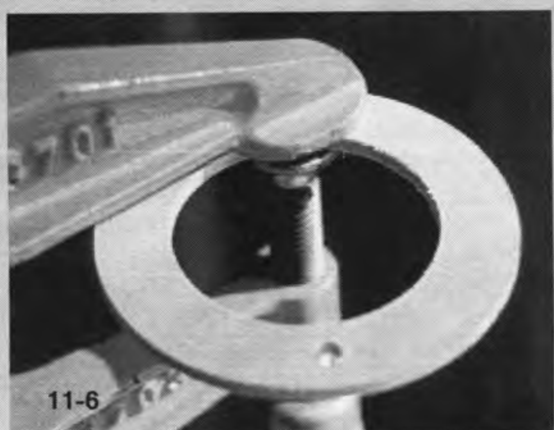

11-6


11-7

wood backing piece when drilling through the ring as this will reduce the chance that the ring will splinter or crack.

Carefully drill two holes in the centering ring, approximately 180 degrees apart. See photo 11-4. Next, press the blind nuts into the holes, using pliers or a clamp, as shown in photos 11-5 and 11-6.

Once the blind nuts are pressed into place, take a small amount of epoxy, and apply it to the outer edges of the blind nut for additional strength. Be careful not to get any epoxy on the inside threads. Stop working on the rocket until this assembly has fully dried.

The finished retaining ring is shown in photo 11-7 (Note that the left blind nut has a screw in it for test fitting.) Keep in mind that on most projects the tabs or ears on the blind nut will be on the inside of the ring (not visible once the rocket is assembled).

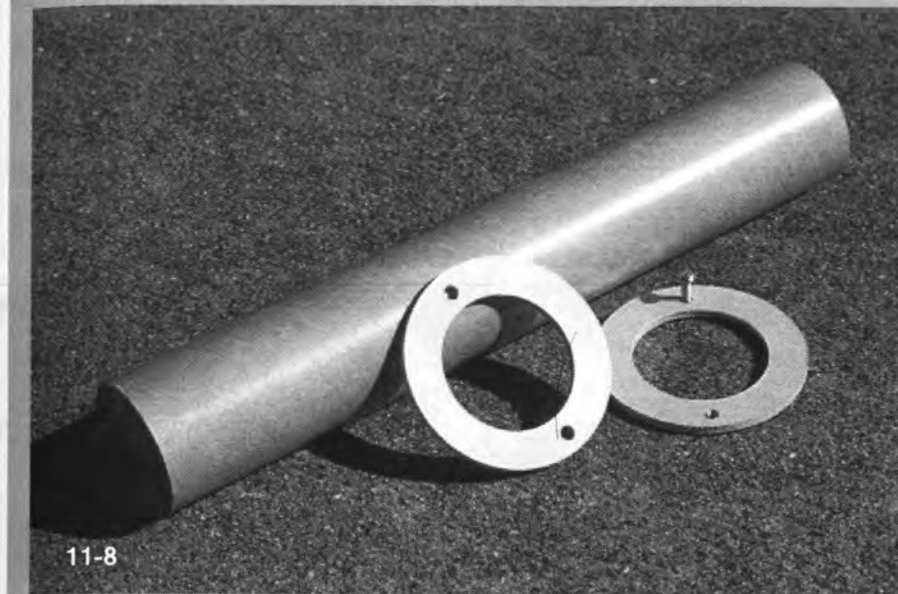
The Motor Tube

The two centering rings--forward and aft--and the 38mm motor tube are shown in photo 11-8.

After the motor retention step is completed and the epoxy is dry, attach the aft centering ring on the motor tube approximately 1/8" from the end of the tube. See photo 11-9. Be sure to give the centering ring-motor tube joint a good fillet of epoxy to ensure maximum strength, as suggested by LOC. The fillet of epoxy should be applied to both sides of the ring.

Now, move to the opposite end of the motor tube. The LOC kit comes with a piece of light rope that is used as a point of attachment for the shock cord.

Although this rope will work as a point of attachment in the lightweight H45, it can be easily improved upon. For our project, the rope was discarded and the point of attachment was replaced with a 3/8" eyebolt that was installed in the forward centering ring, as shown in photo 11-10. This eyebolt is used to attach the shock cord to the rocket body, as illustrated in photo 11-10. This picture shows the completed 38mm motor-tube assembly ready for placement into the main rocket body. (Note: The open eyebolt used in this rocket should

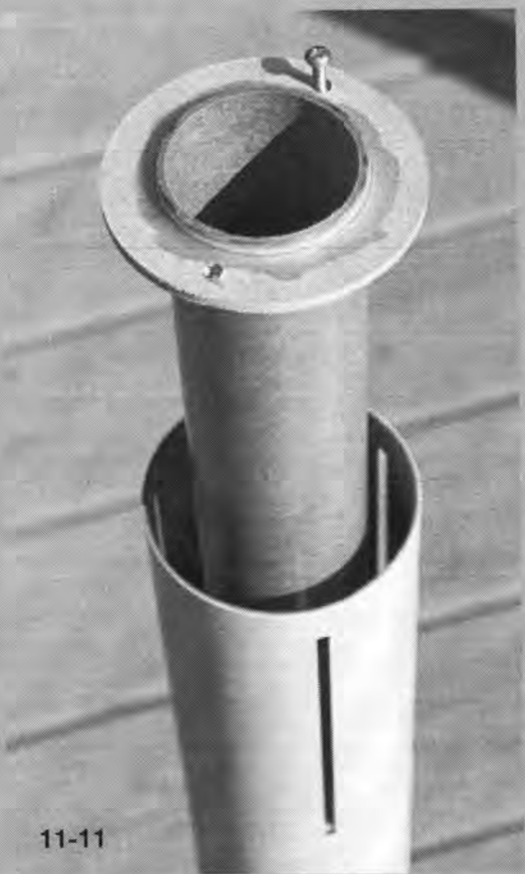

11-8


11-9


11-10

The EPOXY

Adhesives with a finish strength less than epoxy should never be used in high-power rocketry construction. Epoxy is often sold with a given drying time of 5, 15, or 30 minutes. The shorter the drying time, the harder the epoxy is to handle when building a high-power rocket. For most projects, 15-minute or 30-minute epoxy is the better choice. These drying times allow you to correct mistakes or minor errors more easily than 5-minute epoxy, which sets up very fast. Minor field repairs, on the other hand, can be repaired quickly with 5-minute epoxy.

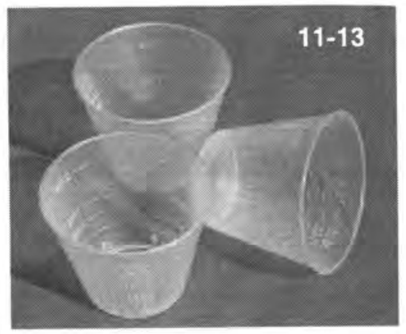


11-11

11-12

only be used in very lightweight rockets. In all other rockets, a closed bolt should be used. The same is true for the kit's elastic-style shock cord.)

To install the motor-tube assembly in the airframe, apply a continuous bead of 30-minute epoxy around the inside of the rocket body eight inches from the slotted aft end. Apply the epoxy with a thin wooden dowel. To gauge how far into the airframe you need to go with the dowel, tie a piece of tape around the wood eight inches from one end. Once epoxy is placed on the end of the dowel, insert the dowel into the airframe until the tape reaches the bottom of the airframe. Do this several times or until you have coated the entire inside circumference of the rocket, in a ring about eight inches from the rear, with the epoxy.



11-13

These small and flexible plastic cups work well for pouring epoxy fillets.

Once the ring of epoxy is in place, pick up the motor-tube assembly and gently push the tube into the rocket body until the bottom centering ring (the one with the blind nuts) is about 1/8" above the bottom edge of the airframe. See photos 11-11 and 11-12.

Set this assembly aside to dry overnight. When it has dried, apply additional epoxy around the edge of the motor tube/airframe joint. Be careful not to get any epoxy in the threads of the motor retention blind nuts, which can be seen in photo 11-12.

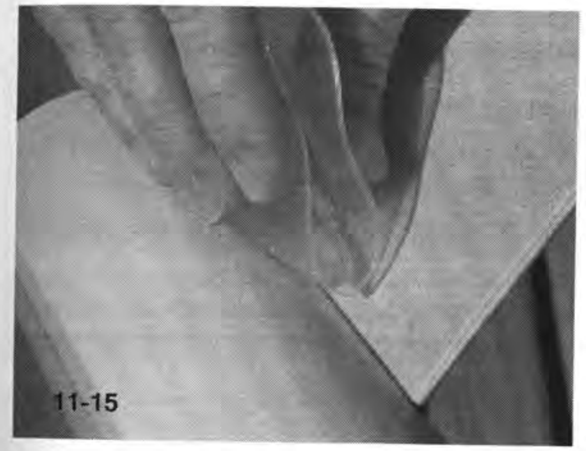
Installing the H45 Rocket Fins

The Hi-Tech H45 comes with three wooden fins that are precut and ready to install. Sand all the fins smooth and round off (bevel) the leading and trailing edges. A small hobby belt sander works well here, although a sanding block works fine, too.

Once the fins are sanded, they are ready for installation. Test-fit the fins first. If they do not fit perfectly, sand where necessary prior to installation.

Place epoxy on the fin's root edge, and insert the fin into the airframe slot. Make sure the fin remains straight up from the airframe tube while the epoxy sets up. Install all three fins in the same manner. (Note: This is a good place to use a faster drying epoxy, such as 5- or 15-minute epoxy. However, 30-minute epoxy works well here, too.)

11-14



11-15

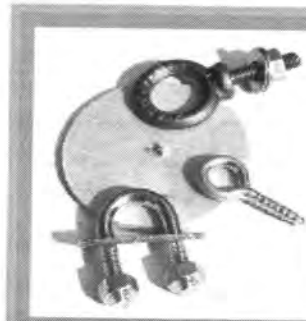
11-16

After all the fins are installed and the epoxy has dried fully, add additional epoxy fillets to both sides of each fin. It is not necessary to go overboard with epoxy here. But do not skimp, either. The fillet should run the entire length of the fin and should fill the valley between the body tube and each fin.

To place the fillet for each fin on this rocket, we used plastic 30-milliliter cups (available at hobby or art stores). See photo 11-13. A small amount of 30-minute epoxy was mixed in the cup. When the mix was complete, the epoxy was carefully poured from the cup along the fin/airframe joint.

To pour the epoxy using this technique, try the following approach. Mix the epoxy thoroughly in the cup until it has a syrup-like consistency. Now, taking care to pour the epoxy slowly, squeeze the sides of the cup together so a relatively thin bead of epoxy pours out of the "spout" of the cup and along the fin-airframe line. See photos 11-14 and 11-15. Start the pour about ¼" from the edge of one end of the fin, and pour along the line until you get to about ¼" from the other end of the fin. Put the cup aside.

Now, tilt the airframe so that the epoxy slowly creeps up along the



The BOLT

One of the many factors that separate a high-power rocket from a model rocket is the strength of the points of attachment. Although very light-weight high-power rockets can safely use an open eyebolt, the better practice is to use a closed eyebolt or a U-bolt (also called a pipe clamp) to secure the recovery harness in your rocket. Don't skimp here. Recovery failures are the biggest cause of lost rockets. Try to make your points of attachment bullet-proof.

Case History

Level One Tripoli WEST PALM

My name is Peter Carvajal. I am 40 years old and I live in Florida. While cleaning out my garage a couple of years ago, I discovered a stash of rocketry stuff, including a LOC Onyx kit that I bought way back when. One thing led to another and soon I was on the Internet, where I found the national web site for the Tripoli Rocketry Association. I could hardly believe my eyes when I read about the high-power launches being held all over the country. I located the nearest high-power club–Tripoli West Palm–and soon I was talking to then-Prefect Bruce Kilby, who patiently answered all of my questions. I finished the Onyx and drove an hour west into the sugarcane fields of South Florida for my first launch. I was hooked.

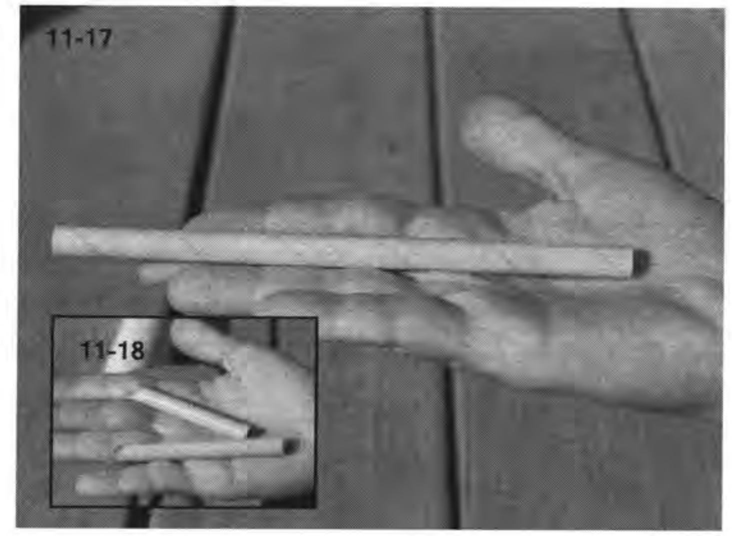
I decided to seek Level One certification shortly thereafter. I liked the technical challenge of certification and the camaraderie of achieving an established milestone in high power. My Level One rocket was a BSD Sprint. I admired the classic lines of the Estes Astron Sprint and was delighted to discover a high-power version at BSD. It was great-looking, reasonably priced, and I had no problem getting it assembled. The biggest challenge was motor selection and preparation. But thanks to new friends, who are easily made in this hobby, it turned out to be no problem at all. Everyone I contacted was as eager to help as I was to learn.

The flight went forward in Florida on a field of more than 600 acres of bright green sod on a beautiful day in January 2004. The Sprint tore off the pad on a Cesaroni Pro 38 I205 motor. Soon the rocket was lost in the hazy sky. But after a few tense moments it reappeared under a bright yellow parachute, landing only 100 yards away! And the best part was that my dad and my girls were there to cheer me on.

Since then I have continued to enjoy high power. The more I learn, the more opportunities I have had to help others who are just getting started. When you put it all together–family, friends, and a day spent in the outdoors-- it just doesn't get any better. In the future, I would like to develop an introductory rocketry program for handicapped children.

Don't sit on the sidelines. Get out of that lawn chair and get ready to make a lot of new friends in high-power rocketry. You will be glad that you did.

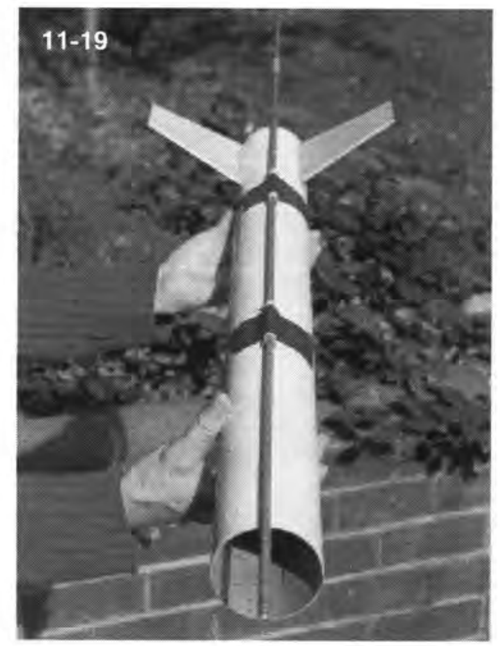
line to the edge of the fin (covering up the ¼" you previously left exposed.) When the epoxy reaches the edge, tilt the airframe in the opposite direction and watch the epoxy run the other way. When the epoxy is covering the entire joint, place the rocket in a horizontal position and let it dry. But keep an eye on it. The epoxy may run over the edges and down the side of the rocket before it sets. If this occurs, wipe away any excess. (Note: If you are planning on using a high-thrust motor in the H45, then consider adding a piece of fiberglass between the fin and the body tube. See Chapter 18 for more details on this technique.) Let the fins dry for 24 hours.



Launch Lugs

Once the fins have dried, install the launch lugs.

The H45 kit comes with a single, heavy cardboard launch lug that is about 6 inches long. See photo 11-17. Cut the lug in half, preferably at an angle, to reduce drag. See photo 11-18. Next, sight in and mark the high point on the airframe between any two fins. The mark should be approximately 6 inches from the bottom edge of the rocket body. This is where the first lug is attached to the body, using epoxy. Make an additional mark on the airframe 12 inches farther up the tube from the first mark. At that point, attach the second launch lug. Be sure that the launch lugs are in good alignment. If the lugs are not aligned, you will have difficulty on launch day placing the rocket on the launch rod, or you may not be able to launch at all. A launch rod, dowel, or other makeshift alignment tool may be attached to the rocket body with masking tape to ensure that the lugs remain in proper alignment until the epoxy has dried. See photo 11-19. Once the initial placement of epoxy has fully dried, place fillets of epoxy on both sides of each lug.

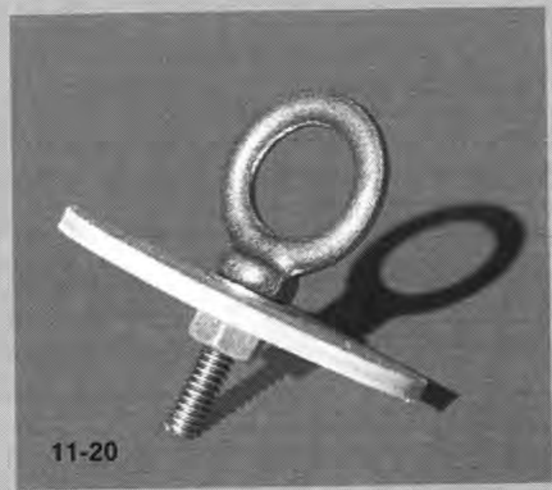


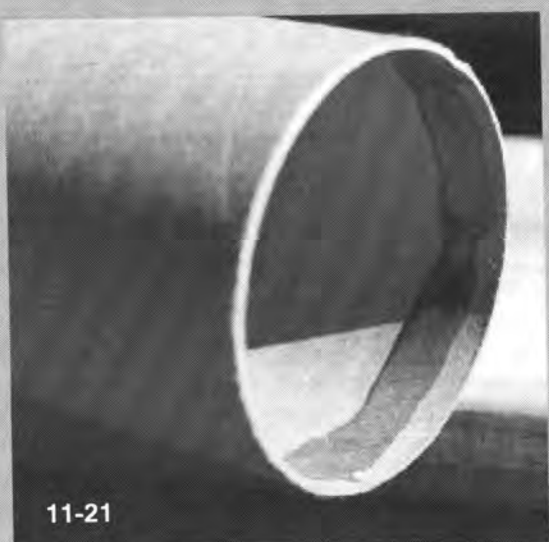
The Bulkhead Assembly

It is time to assemble the bulkhead. The kit comes with an eyebolt that will work fine with the H45, but this can be improved upon.

For our rocket, we purchased a 1/4" closed metal eyebolt that provides a more secure attachment point for the shock cord and helps further ensure that the rocket will not come apart at apogee when the motor-based ejection charge is fired.

To install the eyebolt in the bulkhead, we drilled out the original hole to hold the larger-diameter eyebolt. The eyebolt was then secured with a washer and nut. See photo 11-20. Place a tiny amount of epoxy on the threads of the eyebolt to ensure that the eyebolt stays secure. Then, place epoxy around the inside circumference of the coupler, and insert the bulkhead assembly into the body coupler. Then apply a fillet of epoxy to both sides. See photos 11-21 and 11-22.

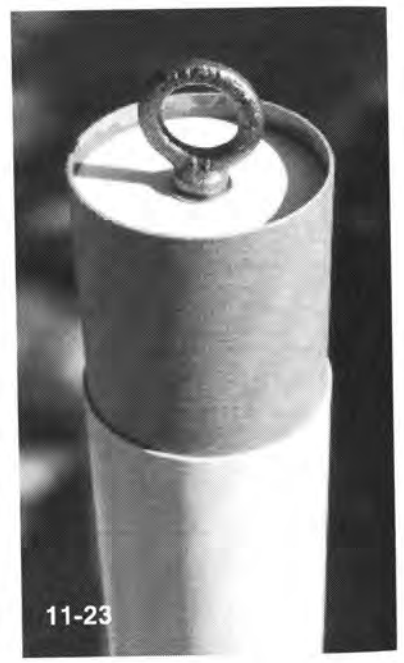

11-20


11-21


11-22

Once the bulkhead assembly/tube coupler is dry, apply a continuous bead of epoxy around the inside of one end of the payload tube, approximately ¼" from the edge. Take the bulkhead assembly and gently push it into the payload section about a third to a half the length of the coupler. As the bulkhead assembly is inserted into the payload section, it will engage the bead of epoxy and form a solid connection. The completed bulkhead/payload assembly is shown in photo 11-23.

LOC recommends that two 1/16" holes be drilled into the main airframe 180 degrees apart about one inch below the seated payload section's bulkhead. The purpose of these holes is to vent out excess air from within the main airframe that could prematurely cause the nose cone to pop off the payload section during flight.


11-23

After the forward bulkhead assembly is dry, it is placed into the payload bay with epoxy. The exposed portion serves as the coupler.

For more information on venting, see chapters 8, 9, and 10.

One other construction tip: Use CA adhesive around the edges of the airframe to increase the strength of the LOC tubing.

A tiny amount of CA is beneficial on most high-power rockets (except for fiberglass or composite airframes) at this location. The edges of couplers and airframes take a lot of punishment during deployment and recovery, and the CA keeps these edges rigid and in shape. See photo 11-24.


11-24

A dab of CA around the circumference of the airframe's edge helps add rigidity to the edge. Just place a little, and then sand it down to make sure the payload bay fits smoothly. This works well with the edges of the launch lugs and portholes as well.

The Recovery System

The H45 comes with a 28-inch nylon parachute that works fine with this lightweight rocket. The instructions recommend that the parachute be tied directly to the shock cord about three inches away from the payload section. For our application, the parachute was tied at the location suggested by LOC, but was attached with a quick-link that allows for an easy change of parachutes depending on wind or field conditions on the day of launch.

If the weather is windy, or if you are flying an H or I motor in this lightweight rocket and you want to further decrease drift, a slightly smaller parachute can be quickly installed in place of the 28-inch chute. On the other hand, if the field surface is hard, such as the desert playa found in many Western launch sites, a larger parachute can be installed to make for a softer touchdown.

Another important consideration at this point in construction of the rocket is the shock cord (also known as the recovery harness). The cord in this kit is elastic and is typical for many Level One rockets. This type of cord works fine in model rocketry and will also work in high power with light-weight rockets. However, in most cases, it is better to replace the thin elastic shock cord with sturdier material, such as tubular nylon or Kevlar. Cords made out of these materials are usually sold cheaply–by the foot–and can be purchased at mountaineering stores or from rocketry retailers. These types of shock cords withstand the forces of separation and deployment much better than the elastic cords supplied in many kits. (See Chapter 10.)


11-25

A pipe clamp or U-bolt also works well in lieu of a closed eyebolt for the point of attachment.

Since our Hi-Tech is so light (less than one pound), it was safe to go ahead and use the elastic cord that was supplied with the kit.

Rocket Stability

If significant modifications are made to commercial kits, such as adding more motors or using motors other than those specified by the maker, the rock-

Case History

Level One Tripoli CHARLOTTE

My name is John Froeb, and I am 46 years old. I live in North Carolina. I was an active model rocketeer when I was younger, but eventually I left the hobby. My interest was rekindled when my young boys became interested in rockets after they watched a Discovery Channel special on high-power rocketry.

I contacted the local chapter of the National Association of Rocketry and soon I was traveling to launches held outside Charlotte, North Carolina. I was hooked. And when my family bought me a Bullpuppy rocket kit for my birthday, I knew it was time for Level One certification.

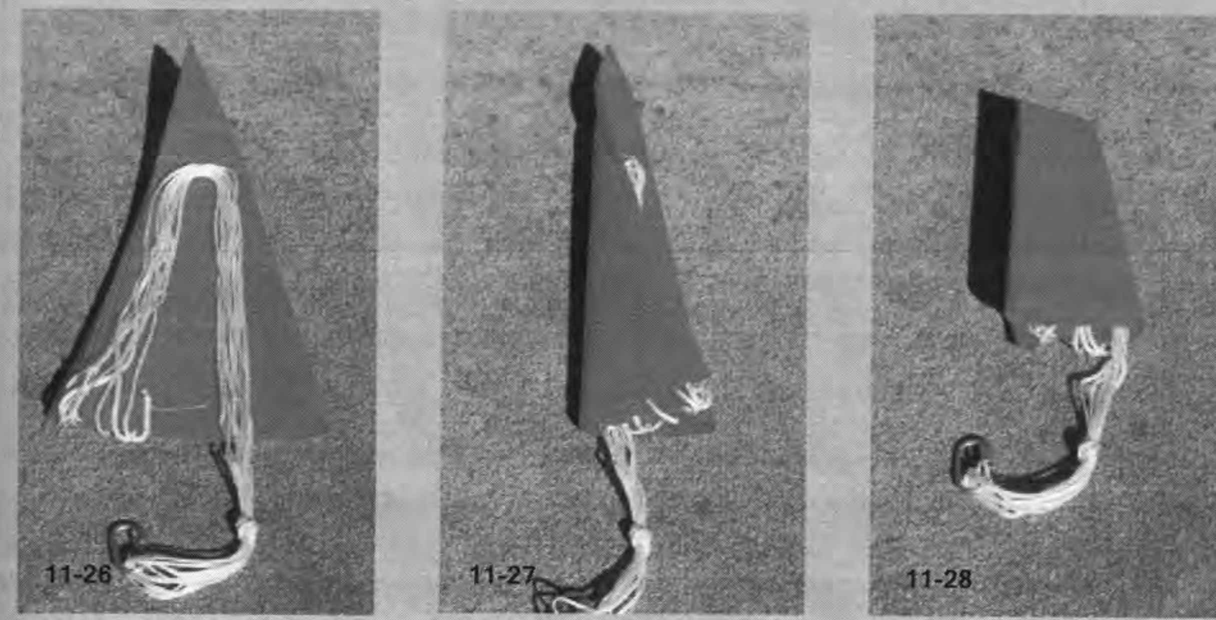
My certification rocket was a Public Missiles Systems three-inch Bullpuppy. I've always liked the looks of the Bullpup missile, and I own the smaller Estes version of the rocket as well. The Public Missiles kit is really nice, with the Quantum tubing airframe and plenty of well-machined parts. The rocket went together perfectly and is very sturdy. It looked great on the launch pad.

The biggest challenge for me in reaching Level One was finding the right time to fly when the appropriate witnesses were available. I was all ready one month, but the launch was canceled. I could not go back the following month, so I had to wait a while before making the attempt.

The launch finally went forward at the Williams Farm launch site in Midland, North Carolina. The launch is conducted by Rocketry of Central Carolina (ROCC).

I used an Aerotech H164 Redline motor with a 10-second delay on the motor-based ejection charge. It was a lot of fun and a perfect flight. The rocket jumped off the pad, trailing a long red flame. It was recovered only a couple of hundred yards from the pad. If I hadn't stepped in a drainage ditch on the way to picking up the rocket, it would have been a perfect day!

In the future I hope to add an altimeter to the rocket and try for some higher flight and data recording. I would like to try for Level Two–maybe next spring.



eteer should re-examine the location of the center of pressure and the center of gravity on the rocket. As discussed in Chapter 1, the center of gravity should be at least one body tube diameter in front of the center of pressure.

Since the H45 is a 2.6-inch-diameter rocket, the center of gravity should be located at least 2.6 inches forward of the center of pressure.

Launch Day

It is good practice to launch a new rocket kit on a lower-impulse (or lower average thrust) motor for its first flight. A single-use 29mm G motor is an excellent motor for the first flight of the LOC H45.

As illustrated in photos 11-26 through 11-28, lay the parachute flat on the ground first and fold the panels together. Then place the shroud lines in the center of the panels and fold the parachute once more.

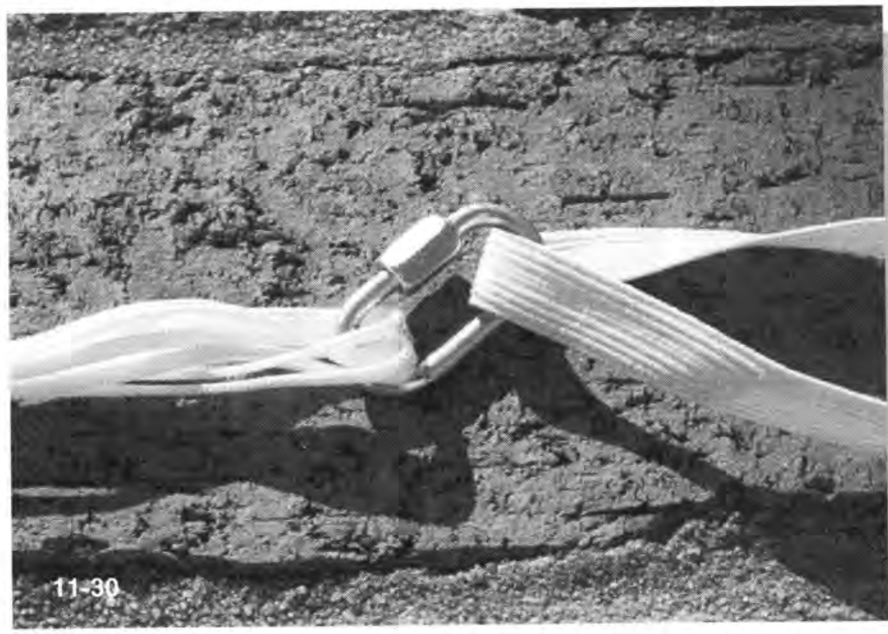
With the lines tucked inside, roll or fold the parachute up so that it will fit into the airframe. There are several ways to pack a parachute for a high-power rocket. For other methods, see Chapter 10.

To attach the parachute to the recovery harness, tie a knot in the harness so it makes a loop several inches from the end that attaches to the nose cone. That loop will be used to secure the quick-link. The link, shown in photo 11-29, is first run through the bottom of the parachute shroud lines and then hooked up to the loop in the harness.

A quick-link is a handy way to attach your parachute shroud lines to the loop in the recovery harness, or shock cord.

Loading the parachute is easy with the H45. The quick-link allows you to change parachutes from rocket to rocket, depending on field conditions on the day of launch.

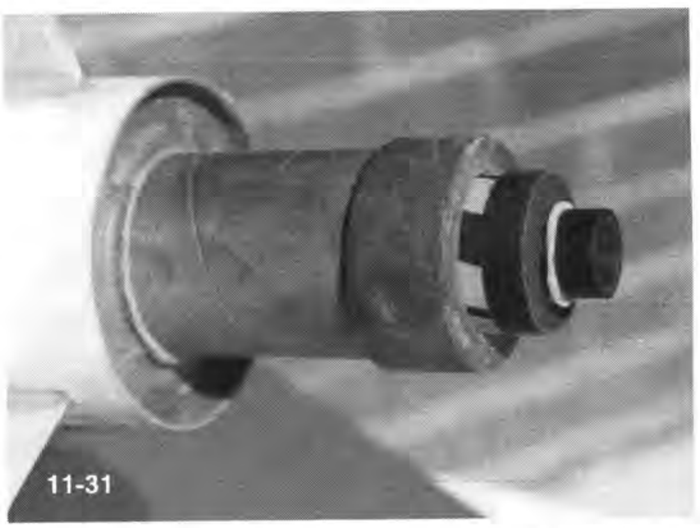
Do not forget wadding or some other method of protecting your parachute from the ejection charge of the motor. If you are using cellulose-type wadding, add the wadding after the motor has been installed in the rocket, or the wadding will simply fall out of the aft



The quick-link connects the parachute shroud lines, left, to the loop in the shock cord. Quick-links come in many sizes and are useful because they provide for easy changing of parachutes between rockets.

end of the rocket. The better practice is to attach a piece of Nomex cloth to the recovery harness and place the Nomex into the airframe first so it absorbs all of the motor-based ejection charge. If you use Nomex, cellulose wadding is not necessary.

As illustrated in photo 11-31, a motor adapter may be used so that the 38mm motor tube of the H45 can hold the smaller 29mm motor. This would include most G and many H motors. Afterward, if the rocket has no problems on its first flight, a good mid-range H reloadable motor–such as an Aerotech H180–should be chosen for a Level One certification flight.



This phenolic motor adapter allows you to use a 29mm G motor in the 38mm motor tube of the H45. Motor adapters are available for most high-power rockets. See Chapter 4 for more examples.

The H45 is a fun and inexpensive rocket capable of altitudes in excess of 3,000 feet with the right motor. The rocket can be used with motor-based ejection charges, or an altimeter bay can be attached for electronic recovery (or both methods may be used).

On launch day, be sure the rocket's body sections fit together snugly. A good test is to pick up the rocket by the nose cone prior to flight and see if the pieces all hold together. Typically, some masking tape needs to be added to the main body coupler tube and the nose cone shoulder to ensure that the rocket holds together.

But do not use more tape than necessary to pick up the rocket by the nose. Too much tape can prevent the rocket from separating at apogee, which can lead to a lawn dart. (But unless you plan on separating the nose cone, place an extra piece of tape on the shoulder of the nose to make sure it fits

tightly and is not accidentally knocked off by the force of the ejection charge in flight.)

Be sure the motor is secure. If you are using a single-use motor and there is no thrust ring, use masking tape as a means of motor retention. With a reloadable motor, you should be able to use the motor retention system, with clamps that are built into this rocket.

Install the motor, add the wadding (as discussed above), and then place the recovery harness or shock cord into the airframe. Then insert the parachute after the recovery cord is almost all the way in the rocket. The parachute for the H45 fits loosely in the rocket. Again, always be sure the parachute is attached to the shock cord.

Also, do not forget a vent hole in the payload bay and the lower airframe. The vent hole allows for pressure equalization as the rocket climbs. Without a vent hole, internal air pressure may force separate pieces of the rocket apart early, resulting in deployment of the recovery system too early. This can cause a zipper in the airframe. See Chapter 10.

Finally, remember not to insert the igniter into the rocket until you have placed the rocket on the launch pad. If the motor you are using does not have a plastic cap for the nozzle, bring some masking tape to the pad to secure the igniter once it has been inserted all the way into the motor. But do not completely cover the nozzle. Leave an air vent in the tape (or the plastic cap).

If this is your Level One certification flight, you will need to get the attention of the appropriate witnesses prior to launch so they are ready to observe the flight when the rocket takes off. This usually involves the club prefect (Tripoli) or other certified members.

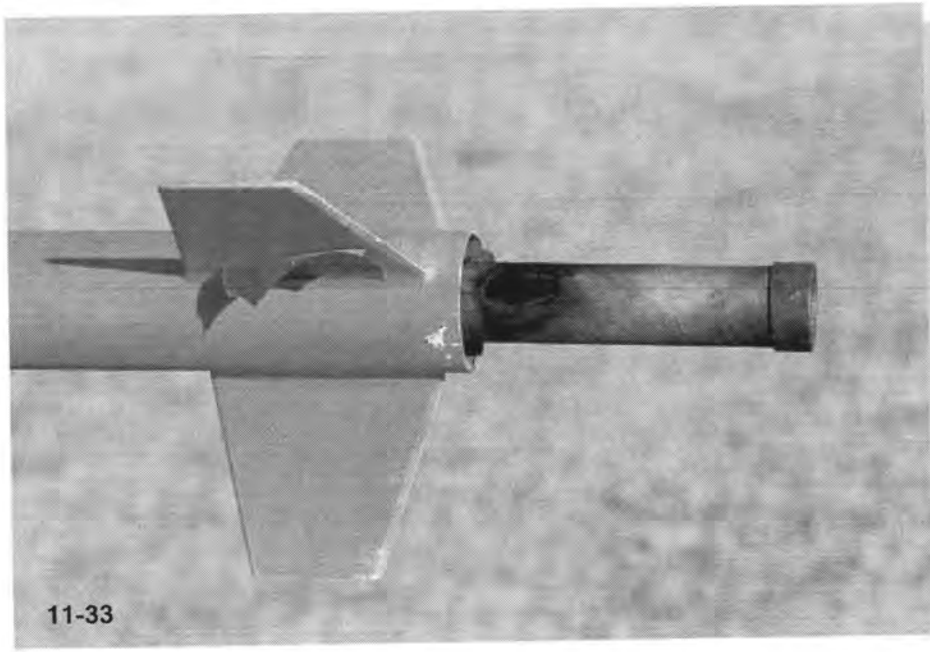
The finished H45 after it had been primered and prior to its first test flight. This lightweight rocket can achieve altitudes in excess of 4,000 feet on the right motor.

Our First Flight

For our first flight, we loaded the H45 with a single-use G40 motor with a seven-second delay. As it turned out, the delay was unnecessary.

The rocket shot off the pad and almost immediately (within 50 feet) came apart. The booster section fell to the ground a smoking hulk, and the payload section returned gently on the LOC parachute. The shock cord had come apart.

The reason for this minor disaster? The motor. Single-use motors rarely CATO (*cato*strophic motor failure), but it can happen. In our case, the motor blew a hole in its side near the forward end, just below the built-in ejection charge. The force of the CATO tore a hole in the motor adapter, but fortunately it did not



11-33

Ouch! On our first flight of the H45, the single-use G motor had a CATO. The phenolic motor adapter absorbed most of the damage. Fortunately, the CATO did not reach the outer airframe of the rocket. But it did cause the elastic shock cord to break, which necessitated some significant (but easy) repairs.

penetrate the airframe, which would have ruined the booster. See photos 11-33 and 11-34.

The biggest problem caused by the CATO was that the elastic shock cord was severed near the eyebolt, deep in the rocket's booster section. See photo 11-35.

The repair was not difficult. But we would have to re-attach a recovery harness to the eyebolt on the forward center-ing ring of the motor tube.

We could not reach the bolt with our hands. So we sawed the booster in half at a point several inches forward of the motor tube. See photo 11-36. This allowed us access to the eyebolt, where this time we installed tubular nylon cord to the bolt.

The tubular nylon was attached to a quick-link, and the link was placed through the open eyebolt. Since the eyebolt was so deep in the airframe, the quick-link would be permanent. It would not come out again.

11-34

You do not see this every day. Single-use motor CATOs are rare. But they can happen. Here, the motor gave way at the forward end, just below the ejection charge.

A coupler was then used to reconnect the booster halves. See photo 11-37. The coupler was first placed into the lower section of the booster with epoxy. After that had dried thoroughly, epoxy was placed around the inside circumference of the upper section of the booster. The two sections were now permanently attached. See photo 11-38. A little sandpaper and some more primer and the repair was hard to detect.

The next flight was a success. An Olsen M2 altimeter was placed in the payload bay. We first flew another G40-7 motor, and the rocket jumped off the pad for a nice flight, to 1,166 feet.

On the same day, we installed an Aerotech H180 in this lightweight rocket. The H45 shot off the

pad on the larger motor and raced out of sight. The tiny parachute deployed, and the rocket settled down nearly a quarter-mile away in almost no wind (an even smaller parachute would have been fine, and would have minimized drift, on this soft ground). The altitude was more than 2,500 feet. This rocket can easily clear 3,000 to 4,000 feet on a larger 38mm motor.

The moral of the story? Bad things that are out of your control sometimes happen to your rocket. The key is to pick up the pieces, analyze what went wrong, and then try again. That's part of the fun.

As noted earlier, there are a number of manufacturers offering kits appropriate for Level One certification. Binder Design, BSD, Aerospace Specialty, LOC, Public Missiles, and DGA are just a few.

A good way to review the many rockets available is to log on to Rocketry Online and search for rocket manufacturers under the Vendors button.

Another way is to subscribe to a rocketry magazine. These magazines frequently feature reviews of rockets and rocketry-related products and books.

In addition, *Essence's Model Rocketry* contains independent rocketry reviews for many kits–including high-power rockets. The web site for these reviews is found at www.rocketreviews.com.

11-35

11-36

11-37

11-38

The ROCKET

There is no special size or weight requirement for the rocket used in a Level Two certification flight. The only requirement is that the rocket launch on a motor with at least 640.01 and no more than 5120 newton-seconds of total impulse. The rocket motor may be solid fuel or a hybrid. Level Two rockets may have a 38mm, 54mm, or even a 75mm motor mount. They also may be the same rocket used in a Level One flight. But the rocket must have been built by the flyer, and the candidate must also pass the written exam prior to the Level Two launch. See Chapter 3 for information on the examination.

12

Building the Level Two Rocket

Level Two flyers build some of the most sophisticated rockets in high power

To achieve Level Two certification, you must build, launch, and then successfully recover a high-power rocket with a motor between 640.01 and 5,120 newton-seconds of total impulse. This is a J, K, or L motor. As explained in more detail in Chapter 3, you must also pass the Level Two examination administered by either Tripoli or NAR.

David Deason and son Conner with David's Level Two Bullpup missile.

Level Two rockets are often the most sophisticated rockets on the field. Minimum-diameter Level Two rockets are capable of altitudes in excess of 20,000 feet. Large Level Two rockets, sometimes equipped with multiple motors or multiple stages, are often mistaken in size and complexity for Level Three projects. What's more, many people remain at Level Two permanently because of the vast selection of rocket motors and the equally large number of rocket projects that can be undertaken without the necessity (and cost) of going to Level Three.

A Level Two certification rocket can be scratch-built, or it may be constructed from a kit. The price of

Level Two flyers Tom and Kay Henderson of North Carolina with their scratch-built Standard Arm and Public Missiles Amraam scale rockets. Level Two offers the widest selection of motors and rockets in high-power rocketry.

the average commercial Level Two rocket runs between $50 and $300. Within this range there are many kits suitable for Level Two certification. These include rockets manufactured by Aerotech, Binder Design, Rocketman, Public Missiles Systems, and LOC/Precision, to name a few. Many people also choose to build their Level Two rocket from scratch. It is a good way to test and expand your building skills, and it's also cheaper than buying a kit, particularly for large rockets.

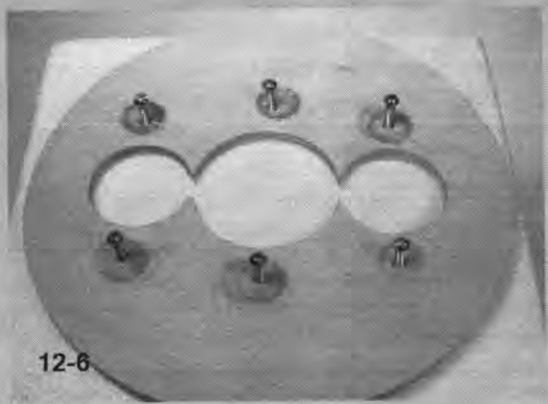
The example chosen for this Level Two project is the LOC Bruiser EXP.

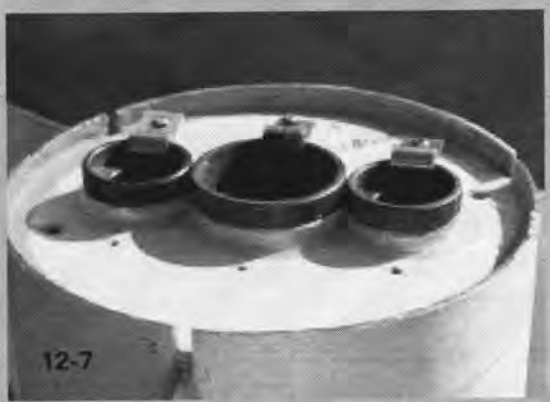
The EXP is not a cheap rocket. It retails for more than $275. Yet this 7.67-inch diameter, 10-foot-tall rocket is simple to build and has the size and appeal of many rockets in the Level Three category. When completed, the Bruiser can handle motors capable of lifting the rocket several thousand feet. And the rocket is versatile. The Bruiser is a cluster rocket, with three motor mounts. The central 54mm motor mount is flanked by two 38mm outboard motors. So there are a lot of options for high-power motors on launch day. This lightweight rocket (under 20 pounds) can be flown on a single 54mm motor or on multiple motors. It can be launched with ignition of all three motors on the pad, or it can lift off on one motor and then airstart two more motors. The Bruiser's large diameter allows us to illustrate not only the cluster, but also an altimeter hatch and the plumbing necessary for an airstart of the outboard motors.

Florida Tripoli member Harold Sasloe prepares his Binder Design Velociraptor on a 54mm Aerotech K550. This is a sophisticated Level Two kit.

Getting the Rocket Started

The instruction sheet for the Bruiser is well written but provides no illustrations. So read the instructions carefully a couple of times to become familiar with the parts involved and how they fit together. Epoxy





is a must for the Bruiser. LOC recommends using 5- or 15-minute epoxy for construction. As a general rule, the lower the epoxy number, the quicker the epoxy sets up and hardens. For this rocket, we chose 30-minute epoxy manufactured by Devcon, because it sets up slowly and allows for minor errors. It is also very strong. As a general practice, prior to joining any parts together with epoxy, sand the surface of each part lightly for better epoxy adhesion.

The Motor Tubes

Construction of the Bruiser EXP begins with the two 38mm motor-mount tubes. Each of the tubes comes in three pieces–one small coupler and two 20-inch sections of tube. See photo 12-4.

Place a liberal amount of 30-minute epoxy in a complete circle around the inside end of one of the long motor tubes. The epoxy should be about 1/4" from the end of the tube. Now, insert one half of the tube coupler into the motor tube with the wet epoxy. Use a slow, twisting motion as you go, engaging the epoxy as you push in and turn the coupler.

Tripoli member Jeff Engelman prepares a LOC Magnum for fight. The Magnum is another good Level Two kit.

Once the epoxy has dried, repeat this process with the remaining 38mm tube, again using the coupler to join the two 38mm sections together. There should be no gap between the joined 38mm tube sections. The coupler will no longer be visible.

Repeat this process with the other 38mm tubes. In the end, you will have two 38mm tubes that are each 40 inches long.

The next step is to affix the two 38mm tubes to the 54mm main motor-mount tube.

Find a flat, even surface, such as a table top, and position one of the 38mm tubes next to the main 54mm tube. The tubes are equal in length, and their edges should be even. Place a piece of wax paper under the tubes in case some of the epoxy leaks between the seams.

Mix a small amount of epoxy and apply it to the middle of the tube assembly where the 54mm and 38mm tubes meet. The two tubes are now joined together. Do not apply any more epoxy at this time than is necessary to lightly connect the tubes. Also, do not apply any epoxy to the last few inches on both ends of the tubes, as the centering rings must still fit over the assembly when you are finished.

Duane Uhl's LOC Bruiser EXP blasts off on K power at DairyAire 2003 in Central California.

Using a centering ring at each end of the tubes as a guide, position and align the remaining 38mm tube with the other side of the 54mm motor mount. Again, place only a small amount of epoxy near the middle of the 38mm tube to connect it to the 54mm tube. More epoxy will be placed later, after all three of the centering rings have been placed. Do not apply any epoxy to the centering rings at this step.

After the epoxy has dried and the three tubes are connected, remove the centering rings. It is time to construct a motor-retention system.

Motor Retention

Motor retention is discussed in more detail in Chapter 4. In this case, the retention system was built from blind nuts and 6/32 machine screws. As illustrated in photos 12-5 and 12-6, six holes were drilled into the bottom centering ring, and the blind nuts were pressed into place using woodworking clamps. The blind nuts have tiny grips, or teeth, which dig into the wood and secure them. Epoxy is used to ensure that the nuts remain in place.

Keep all epoxy away from the threads of the nuts. The shoulder of the nut goes on the side of the centering ring that will be inside the rocket's airframe. The six screws will then be used to secure clamps that hold the motors in place, as shown in photo 12-7.

For additional possibilities or alternatives for motor retention, see Chapter 4.

Electrical Conduit

This cluster rocket can be used in several configurations. The outboard motors can be ignited on the pad or they can be airstarted several seconds into the launch.

For airstarts, conduit must be installed, to route the wiring from a timer in the payload bay back to the aft end of the rocket to ignite the motors after launch. So the next step is to drill holes through all three centering rings for the conduit to traverse the necessary pathway.

The size of the holes depends on the diameter

Case History

Level Two NAR ROCC

My name is Terry Baucom, and I am a member of Rocketry of Central Carolina (ROCC), and we fly at a nice field outside of Charlotte, NC. I am 41 and also a member of the National Association of Rocketry (NAR).

I discovered rocketry through the web site of our local club and by making a phone call to the club's president, Ralph Roberts. Ralph invited me out to a launch, and I have been having fun ever since.

I wanted to get certified for one simple reason: more power! I enjoyed the bigger rockets at our launches, and I wanted to fly them, too. So I needed to get certified to be able to use the bigger motors.

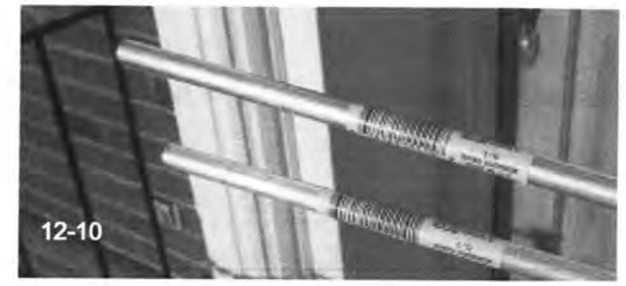
I chose as my Level Two rocket the LOC/ Precision Warlock. I really liked this kit and the way the rocket looked. I really beefed up the fin fillets using PC-7 epoxy, and the rocket was ready to go in December 2004. The biggest challenge for me in obtaining my L2 certification was all the second-guessing about my preparation, even though I had done everything before, and I had even flown this same rocket twice. (I used the LOC Minnie Magg for my Level One certification, which was a memorable flight. The rocket drifted about a mile down the road onto a neighbor's barn. Luckily I was able to retrieve it for my certification.)

The L2 flight was great. I used a Cesaroni Technology Pro38 J400 Smokey Sam motor. The rocket roared off the pad, trailing a big column of black smoke. Recovery was perfect, and my certification was successful.

The next step for me in high-power rocketry is to work on dual deployment, and I will be attempting my first flight soon.

My advice to new rocketry members who want to certify is simple: First, join a local club. The members are all willing to lend a hand and answer any questions you might have. Second, keep your certification flight and rocket as simple as possible. It won't be as stressful on the day you launch, and you will have a lot more fun. The more complex flights can be done later–after you achieve certification!

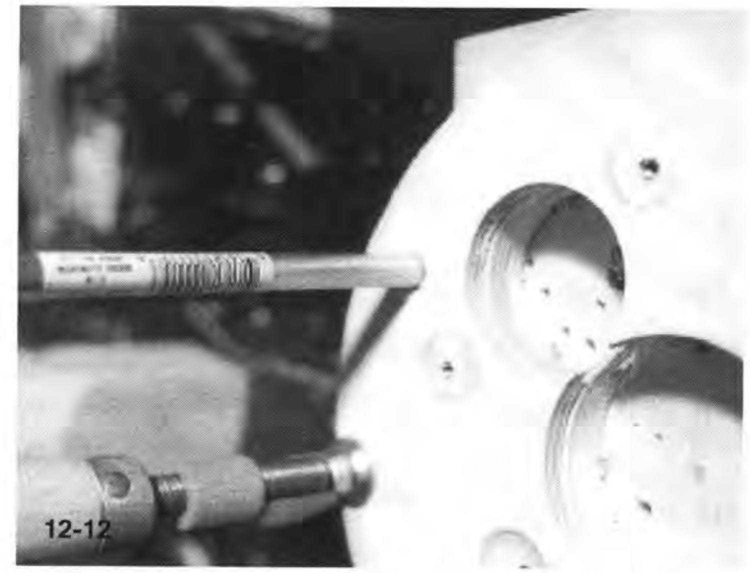
of the conduit. In this case, 5/16" and 9/32" round aluminum tubing was used. See photo 12-10. This tubing is available at many hobby stores. The 9/32" tube will fit cleanly into the 5/16" tube to provide the overall length needed for this project. See photo 12-11.



Be sure to consider how many wires will need to pass through the conduit when picking the right size for your project. In this case, two igniter wires will fit snugly in each tube, which is more than sufficient for our airstarts.

We secured the three rings together against a wood backing and drilled through all three at the same time to ensure that the holes were perfectly aligned.

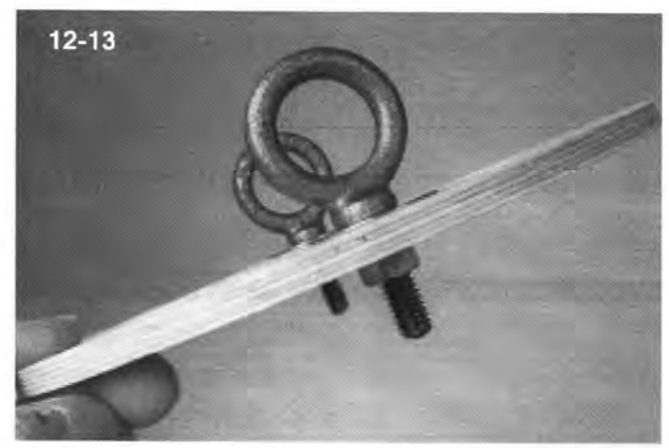
Once the holes are drilled, test-fit with the aluminum tubing to ensure a good, snug fit. See photo 12-12. Set the tubes aside for now. They will be placed in a later step after, the centering rings are attached to the motor tubes.



Recovery Points of Attachment

The next step involves the forward centering ring. This ring will secure the eyebolt for the recovery harness.

The LOC kit comes with a sturdy 3/8" open eyebolt that will work fine on most lightweight projects, including the Bruiser. However, with large rockets, it is good practice to discard the open eyebolt and replace it with a forged, closed eyebolt. This reduces the possibility that the bolt will open as a result of the forces of deployment and recovery. The forward centering ring in this case has a single 3/8" hole for the eyebolt. For our project, we drilled an extra hole and then installed two closed



Top: Aluminum tubing in two sizes was used as conduit for wiring of airstarts. Above: The tubing is test-fit into the centering rings. Left: Two closed eyebolts were test-fit into the forward centering ring.


12-14


12-15

eyebolts in the ring, as seen in photo 12-13. Set this assembly aside for now.

The Secondary Tube

The Bruiser comes with a 10.7-inch-long, 7.5-inch-diameter secondary tube that will fit into the outer grooves of the aft and middle centering rings. The purpose of the secondary tube is to strengthen the bottom end of the Bruiser and to also provide for a uniform place of attachment for all three fins. Without the tube, it would be more difficult to attach the three fins to the motor tubes on this three-motor cluster.

Prior to using epoxy, test-fit the tube into the grooves on the centering rings. Then, on a flat surface, apply modest amounts of epoxy into the groove of the centering ring that contains the motor retention system. Now place the secondary tube on the ring so the tube fits into the groove on the ring. Invert the assembly. See photo 12-14. Place weights on top of the ring so that it remains firmly in position until dry.

Pick up the middle centering ring, which will fit the other end of the secondary tube, and slide it onto the motor tube assembly at least 18 to 24 inches from the aft end. Be sure that the holes for the airstart conduit line up on the two rings. Do not apply any epoxy to the ring yet, as you will slide it into the final position in a moment.

Now, carefully push the motor mount tube assembly–with the ring on it–through the secondary tube and out through the aft centering ring so that the motor tubes protrude 1/8" beyond the aft ring. With a wooden dowel or other device, apply liberal amounts of epoxy between the motor tubes within the secondary tube, and let dry. Then apply epoxy to the groove of the middle ring, and slide it into place on the secondary tube. Be sure it is fully seated on the tube.

As shown in photo 12-15, clamps are helpful in holding the assembly together while it dries.

It is time to move back to the forward centering ring. Slide the ring onto the motor-mount tube assembly so the tubes protrude slightly above the

ring. Again, be sure the conduit holes on all three centering rings line up before applying any epoxy to the top ring. Once you are satisfied with the fit, apply liberal amounts of epoxy to all joints and connections throughout the motor-mount system. Also apply epoxy between the motor-mount tubes and to the threads of all eyebolts. See photos 12-16 through 12-19. Connect the aluminum conduit together, and carefully insert it all the way through all three centering rings. The conduit should be flush at the aft ring, but it can protrude slightly out of the top ring. As illustrated in photos 12-18 and 12-19, secure the conduit with epoxy at every point possible. The conduit cannot have any kinks or even slight obstructions. Prior to applying epoxy, run igniter wire through the conduit to ensure that the wire will pass easily from one end through the other.


12-16

A dab of epoxy on the threads and nut help prevent these pieces from ever coming loose.

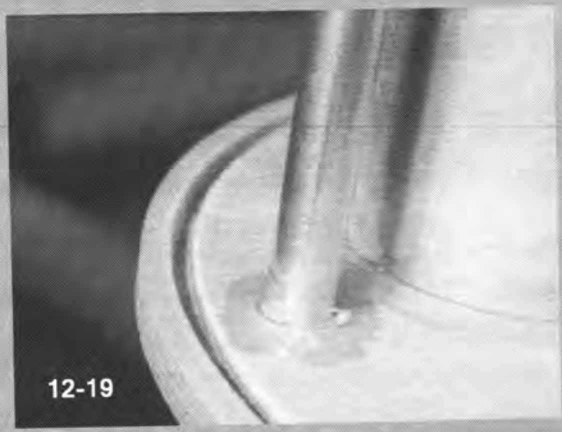
Installing the Fins

The Bruiser kit comes with a fin-alignment guide that works well with any three-finned rocket. Center the secondary tube directly on the guide, and mark the location for the three fins on the tube. Do the same with the main airframe. (Do not discard the fin-alignment guide after you have finished the Bruiser. It is handy for use on other three-finned rockets, too.)

On the main airframe, extend the mark approximately 11 inches up the tube. This will be the mark where the fin slots will be cut later. Use a straight edge when marking these lines, as it is important that the slots be as straight as possible. The three lines on the secondary tube should also


12-17


12-18


12-19

Case History

Level Two NAR ORANGEBURG

I'm Todd Haring, and I achieved my Level Two certification in Orangeburg, South Carolina.

I discovered high-power rocketry when I lived in Arizona. I attended the G. Harry Stine Memorial Launch near Phoenix in 2002, and I met Brad Vatsaas and several other flyers who were launching some really large rockets. I was hooked and I decided to join the local club, the Superstition Space Modeling Society. I kept watching those big rockets fly, and I asked a lot of questions.

I scratch-built my Level One certification rocket–a three-inch Der Red Max--which flew successfully in early 2003. I decided to proceed to Level Two because it was the next challenge in the hobby for me. I also liked the thrill of successfully launching a rocket that I had built from scratch.

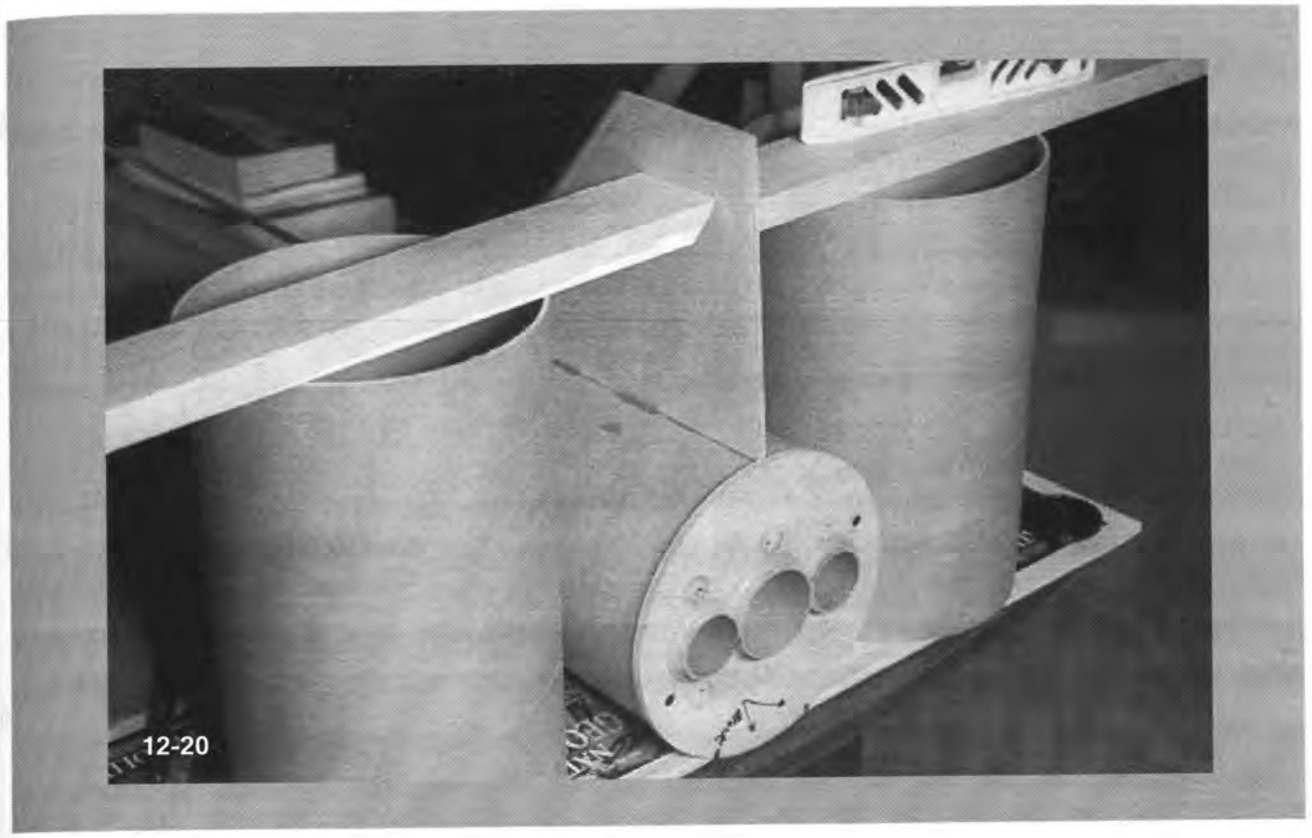
For my L2 flight I upscaled Der Red Max to six inches in diameter using the RockSim computer software program.

Overall, the rocket was a big challenge for me. But I had a lot of help from the certification team, especially Burl Finkelstein. The best part of this hobby is the people!

I had a beautiful wooden nose cone made by my father but due to the weight I used a fiberglass cone for the actual flight. I also used fiberglass reinforcement for the first time and there was more planning at each stage of construction. The rocket was set up for dual deployment.

The flight went forward in October 2004 with an Aerotech J275. I used a Missile Works altimeter for the main ejection charge and motor ejection as backup. I housed the altimeter in a bay in the aft end of the rocket. It all went as planned, and the rocket returned safely on dual parachutes. It was a lot of fun.

My advice for people seeking L2 certification: Take your time, and really think everything through. Ask for a second opinion on the project from other L2 or L3 flyers. And don't forget to use a checklist. Most of all, enjoy the process.

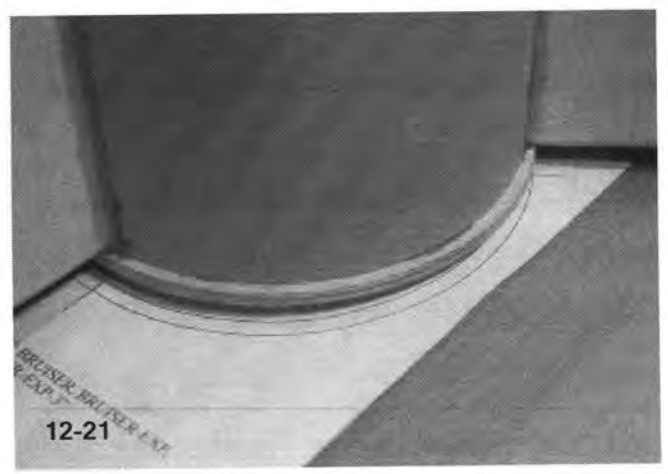


12-20

be made with a straight edge. The three wooden fins of the Bruiser will be attached directly to these lines.

Prior to attachment, sand the fins smooth, and bevel the leading and trailing edges. The fins should be sealed with a sanding sealer. (This can be done now or after they are attached and prior to painting. It is easier to do it now.)

Once the fins are sanded and beveled, they can be attached one at a time to the secondary tube. Prior to attachment, scuff up the secondary tube with sandpaper to improve the epoxy bond between the fin and the tube. Attachment is simple, but it takes patience. (This is a good place for 5- or 15-minute epoxy.)



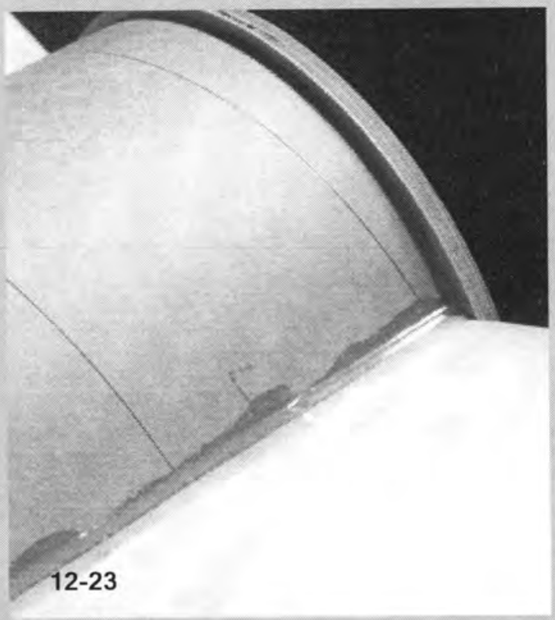
12-21

A fin alignment guide helped locate the three fins in the correct position on the secondary tube.

Apply a thin bead of epoxy to the root edge of the fin, and after the epoxy becomes tacky to the touch, firmly place it on one of the lines on the secondary tube between the two centering rings. (Do not use too much epoxy at this point in the process. Later, after all three of the fins are tacked into place, you will add epoxy fillets to both sides of each fin to really strengthen the bond).

The fin should be perfectly straight and needs to be fully supported to prevent any lateral movement as the epoxy dries. See photo 12-20. A small level is helpful here to ensure that the fin is in good position.

Let the fin dry for an hour or two. After the



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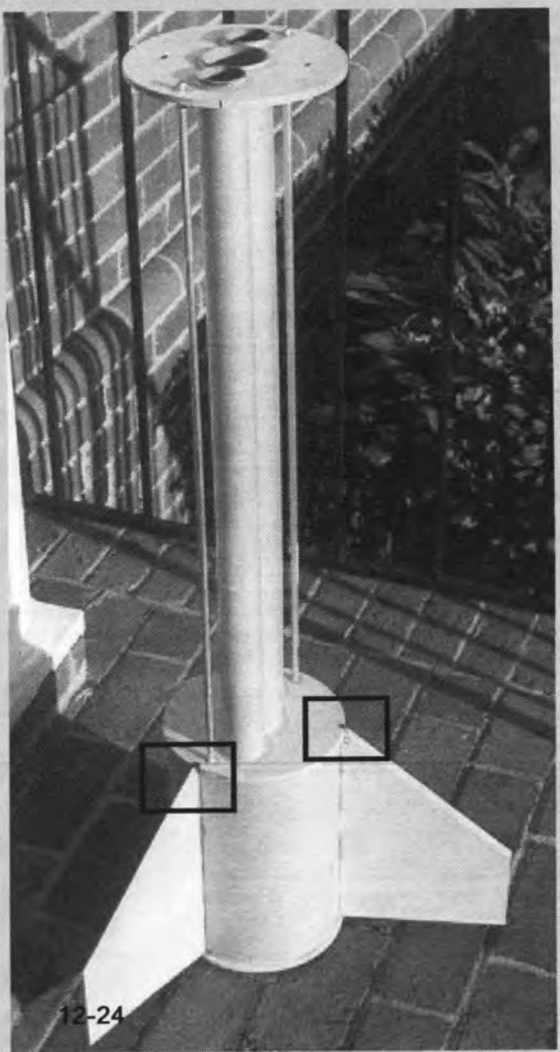


12-24

epoxy is dry, carefully inspect the fit and alignment. Again, be sure the fin is straight and firmly attached to the secondary tube. If you have doubts, this is the time to correct any problem--before you apply more epoxy.

If the alignment shifted during the process, remove the fin, sand the tube and root edge, and try again. If it looks good, move on to the other fins. If not, sand some more until you get the fit right again.

Photos 12-23 and 12-24 show the fins attached to the secondary tube and also show the entire motor tube-fin assembly. Note that on our Bruiser the fins were slightly longer, so a small notch was made in the middle ring to accommodate the extra length. (See boxes in photo 12-24.)

Once the fins are aligned and tacked in place, place a continuous bead of epoxy on each side of all three fins where they attach to the secondary tube. As illustrated in photo 12-23, this inner bead should be substantial. A similar, outer bead will be placed later where the fin meets the main airframe.

The completed motor housing-fin assembly appears in photo 12-24 (minus the eyebolts).

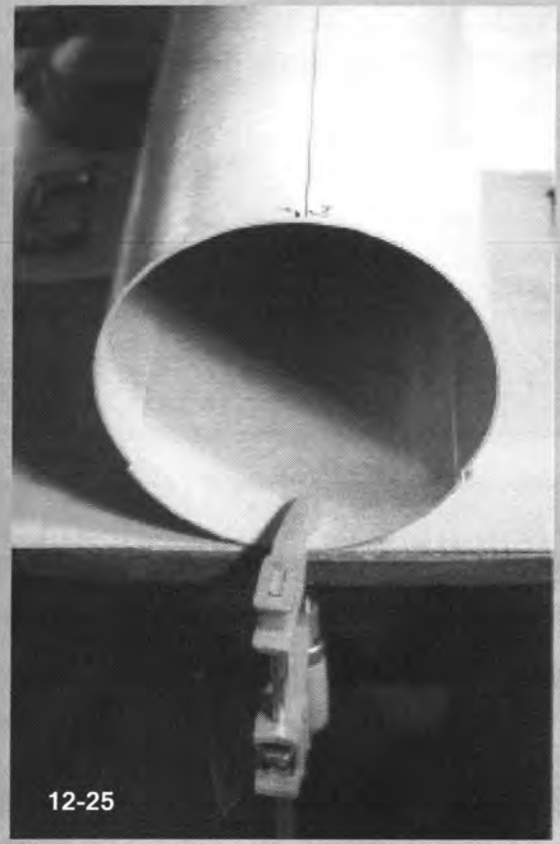
Cutting the Fin Slots on the Airframe

It is time to cut the fin slots in the main airframe.

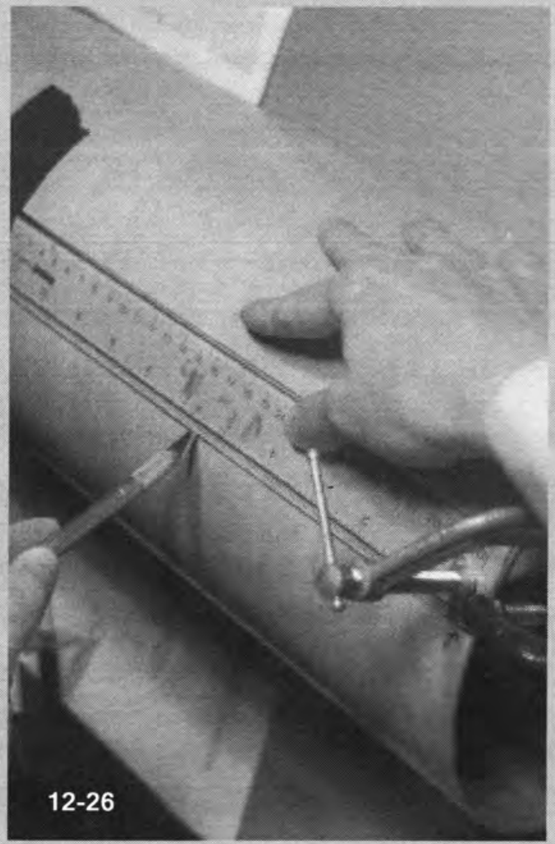
Previously, three 11-inch lines were drawn up the side of the main airframe. These lines will be used to cut the fin slots. As the LOC instructions point out, these three lines act as a centerline guide so that the slot width will be cut 1/8" each side of the line. However, before cutting the slots, invert the motor tube/fin assembly and push it into the airframe as far as it will go (up to the fins). Be sure that the fins that were epoxied to the tube assembly line up with the three lines that were previously drawn on the tube. If they do not, adjust the lines on the main airframe accordingly. Then, label each fin and each anticipated slot so that they are lined up again after the next step.

The slots can be cut with a number of tools, including a Dremel or even a simple hobby knife.

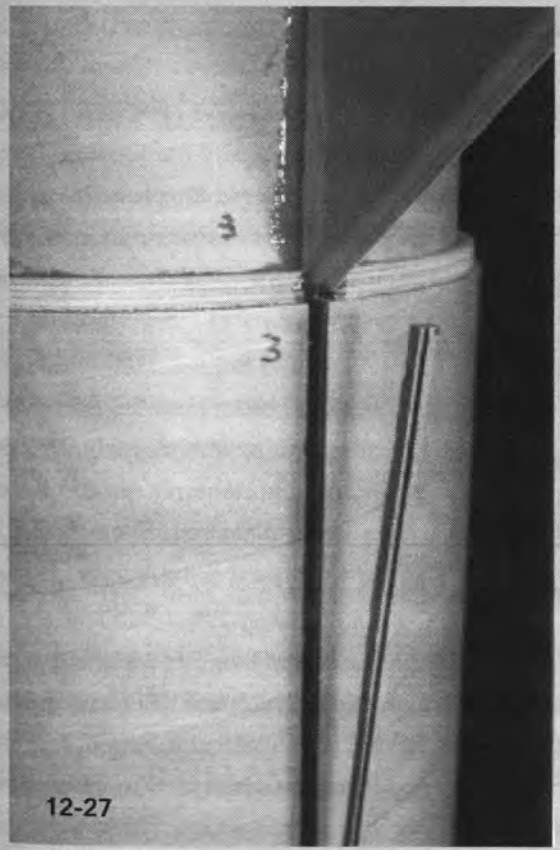
Secure the airframe in place so it does not move in the cutting process. As illustrated in photo



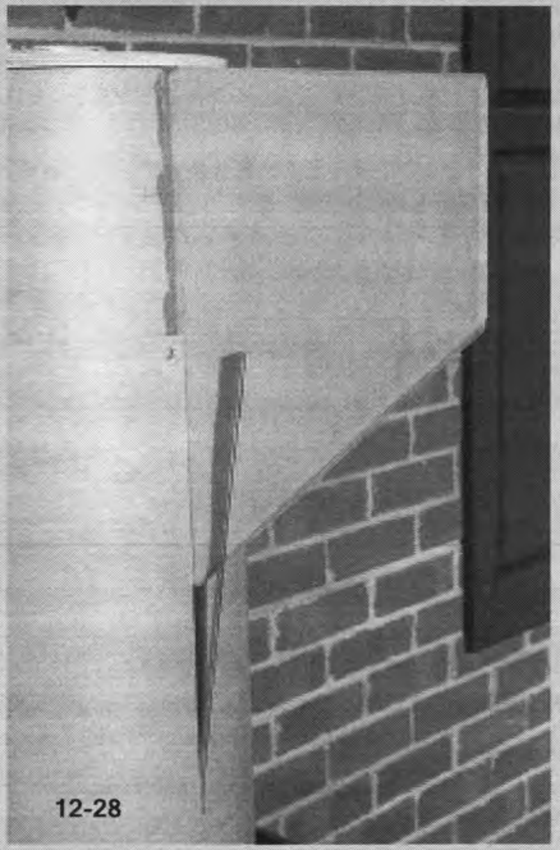
12-25



12-26



12-27



12-28

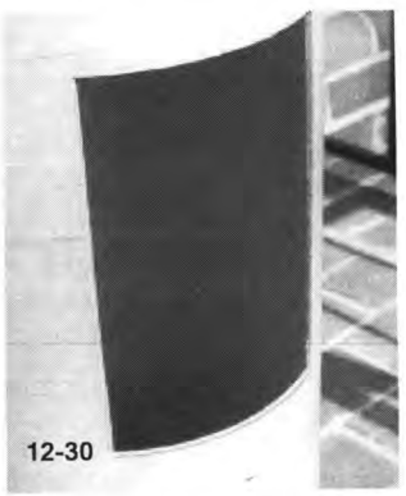
12-29

12-25, a clamp attached to a table will work. Using a ruler as a straightedge (clamped and taped in place), we took a hobby knife with a sharp, new blade, and gently ran it the length of the fin slot, creating a tiny groove in the airframe. See photo 12-26. Repeat this process slowly and carefully with repeated passes of the blade to make the groove deeper and deeper. Within a few minutes, the knife will break through the airframe.

Patience is the key here. Do not hurry the job. The result will be a clean, straight line on the tube. Repeat this on each side of the three lines, for a total of six cuts.

In this next step, use no epoxy. This is the test-fit of the motor tube-fin assembly into the airframe. Stand the airframe on end, with the aft end facing up. Take the motor tube-fin assembly and gently place it on top of the main airframe. As you do this, line up the fins with the fin slots. As illustrated in photo 12-27, each slot should line up with the corresponding fin. Gently push the tube-fin assembly into the airframe, as illustrated in photos 12-27 and 12-28. Keep the hobby knife handy to make any adjustments necessary. Push the assembly all the way into the airframe. Repeat this process a couple of times to become familiar with the way the components fit together, prior to moving on to the next step. When you are confident of the fit and alignment, remove the assembly from the airframe and set it aside.

It is time to apply the epoxy and permanently set the assembly in the airframe. For this step, use 15-minute or, preferably, 30-minute epoxy. Per the LOC instructions, apply a large and continuous ring of epoxy around the inside of the main airframe, approximately 38 inches from the aft end of the tube. A thin wooden dowel works well for this task. Once the bead has been applied,



12-30

The first step in our altimeter bay construction is to cut a hatch in the upper airframe.

insert the motor tube-fin assembly and slide it all the way into the main airframe–the assembly should fully engage and then pass the point where the epoxy was placed. When the middle and then the aft centering rings come close to the bottom of the airframe, apply epoxy around the edges of each ring as it slides into the tube. As shown in photo 12-29, Quick-Grip clamps will secure these components in place while the epoxy dries. This entire assembly should be set in an upright position to dry.

After the assembly has dried, turn the rocket over, and apply epoxy in a bead or fillet around the aft ring where it meets the airframe.

Building the Altimeter Bay

If electronics-activated recovery is used, an altimeter bay must be added to the rocket. In this case, a hatch-accessed bay was built. The altimeter bay would hold two altimeters and at least one timer (for the airstarts). The altimeters and timers would attach directly to the airframe.

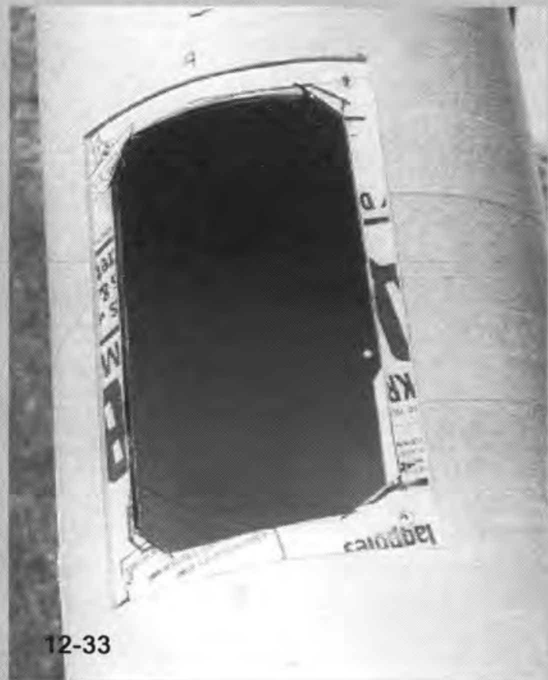
The electronics bay must be sealed from any ejection charges, so in addition to the bulkhead plate supplied in the kit, another bulkhead was made to create the electronics compartment. This bulkhead was simply 3/16" aircraft-grade plywood. The bulkhead was 7.51 inches in diameter (to match the inside diameter of the airframe) and was placed two to three inches above the hatch opening. This extra bulkhead would seat against an inner hatch tube, discussed below. The main bulkhead plate assembly (supplied in the kit) was located approximately 11 inches below the hatch–providing for nearly 20 inches of internal space for the electronics bay.

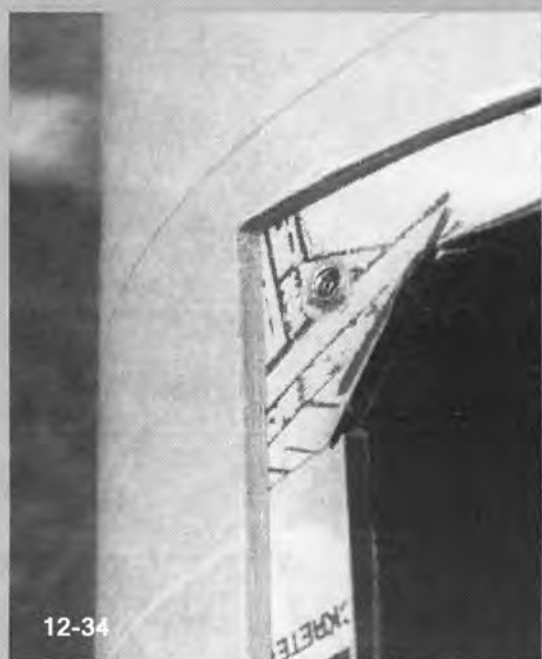
To cut out the hatch, use the same technique you used to cut the fin slots. Here, a sharp hobby knife was used to cut a clean, rectangular opening in the upper airframe, as illustrated in photo 12-30.

Photos 12-31 and 12-32 illustrate the placement of a support coupler for the blind nuts that will help secure the hatch to the rocket. The coupler is made from 8-inch nominal sono tube available at most home-improvement stores. A small vertical

12-31

12-32


12-33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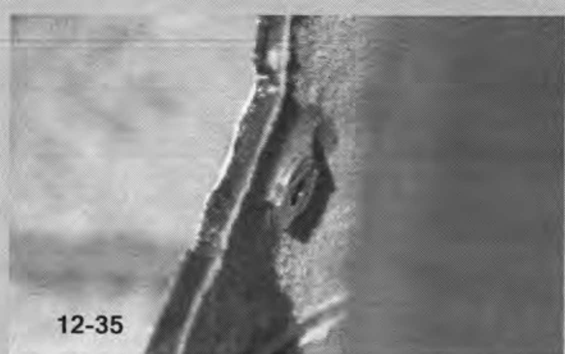
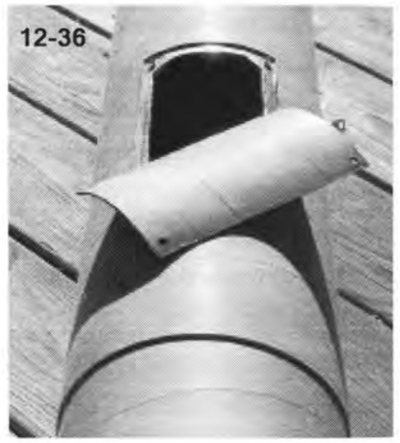

12-35

section of the tube is removed with a hobby knife, to reduce the diameter of the sono tube. The tube then slides into the airframe like a coupler. Use plenty of epoxy to secure the sono tube in place.

When installed, the sono tube completely fills the opening for the hatch. After the epoxy is fully dried, the sono tube is cut so there is, in effect, a hatch within a hatch, as shown in photo 12-33.

Blind nuts are then installed at the edges of the sono tube. Put some epoxy around the edges of the blind nut on the inside of the bay to keep them in place. (Again, be careful not to get any epoxy on the threads of the blind nuts.) See photos 12-34 and 12-35.

The hatch door is secured to the rocket with four 6/32 machine screws. For more altimeter bay examples see chapters 8, 9, and 15.


12-36

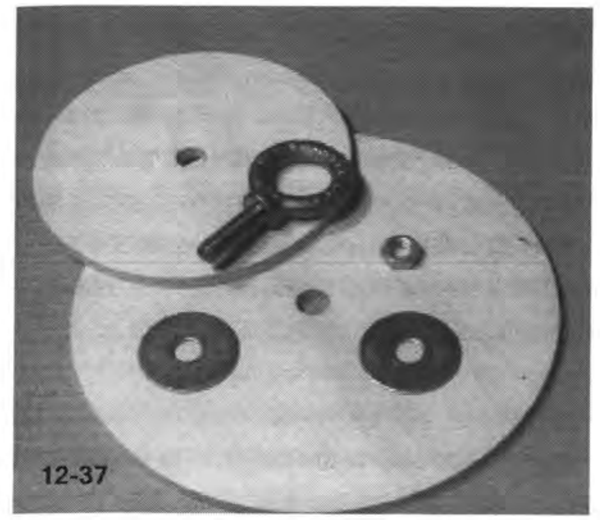
The hatch door looking up from below the payload bay.

Assembling the Bulkhead

Assembly of the lower bulkhead plate is next. The LOC kit came with a two-part bulkhead. A smaller bulkhead is mated to a larger bulkhead and the eyebolt passes through a hole in the center of each piece after they have been joined together. The parts are shown in photo 12-37.

As illustrated in the photo, we replaced the open eyebolt supplied in the kit with a forged, closed eyebolt. A U-bolt would work well here, too.

Using 30-minute epoxy, the two bulkheads were clamped together for a few hours to ensure a good bond. See photo 12-38. Afterward, the eyebolt was secured to the bulkhead. Epoxy was placed on the threads of the bolt after it had been attached, to ensure that the bolt would never come loose.


12-37


12-38

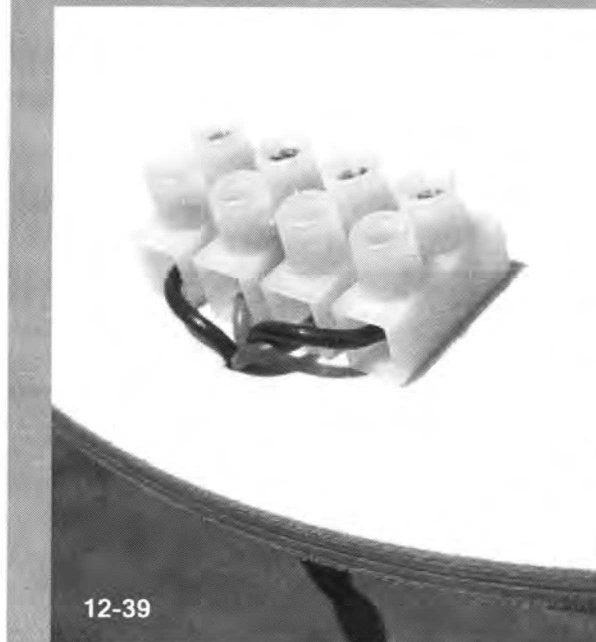
We then added two separate electrical terminals for ejection-charge and airstart wiring. See photo 12-39. We bought the electrical terminals from Radio Shack and cut them to length with a hacksaw.

We also added blind nuts as attachment points for the multiple ejection canisters. Holes were drilled in the bulkhead to allow wiring to pass from the altimeter bay to the electrical terminals. See photo 12-39. The wiring was color-coded to help us match up the correct terminals with the right ports on our electronics later. After the wiring was routed through each hole, epoxy was used to seal up the holes and their edges.

The bulkhead assembly was attached to the 7.51-inch main body-tube coupler using 30-minute epoxy. Epoxy fillets were placed on both sides of the bulkhead where it attached to the coupler. The completed bulkhead is shown in photo 12-40.

The upper bulkhead-plate assembly was created in a similar fashion. The bulkhead was slid down the inside of the airframe and placed on the "ledge" created by the sono tube coupler. Epoxy was used to permanently affix the bulkhead in the tube.

The altimeter bay was now complete, with the bay protected by an upper and a lower bulkhead. Each bulkhead had small holes through which wiring would pass for ejection charges and airstarts. Access to the bay was made easy by the hatch.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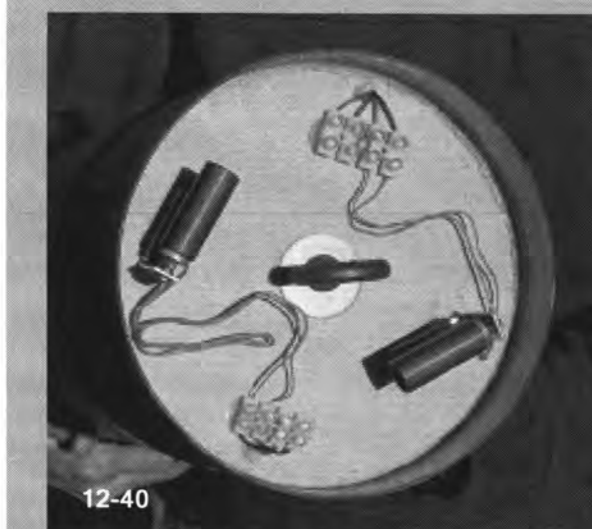
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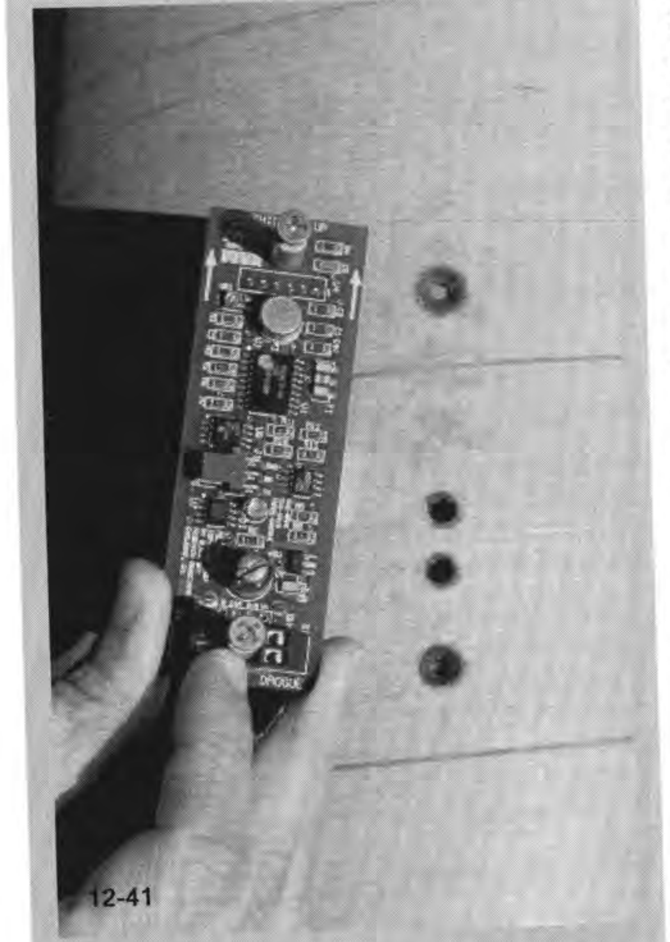

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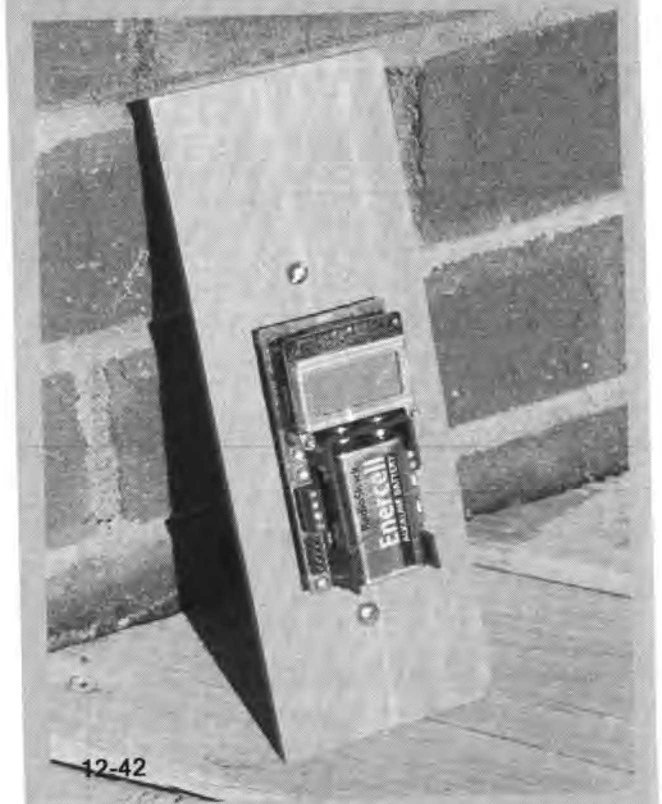


12-42

Installation of the Electronics

For launch, the rocket would be equipped with an Olsen M2 altimeter, a blacksky Altacc altimeter, and, for airstarts, a blacksky Timer 2. The blacksky units both attach directly to the airframe of the rocket. Each unit comes with a template that allows the builder to drill the appropriate holes for the two mounting screws and, in the case of the Altacc, a hole to view the arming light and a hole to access the arming screw on the altimeter.

Photo 12-41 shows the blacksky Altacc altimeter on the outside of the bay next to the holes that have been drilled for the unit. Each hole has a drop of CA added to keep it clean and intact. The altimeter (and the blacksky timers) mount on the inside of the rocket. The top and bottom holes are for the mounting screws. The two smaller holes are for the arming screw and the arming light.

The Olsen altimeter could not be mounted directly to the airframe. Instead, the altimeter was mounted to a thin plywood board, and then the board was attached to the airframe wall with two screws and wing nuts. This can be done with almost any altimeter and timer (our alternative boards held a Missile Works RRC2 and a G-Wiz altimeter). See photo 12-42.

The Olsen altimeter would be armed by reaching into the bay before the hatch was closed or, in the alternative, by attaching an external switch that would be used after the altimeter bay was closed. This made the electronic units easily removable so they could be installed and armed with a minimum of effort on launch day.

Two altimeters on board would allow for redundant ejection charges. In the dual-deployment flight mode, there would be four ejection charges. Two of the charges would be for deployment of the drogue at apogee, and two more charges would be for the main parachute at a lower altitude.

Modifying the Bruiser EXP Nose Cone

LOC supplies an excellent 7.51-inch nose cone with this kit. The cone is constructed of hard plastic and is very strong. It comes with a point of attachment

for the recovery harness that works fine in a stock application. But for our rocket we decided to modify the cone with the addition of several ounces of forward weight held in place with epoxy. This extra weight allowed for adjustments to the center of gravity in this rocket in the event that larger-than-stock motors were used in flight.

To get inside, the aft end of the nose cone was removed with a hacksaw, exposing the hollow inner core. We then sanded the inside of the core as close to the tip as possible to give the epoxy something to grip as it set. Small fishing weights were then added to the tip of the nose and a piece of 3/8-inch all-thread was placed in the center of the weights. Slow-drying 30-minute epoxy was poured in to cover the weights and the tip of the all-thread.

Since epoxy in large amounts can generate enough heat to damage a plastic nose cone, the cone assembly was inverted in a bucket of cool water while the epoxy hardened.

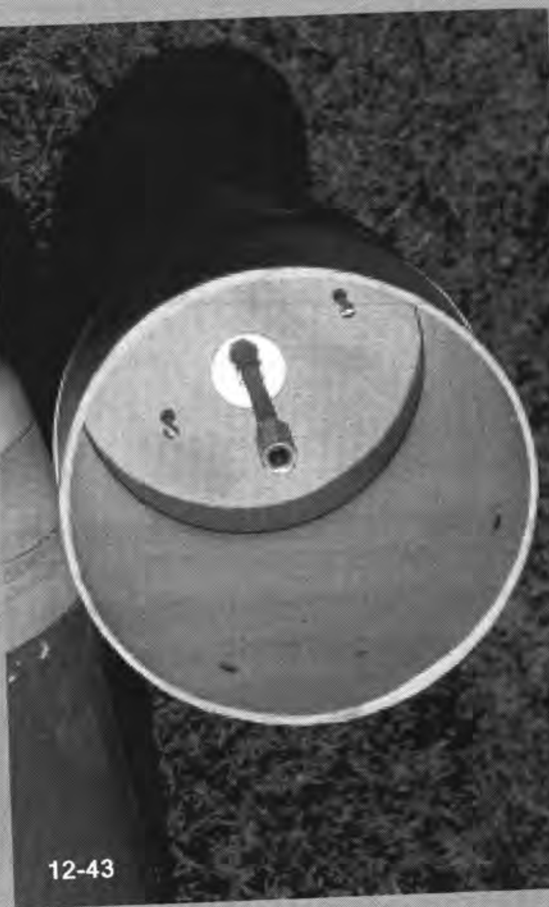
Finally, a new bulkhead was created for the nose cone, as shown in photo 12-43. The bulkhead had blind nuts installed in the event we wanted to secure ejection charges in the future.

The bulkhead was floating--it was not permanently affixed to the nose cone. It was held in place by nuts placed on the all-thread on either side of the bulkhead. This design allowed us to change the weights in the nose, if necessary, by simply removing the bulkhead to get to the tip of the cone again.

Placement of the Recovery Harnesses

The LOC kit comes with a good attachment cord made of tubular nylon. Since this rocket would be set up for dual deployment, another cord would also be necessary. Both cords would be attached to the bulkheads in the rocket with quick-links. See photo 12-44.

Each cord or harness would have a loop of material tied off in a knot. See photo 12-45. The loops would be used to attach parachute shroud lines with a quick-link. As already seen above, all of the bulkhead points of attachment would be closed eyebolts.



12-43

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12-47

The recovery harness in the lower bay would hold a drogue parachute that would be deployed at apogee. The upper payload bay would hold a LOC parachute that would deploy under 1,000 feet, depending on wind and field conditions on the day of launch.

Installation of the Launch Lugs

The LOC kit comes with two large cardboard launch lugs. These lugs work with a very large launch rod. However, we had several styles of lugs available and wanted to try something different for the rocket. As seen in photo 12-46, we had the stock lugs and three types of rail lugs.

For the launch of our project we anticipated using a rail system. Therefore, two Acme conformal rail guides were installed with liberal amounts of epoxy. The airframe was scuffed up with sandpaper prior to using epoxy to place each guide. Photo 12-47 shows one of the Acme guides installed.

The guides were located on the rocket in the same manner as suggested by the LOC instructions: Sight in the high point on the airframe between any two fins. Make a mark on the airframe (along the high point) six inches up from the bottom of the airframe. Now from this mark make two separate lines that are each three inches long. The first line begins at the mark and the second line starts 25 inches from the mark. These two three-inch lines mark the locations of the launch lugs, or in our case, the launch-rail guides, on the airframe.

For more information on rail guides and launch pads, see Chapter 7.

Using Shear Pins for the Nose Cone

In a dual-deployment rocket, shear pins are often used to ensure that the main parachute does not deploy inadvertently at apogee. For the Bruiser EXP we used four 2-56 nylon pins (4-40 pins work fine here, too).

The pins were located around the circumference of the upper payload bay, where the nose cone and the bay linked together. Four holes were drilled through the plastic shoulder of the nose cone and the payload bay. Four 2-56 blind nuts were then

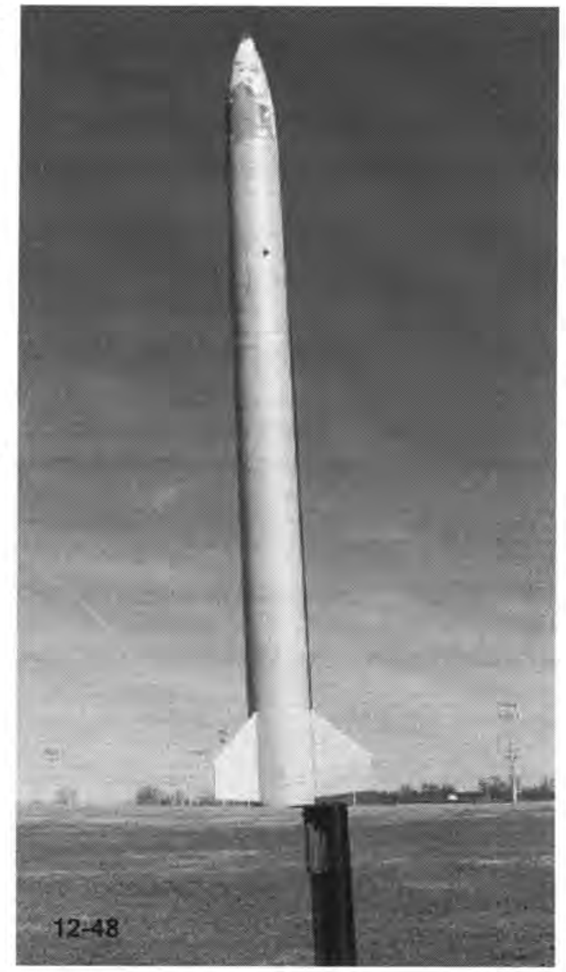
installed on the inside of the nose cone. The blind nuts were pressed in place using a clamp, and then epoxy was applied to each blind nut to hold it firmly in place.

As discussed in Chapter 6, it is good practice to test-fire ejection charges on the ground to ensure that you are using enough black powder to separate the airframe. This is especially true if you use shear pins to hold the airframe together.

In this case, three grams of black powder were used to test the shear pins on the upper bay, where the main parachute was located. The bay was loaded just as it would be on launch day, with the parachute, recovery harness, and Nomex cloth. The ejection charge was hooked up, and the rocket was placed flat on the ground, with the nose cone slightly elevated. When the charge was fired, the nose cone jumped off the upper airframe, pulling the recovery harness out of the rocket. The shear pins were cleanly cut.

We did the same thing to test the charges for the drogue parachute that was located in the lower section of the rocket as well (but without shear pins).

For a shear pin diagram, see Chapter 10.



12-48

The unpainted Bruiser EXP is test-fit on a rail prior to launch. This rocket is easy to build and provides for great Level Two performance, whether on one motor or three.

Launch of the Bruiser EXP

On launch day the rocket was loaded with an Aerotech 54mm K700 and two Aerotech 38mm J350s. The K700 has a burn time of about 3.7 seconds and the smaller J350s would burn for less than two seconds. All three motors would light on the pad. To ensure ignition, each Aerotech igniter was augmented with slivers of Blue Thunder propellant attached to the igniter tip with ordinary sewing thread. The igniters must be hooked up in parallel. See chapters 5 and 13 for more information on igniter wiring and clusters.

The three-motor cluster ignited well and carried the Bruiser off the pad in a rush of smoke and flame. The lightweight rocket cleared more than a mile and returned via drogue and then a main parachute. The Rocketman drogue deployed at apogee and the main parachute opened at less than 500 feet. In retrospect, the main could have been set to deploy higher. This would allow more time for the parachute to unfurl.

Alternatively, the rocket could have been an airstart project. Each motor is controlled by a single blacksky Timer 2. The wires for the motors would run from the Timer 2 to the electronic terminal in the lower bulkhead. The wires would continue through the conduit and emerge at the aft centering ring where each of the two igniters would be connected to the J350s.

The wiring that emerged at the aft centering ring should be protected from the heat and flame of the main K700 by heat-resistant tape. See Chapter 13 for more information on clusters and airstarts and the use of protective tape to protect cluster wiring.

Cluster RULES

NAR and Tripoli have slightly different rules regarding clusters and certification levels. NAR Level One flyers can cluster up to 640 total installed newton-seconds. NAR Level Two can cluster up to 5,120 total installed newton-seconds. Tripoli, however, allows Level One flyers to cluster up to 1,280 total newton-seconds (a J motor equivalent). Level Two Tripoli members can cluster motors up through an M-motor equivalent.

13

Clusters and Airstarts

An investment in multiple motors can pay big dividends in excitement and fun

A high-power rocket that is equipped with two or more motors is known as a cluster. Clustered rockets are challenging to build, exciting to launch, and fun to watch. They bring more punch to a launch, provide for spectacular special effects, and, in some cases, increase a rocket's overall performance.

The owner of a clustered rocket may ignite all of the motors on the launch pad. But not always. Sometimes the user will light some motors on the ground and other motors during flight. In a clustered rocket, the ignition of additional motors in the cluster after launch is known as airstarting. The advantages of an airstart are visual appeal and performance. The biggest challenge is in constructing a system that will reliably and accurately fire multiple motors that are static at launch.

A hybrid cluster at the Black Rock Desert in 2004.

The purpose of this chapter is to introduce the reader to the basics of clustering in high power and then demonstrate how to build a seven-motor airstart project. This chapter will also discuss mutli-stage rockets in high-power.

Cluster Basics

The number of motors a clustered rocket can hold is limited only by the size of the motors and the diameter of the rocket. Clusters may range from rockets packed with more than 100 Estes B6-4 motors to huge, 200-pound Nike Smokes with multiple M motors.

Dan Lord's 180-pound Nike Smoke is hauled to the away cell at LDRS23 in New York in July 2004. The five-motor cluster had a central N motor, two Ms, and two Ls.

Cluster rockets must follow the same basic rules of design–in terms of stability, strength, and safety–as all other high-power rockets. However, with clusters, extra care must be taken during construction of the rocket because of the higher-than-ordinary average thrust these rockets can generate.

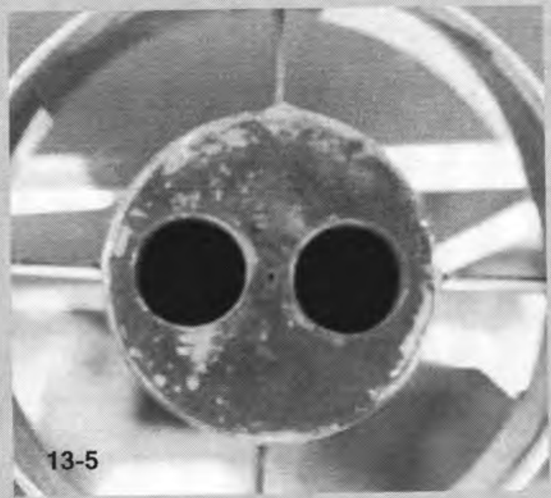
The most common clusters contain two to seven motors. (See photos on next page.) Rockets with a cluster configuration in this range are common at high-power launches, and several manufacturers offer rocket kits in this cluster range. The LOC/Precision Magnum is a clustered rocket that uses three in-line motors: two outboard 29mm motors and one central 54mm motor. Public Missiles Systems also offers a cluster kit in its Ultimate Endeavor rocket. This rocket has a central 54mm motor mount surrounded by four 38mm mounts.

Woody Hoburg and crew prepare igniters for a five-motor cluster on his upscale 100-pound Mosquito in New York.

For even more performance right out of the box, LOC's legendary Top Gunn is an attraction at any high-power launch. The six-finned, 7.67-inch rocket houses seven 54mm motors and has been flown on seven K motors in a single launch. Although discontinued a few years ago, the Top Gunn is still seen at regional events around the country.

For a seven-motor cluster on a budget, try LOC's Ultimate. This rocket has seven 29mm motor tubes and retails for less than $100. It can be flown on just one motor or on seven, or anyl combination in between.

A high-power kit is a good way for the average builder to gain experience with clusters before he or she moves on to scratch-building clustered rockets.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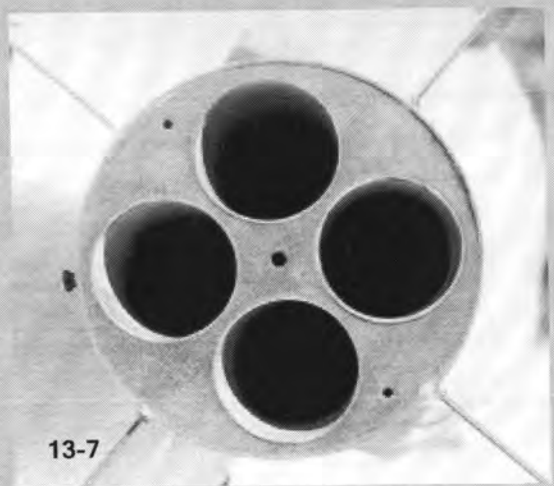
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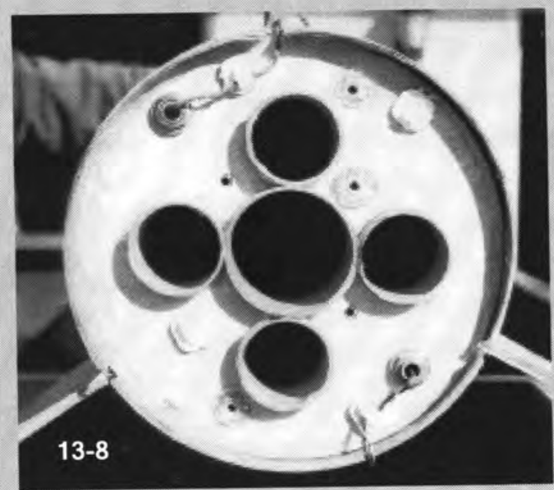
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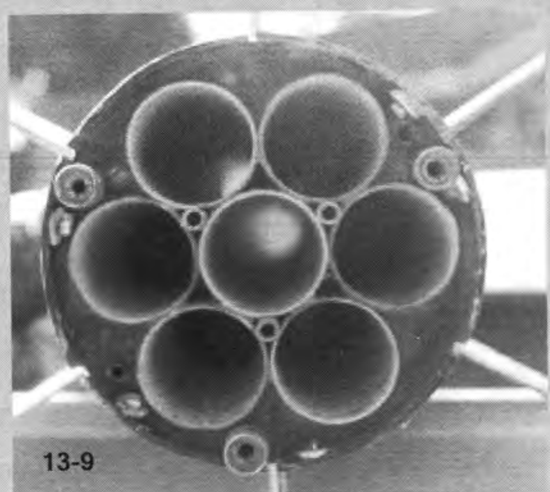
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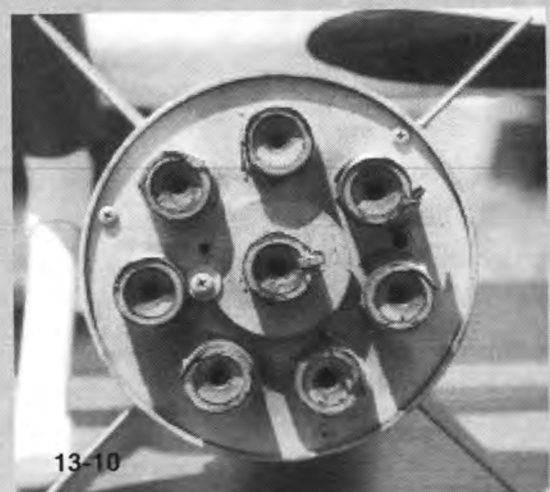

13-10


13-11

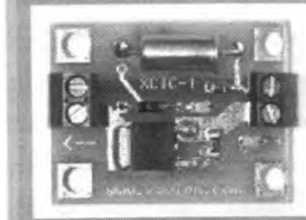
Choosing the Right Motors for Your Cluster Project

The selection of motors for a cluster requires careful consideration. A cluster rocket should never be filled with whatever motors might be available on a given launch day. And the builder should always consider what might happen to the rocket if one or more of the chosen motors fails to ignite as planned.

Not all high-power rocket motors ignite or come up to pressure in exactly the same amount of time. Large-core motors generally take more time to pressurize than small-core motors, and there may be a delay of a second or two between the ignition of, say, a J350 and that of a K185 in a given cluster. In these situations a group of smaller-core motors may actually lift the rocket off the pad before the main motor(s) come up to speed. If a rocket is launched on a K700 and two J350s, the rocketeer should consider–prior to launch–what might happen if the two smaller J350s ignite and the K700 fails to ignite, or if the K700 ignites late. What is the thrust-to-weight ratio of the rocket with only the J350s? Will the average thrust of the two J350s be sufficient to safely lift the rocket in a vertical trajectory?

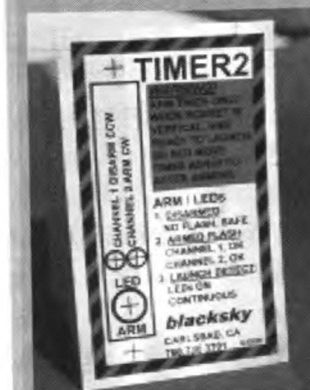
What happens if the K700 ignites late? If the average thrust of one or two J350s is not sufficient to maintain a safe ratio, it might be better to launch the rocket on the single K700 and then *airstart* the J350s using a timer (discussed below). In any event, give some consideration to these issues–and the related issue of asymmetrical thrust (also discussed below)–before planning a cluster flight.

Try to cluster motors of the same type in a given rocket. Use all composite motors or all black-powder motors. If you decide to use



The Timer

Most timers in high-power rocketry operate on a tiny g-switch that senses the rocket's takeoff and then fires additional motors in a cluster with on-board electric matches or igniters. Timers help alleviate the worry that smaller motors may ignite first. The timer will not allow the ignition of the smaller motors until it has sensed takeoff on the main rocket motor. Some timers can even delay the firing of the smaller motors for many seconds into flight.



both black-powder and composite motors in the same cluster, ignite the composite motors first. Do this because composite motors are generally not as easy to ignite as simple black-powder motors. If smaller black-powder motors are ignited first, the rocket may leave the pad before the composite motors come up to speed. If the early ignition of the black-powder motors leads to an unstable rocket, the later ignition of a powerful composite motor could make problems worse.

The Center of Gravity and Extra Motors

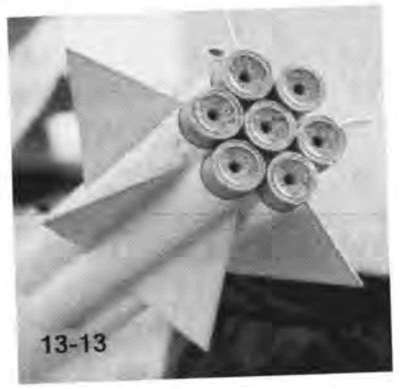
Another motor consideration in a cluster is the relationship between the center of gravity (CG) and the center of pressure (CP). As set forth in Chapter 1, the center of gravity should always be at least one body-tube diameter forward of the center of pressure. Otherwise, the rocket will be unstable, and the flight path may become dangerous.

In a cluster, the extra weight of multiple motors moves the CG aft in the rocket. This is especially the case in a cluster that was originally constructed with a smaller or lighter set of motors in mind. Many times a commercial rocket manufacturer will construct a clustered rocket kit with certain motors in mind, but the flyer decides to place larger–and heavier–motors in the cluster.

This should be done with caution and care. A rocket that is once stable with multiple J285s on board may become unstable with the same number of heavier K700s. The extra weight of the larger motors moves the CG aft. How far aft will depend on the rocket, the number of motors in the cluster, and the difference in the total weight of the motors. The important thing is to recognize this potential problem and ensure that the rocket is made stable prior to launch. As discussed elsewhere in this book, moving the center of gravity forward is usually accomplished by adding weight to the nose cone.

If the rocketeer is scratch-building a clustered rocket using an unusual motor configuration, then canting of the motor tubes might also be desirable.

13-12



13-13

Above: The aft end of Wedge Oldham's 700-pound Black Brandt reveals a cluster for three P motors. Here, the rocket rests on a stand prior to flight. For a liftoff photo, see Chapter 8. Left: A cluster of black powder motors that ignite with "flash in the pan" ignition.

Canting is accomplished by varying the angle of the motor tubes relative to the vertical axis of the rocket. This construction technique helps maintain the stability of the rocket during flight, particularly if one or more of the motors fails to ignite. In his 1993 article in *High Power Rocketry* magazine entitled "Clustered Rocket Design," Mark Page suggested that, multiple motors be angled toward the rocket's focal point–that point on the rocket midway between the center of pressure and the center of gravity. This general rule of thumb, suggested Page, may help maintain a rocket's stability if a motor in the cluster fails.

More recently, rocketeer Andy Woerner–who has perfected the art of clustering black powder motors in large numbers–wrote in *Extreme Rocketry* magazine in August 2002 that canting in scratch-built rockets is especially important when the motors are spread farther away from the center of the rocket. This is true, observes Woerner, because the farther from the center axis of the rocket you move the motors, the less stable the rocket will be if one or more of the motors fails to ignite. Be sure to consider your options if your scratch-built project contains a motor configuration that falls into this category.

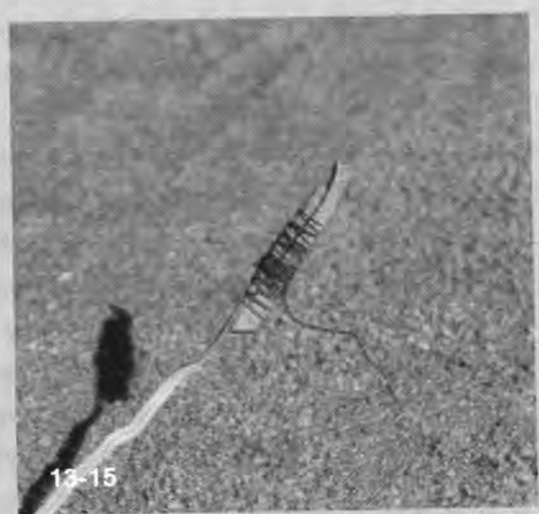
13-14

This 345-pound rocket was powered by a cluster of five motors: A central O motor and four M motors. The 20-foot-tall rocket, built by Team UROC, launched at the Tripoli experimental launch in 2004. For this rocket's story, see Chapter 14.

The Dangers of Asymmetrical Thrust in Clustered Rockets

The biggest enemy of clustered rockets is asymmetrical thrust. Ideally, when a clustered rocket is ignited at the pad, all of the motors in that rocket will light at roughly the same time (except in planned airstarts). This will contribute to a stable, vertical trajectory–assuming all else goes well. Asymmetrical thrust, on the other hand, may occur if one or more of the motors in the cluster fail to light on time–or at all. Asymmetrical thrust can cause a rocket to veer off course, turning an otherwise well-built rocket into a cruise missile, with dangerous consequences.

In 2001, at a large regional launch in California, there was a beautiful scratch-built ringtail rocket that had a two-motor clustered engine mount. For its first flight, the rocket was prepared with two 54mm Aerotech J415 motors. The six-inch rocket weighed around 25 pounds and looked terrific on the pad. At launch, however, there was a slight delay in the ignition of one of the J415s. The rocket rose on one motor in a haphazard manner for a few dozen feet and then tipped over into a "cruise missile" attitude. Suddenly, the second J415 came to life and the rocket


13-15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13-17

roared into the distance in a nearly horizontal flight path. It was exciting to watch, but the rocket was seriously damaged when it slammed into the ground downrange.

To avoid the problem of asymmetrical thrust, it is essential that all of the motors ignite as close to simultaneously as possible. This is not difficult to accomplish, but it does take some planning and experience. It also takes a reliable ignition system.

Igniters: The Critical Component in Clustered Flight

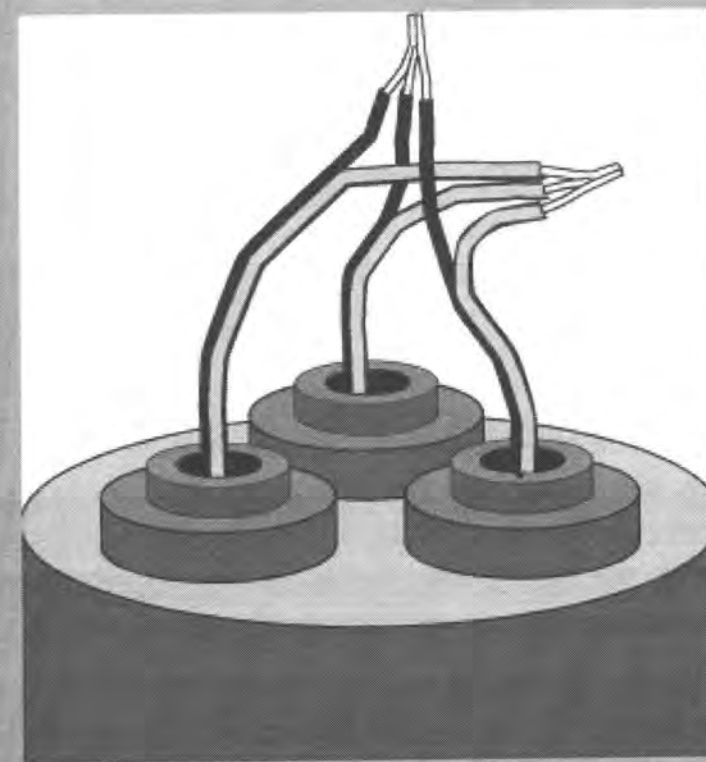
The first step in achieving simultaneous ignition of all motors in a cluster is to use quality igniters or electric matches. High-power igniters are among the least expensive items in your rocketry toolbox. Yet some people use the cheapest igniters they can find, even when attempting to start a clustered rocket. Do not make this mistake. When preparing your clustered rocket on the pad, use the best igniters you can afford and only use igniters that you are already familiar with from experience.

The next step in assuring ignition of the cluster is to modify your igniters correctly. The average, unmodified igniter will work fine with most high-power rocket motors in the H-J range. It may even work fine with a cluster.

But do not take chances. As observed by Hyam Sosnow in his article on clusters in the October 1999 issue of *High Power Rocketry* magazine, "For cluster flights it is crucial that the igniters be able to deliver a large, hot, and long-lasting flame front to the propellant." This means the spark better be good.

This is good advice. Unless you are clustering motors smaller than an H reload, do not rely on a stock igniter in a clustered rocket. This is particularly true for unmodified electric matches. To guarantee that your igniters will light every motor in the cluster on time every time, be prepared to make some simple–but crucial–modifications prior to launch day.

One of the easiest ways to augment an igniter is to obtain a sliver of Aerotech Blue Thunder propellant and attach the propellant directly to the



Cluster wiring

Wiring igniters in a cluster is simple. The wires should be connected in parallel. As this illustration of a three-motor cluster shows, each motor has an igniter. Each igniter has two leads. The leads are split and like-colored leads (in the diagram) are connected together to form two distinct leads (three wires each). These two "multi-leads" will be connected to the alligator clips of the launch control system. For a photograph of a three-motor cluster, see Chapter 5. Illustration by Ray Dunakin.

Diagram 13-1

igniter in proximity to the igniter head. As discussed in Chapter 5, the propellant can be attached with Super Glue, epoxy, other adhesives, or even tightly wound fishing line or sewing thread. The key is to attach the sliver to the igniter wire so that the propellant is held firmly in place and a portion of the propellant is as close to the igniter head as possible. When the igniter lights, the Blue Thunder propellant should ignite as well. Blue Thunder propellant ignites very quickly and easily and gives your igniter the extra boost it may need to get each motor fired *right now*. See photos 13-15 through 13-17 for an example of a Blue Thunder-modified igniter. (Note that the propellant was attached to the igniter with simple sewing thread.)


13-18

Another way to increase the certainty of near-simultaneous ignition of a cluster is to do some minor prep work on the motor prior to its insertion in the rocket. While building the motor, take a small paint brush and gently paint the inside of the top grain in each motor with a small amount of pyrogen. Pyrogen is a flammable substance placed at the head of many commercial igniters and is also available in liquid form. A little pyrogen at the top of the motor core will end up being in close proximity to the igniter head after the igniter is placed into the motor on the pad. This should aid in ignition of the motors in the cluster–and is particularly helpful when attempting large airstart projects, discussed below. (Note: This technique may run afoul of the NAR and Tripoli Safety codes--

check before using it at a regularly scheduled launch.)

If you are building or augmenting your own igniters directly with pyrogen, be sure to do so in a manner that ensures ignition of your cluster. In the same article, Sosnow describes making modifications to the igniter with pyrogen to aid in the ignition of clustered rockets. For motors through I total impulse range, Sosnow suggests dipping the stock igniter head into the pyrogen about 1/2"to 3/4" past the igniter head. Then, withdraw the igniter from the pyrogen slowly, letting the excess drip back into the bottle.

With larger-bore motors–such as J or K reloads–Sosnow says a different approach may be necessary. For these motors, fold the igniter wire against itself about 3/4" from the igniter head, and then dip the entire folded end into the bottle. Slowly withdraw the igniter from the bottle, and let the excess drip off. The larger fold in the wire allows the igniter head to pick up a little more pyrogen, which should increase the spark at the moment of ignition.

Wiring the Igniters for Launch

Every motor in a high-power rocket must have its own igniter. Therefore, in a cluster rocket, you must prepare the same number of igniters as motors. If the cluster is a three-motor cluster, you will need three igniters. If the cluster is a seven-motor cluster, you will need seven igniters, and so on.

Wiring a cluster is simple, but it does take patience. The igniters must be hooked up in parallel–not in series. Series wiring sends the electrical current through the igniters one at a time in a line. If the first igniter burns, then the circuit may be broken, and the remaining motors will not be fired. In parallel, every igniter is connected to the alligator clips of the launch-control system. If any single igniter fails, the remaining igniters should still work.

In Chapter 5, there is an illustration of the wiring of a three-motor cluster with igniters. See photos 5-16 to 5-21. See also Diagram 13-1.

As always, be sure that each igniter is secured in each motor with either masking tape, a plastic

13-19

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13-22

cap, or some other device. Clustered motors sometimes fail to ignite because one of the igniters simply slips out of its motor on the pad. So do not overlook this very important step. Remember that the goal is to get the electrical current to all igniters simultaneously and to have each igniter in a position to immediately fire its motor.

Protecting the Igniter Wires in Airstarts

If you are airstarting motors in your cluster, you must provide protection for the igniters that are not fired on the pad. Otherwise, the central motor may very well burn the igniter wire in the first moments of ignition.

Tripoli member Scott Lemm of Chico, California, has come up with a great way to protect the airstarted igniters of his projects. Lemm has flown a number of flawless airstarted rockets on three and five motors--each time with success.

As illustrated in photos 13-19 through 13-22, Lemm uses foil tape, commonly used for heating-duct work, to secure all of his extra igniters in place on the pad. The tape allows Scott to hold all of the airstart igniters in place against the aft centering ring, sealed by the adhesive and protected by the foil backing of the tape.

Although the tape will not save an igniter that is directly in the flame of a central motor, it moves the igniters out of harm's way and provides significant heat protection from the main motor. The tape is available at many home-improvement stores. A single roll will last for a lifetime of flights.

13-23

Tripoli member Tom Binford's upscale Deuces rocket takes to the sky in South Carolina on two J motors. Note that one motor has fully come up to pressure (at right) before the other.

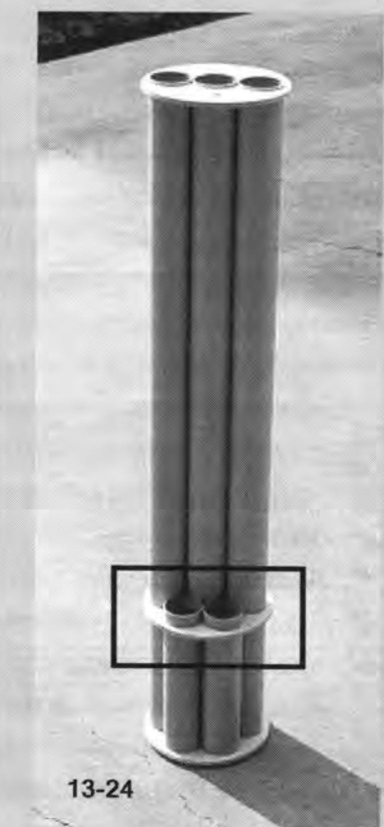
Timers and Their Use in Clusters

In the typical cluster, a large central motor is surrounded by two or more smaller outboard motors. If for some reason the central motor does not light quickly, or fails to light at all, the rocket may be lifted by the outboard motors. If the motors are too small, the rocket may have enough thrust to clear the pad but not enough to achieve a stable flight.

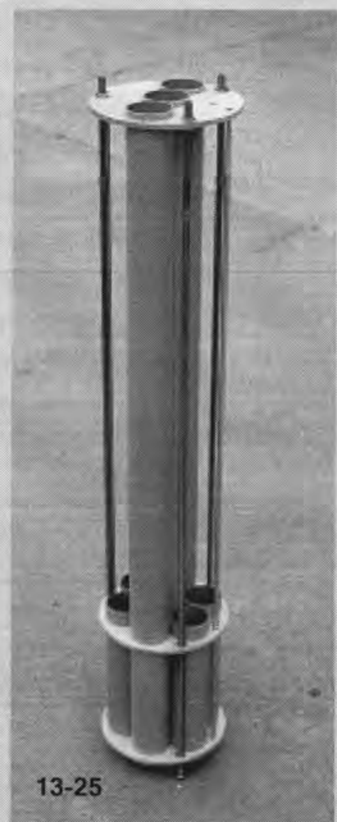
A timer can be used to prevent this from happening. A timer with a simple g-switch launch-detection circuit can prevent smaller outboard motors from firing before a large central motor has been ignited. For example, Xavien's XCIC-1 timer will not fire any igniters until launch has been detected. In a three-motor cluster with a central 75mm motor and two outboard 38mm motors, for example, the Xavien timer can be used to prevent ignition of the outboard 38mm motors until the timer has detected ignition of the central 75mm motor. This form of airstarting is also useful when mixing motors of different propellant types, so that black-powder motors do not ignite prior to a central composite motor Timers are available from several makers and are usually less expensive than altimeters. For more information on timers, see Chapter 8.

Airstarts in High-Power Rocketry

As mentioned above, airstarts are usually controlled by on-board timers. A timer fires an igniter, or a series of igniters, at a predetermined time after the



13-24

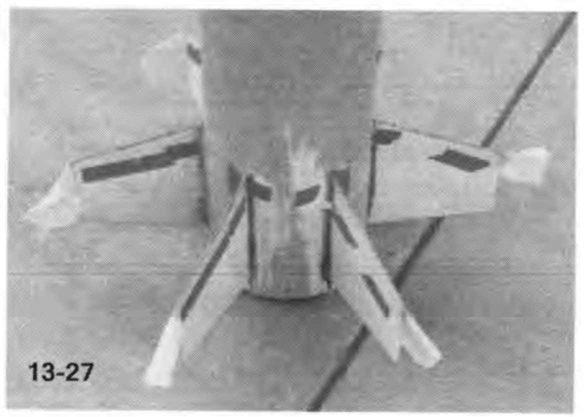


13-25

13-26

rocket has left the pad. This usually occurs within a few seconds after a g-switch contained in the timer senses liftoff. Some timers can fire the igniters as soon as takeoff is detected.

Airstarting a series of motors brings a new dimension to high power. But it can get expensive. The cost of reloading a complex airstart project that holds multiple I, J, or K motors can exceed the cost of an M reload. An M reload can cost $300 to $500. But a seven-motor 54mm cluster of K motors can cost $600 to $700 (at a price of around $100 per individual motor). There are also costs associated with the purchase of timers to control the airstarts. So do some budget planning before construction starts, and be sure that the cluster of motors you have chosen for your airstart project will fit your pocketbook.



13-27

There are several kits available that lend themselves well to airstart projects. These kits include the LOC Bruiser or Bruiser EXP, the Public Missiles Systems Ultimate Endeavor, and the LOC Magnum. For our sample project, two kits from LOC were combined: the Esoteric and the Top Gunn. This rocket would carry seven 54mm Aerotech K motors: Five K550s and two K185s. The rocket would lift off on three K550s, ignited simultaneously on the pad. Four seconds into flight, two more K550s would be ignited. At eight seconds into the flight, the final two K185s would be ignited, for a total burn time–counting all of the motors–of nearly 15 seconds.

Construction

The basic construction of this project was similar to the other rocket projects in this book. Slow-drying, 30-minute epoxy was used throughout, and the motor tubes were attached to the centering rings, and each other, in the same manner described in Chapters 11 and 12. Be sure to sand or rough up the surface of any parts before you apply any epoxy fillets to attach them together.

13-28

A hatch was created for access to the timers and altimeters.

The motor housing of the stock Top Gunn kit came with two centering rings. To increase the strength of the housing, one extra ring was added just forward of the six fins, as illustrated in photo 13-24 Then, to tie all three rings together, three 3/8" threaded steel tubes were added, as shown in photo 13-25.

These rods were three feet long. They were purchased from an electrical supply store and are normally used as conduit for wiring in household lamps. These rods would serve as backup conduit for airstart wiring, discussed below.

When drilling holes for conduit in any airstart project, be sure that the holes in each bulkhead or centering ring are well-aligned prior to drilling. To ensure that in this project, all three rings were taped together and clamped tight. The rings were then drilled as a single unit. When the rings were later separated, each hole was marked to ensure that the rings would be properly aligned when the rings were epoxied to the motor tubes. (See also Chapter 12.)

The Top Gunn kit includes six plywood fins. See photo 13-26. The leading edge of each fin was strengthened with strips of two-ounce fiberglass cloth to ensure that the fins would not come apart under thrust. See photo 13-27.

Sections of six-ounce fiberglass cloth were

13-29

The timer for airstarts is usually--but not always--located in the upper airframe. Here, NAR member Jeff Proschold of California has placed his timer in an altimeter bay located in the aft end of a Bruiser EXP. This eliminates the need for wiring conduit. The timer controlled the airstarts of the two outboard 38mm motors. The central motor is 54mm.

In Scott Lemm's "Shoot To Thrill," the timer for the airstarts was placed near the aft end of the rocket, between the fins. A hatch was used to allow access to the electronics inside. This type of timer mounting minimizes the need for conduit for airstart wiring.

placed between the fins and over the motor tube. The motor housing was then placed into the booster section with plenty of slow-drying, 30-minute epoxy. The rocket body was then covered with six-ounce fiberglass cloth.

Wiring for the Airstarted Motors

Wiring for airstarts is pretty simple. The only real issue is where the conduit for the wires must be placed in the rocket. This depends on the location of the electronics, which varies according to the rocket and the judgment of the rocket builder. In our 12-foot-tall, seven-motor example, the wiring must run from the aft end of the rocket (where the motors are located) to the top third of the rocket, where the timers are located.

But it does not necessarily have to be that way. As illustrated in photos13-29 and 13-30, the location for timers and altimeters can be much closer to the aft end of the rocket. Some builders place the electronics adjacent to the motor housing and between the fins. Some users have even placed timers or electronics in the aft centering ring.

In our project, the timers were placed in the top third of the rocket in a hatch-accessed altimeter bay.

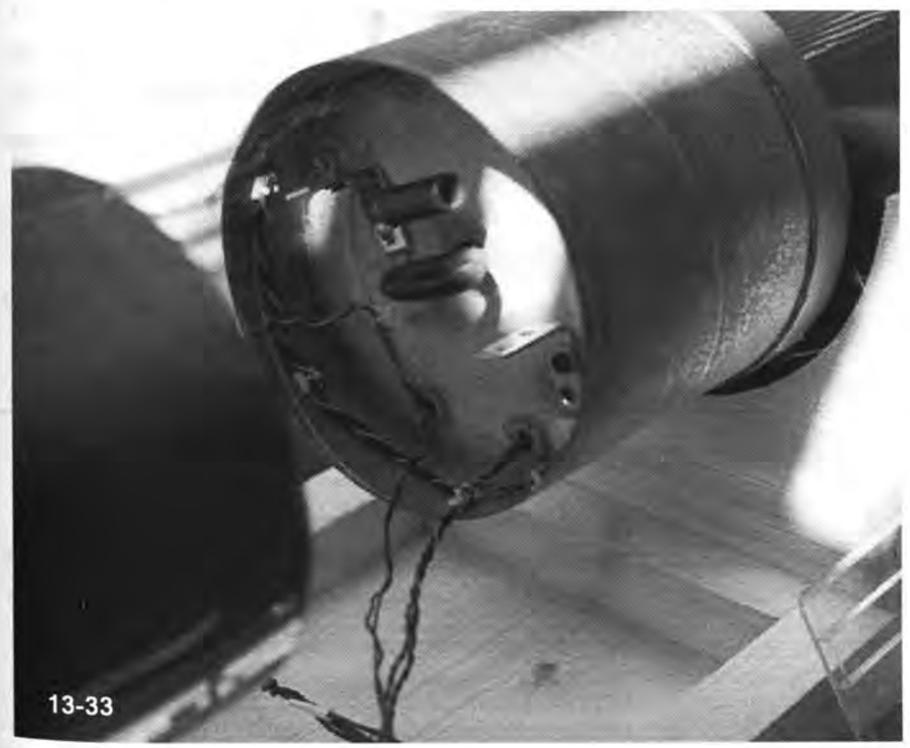
In our example, eight separate wires (for four separate igniters--two wires per igniter) would have to run two-thirds of the length of the rocket. The wires would have to pass through three centering rings and one bulkhead. These wires would also have to break apart easily at the midsection of the rocket so as not to interfere with the recovery harness at apogee/main.

As illustrated in photo 13-32 (and prior photos), multiple sections of conduit were installed in the motor housing during construction. There were a total of five sections of conduit: The three pieces of threaded metal tubing that served as strengthening rods (discussed above) and two pieces of relatively pliable hobby aluminum. These hollow rods did not extend much past the top centering ring of the motor housing. Be careful when installing hobby aluminum rods, as they are subject to kinks or dents with very little lateral pressure. After they have been placed, but before the motor housing is inserted into the airframe, test each rod by running wire from one end to the other, to be sure that the rods are free of obstructions.

Choosing Electronics for the Airstart

For this project, a blacksky Timer 2 was used to fire the airstarted motors. This timer can be programmed to fire multiple charges at intervals between 1 and 255 seconds after launch is detected. The timer has two separate channels and can handle two igniters easily. Since the plan for this rocket was to airstart four motors, two timers were used. These timers are also easy to install, as they attach directly to the rocket's airframe and can be armed from the outside with a small screwdriver.

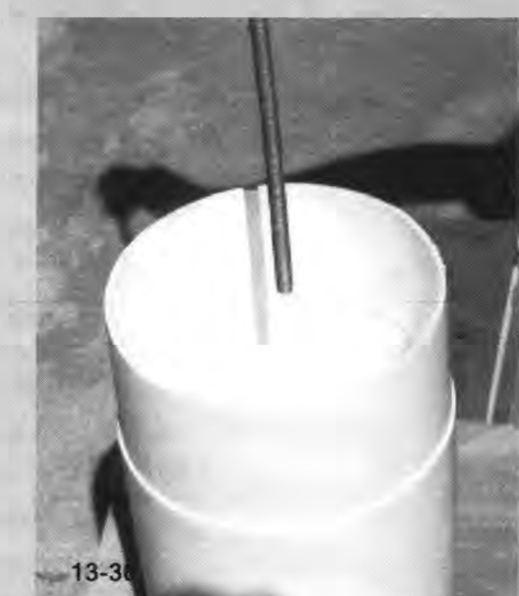
To handle deployment of the recovery system and to monitor flight information, an Olsen M1 altimeter and a blacksky Altacc altimeter were also installed. As noted in chapters 8 and 9, it is always a good idea to have multiple altimeters on board any large high-power rocketry project. Both altimeters would be fully set and armed to fire separate ejection charges at apogee and also at main. Hopefully, this would



Wiring from the timers in the upper payload bay passes through the aft bulkhead in the coupler. The wires are color-coded and braided together to ensure that the correct wires are placed in the right motors for the airstarts. The airstart wires are cut at this point, leaving several inches of stripped leads that will eventually be twisted together with leads traveling up from the aft end of the rocket.


13-34


13-35


13-36

ensure safe recovery of this expensive project. To gain easy access to all of the electronics on the pad, two hatches were cut into the upper airframe 180 degrees apart from each other. Each hatch was rectangular and secured in all four corners (and at the sides) by 6/32 screws and blind nuts. All four electronics units (the two timers and the two altimeters) were then placed around the circumference of the payload bay, with the two timers being attached directly to the hatches. This arrangement allowed for plenty of light and lots of room as the altimeters, and then the timers, were armed prior to launch.

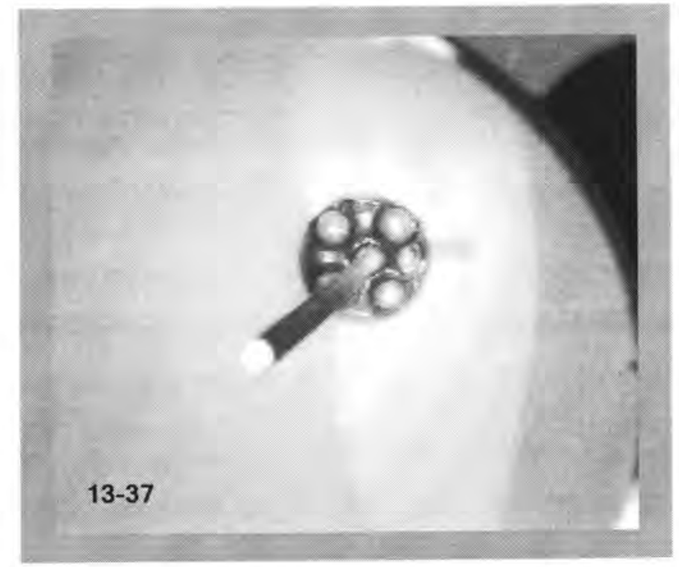
On launch day, the process of wiring the entire rocket was completed in less than an hour. We started with the timers in the upper payload bay and worked our way down toward the aft end of the rocket. The two wires from each side of each timer were braided together and marked for identification. Once all eight airstart wires were twisted together, there were four main leads. These leads ran down the interior of the electronics bay and emerged through holes cut in the aft bulkhead of the upper payload section.

As seen in photo 13-33, the bulkhead coupler from which the wires emerged was also the location of the ejection charges. To keep things neat and in order, small plastic clips from Radio Shack were placed on the inside walls of the coupler to secure the wires in a reasonable manner. The airstart wires were then cut, leaving approximately six to eight inches of free wire on the ejection-canister side of the bulkhead. The ends of all of these wires would then be stripped about one inch. These wires would eventually be connected to similar wires running forward from the aft end of the rocket.

At this point, we set the upper airframe aside. The booster section was turned over, exposing the seven motor tubes and the conduit openings in the aft centering ring. We tied eight more wires together in the same exact color pattern as the wires from the timers: Four more braids were created and then passed through the bottom end of the rocket, through the conduit, and into the main-payload bay

above the motor housing. The wiring extended, as it should, just beyond the end of the parachute/payload bay. The ends of the wires in the payload bay were then stripped about one inch.

Later, after the parachute was packed and just before the upper airframe was attached to the booster, the stripped ends of the wires from the upper and lower sections were twisted together–firmly, but not tightly. Then, a small piece of regular masking tape was placed on the exposed end of the wires. (Do not use electrician's tape, as it is too sticky and strong and may hinder the wires from pulling apart later.) These connections need to be tight enough to carry an electrical charge but not so tight as to interfere with deployment. When ejection charges in the bay are fired during flight, the upper and lower body tubes should pull apart, and the wires should then separate easily.


13-37


13-38

Maintaining Stability with Seven Motors

As discussed above, the stability of any clustered rocket should be evaluated prior to flight. The center of gravity should be at least one body tube diameter forward of the center of pressure. In this project, the weight of the seven K motors added nearly 21 pounds to the aft end of the rocket. Using the Winroc computer program, it was determined that the center of pressure was 108 inches from the nose cone. The center of gravity–due to the weight of the motors–was well behind the center of pressure. The rocket was unstable.

To correct this problem, weight was added to the nose cone. To accomplish this task, the shoulder of the plastic LOC 5.38-inch cone was sawed off, exposing the hollow core. A 3/8" threaded rod was then placed into the forward end of the cone, surrounded by several round, two-ounce fishing weights. The weights and the rod were then embedded in several inches of slow-drying, 30-minute epoxy. Prior to pouring epoxy and placing the weights, the inside tip of the nose cone was scuffed up with sandpaper to help improve the bond between the epoxy and the cone. See photos 13-34 through 13-37.

Large amounts of pooled epoxy can generate heat while curing–enough heat to deform a thick plastic nose cone. To guard against this problem, the tip of the nose cone was inverted and placed in a bucket of cool water while the epoxy set up. See photo 13-35. When the epoxy had set, there was an extra three to four pounds in the tip of the nose cone–more than enough to move the center of gravity forward of the center of pressure.

The 3/8" threaded rod also provided for a strong point of attachment for a recovery harness in the upper airframe, between the body tube and the nose cone. This harness could be used for either a main or drogue parachute, depending on flying conditions. A bulkhead was cut for the nose cone, and the rod ran through the center, as seen in photo 13-38.

Asymmetrical Thrust–Again

Asymmetrical thrust was a real concern for this rocket. The rocket had three K550s for takeoff, and it was important that all three of these motors light simultaneously. Each airstart sequence also had to be on time and occur when the rocket was in a stable, vertical flight. This required all motors to fire as planned–and on time. So a little extra effort went into the construction of each of the K motors.

First, the upper core of each motor was painted with a small amount of Pyrogen. Next, a sliver of Thermalite was bent into a small horseshoe shape and placed into the center of the top grain of each motor. In the alternative, a sliver of Blue Thunder propellant should work well here, too. Once fully inserted into the motor, the head of each igniter would be nestled between not only the Thermalite but also the Pyrogen-painted grain. This should be more than enough to start even the hard-starting K185s.

For even more insurance and to guarantee that the first three K550s would light effectively and at the same time on the pad, slivers of Blue Thunder were placed on the igniters, adjacent to the igniter head, before the igniters were pushed into each motor.

On the pad, red plastic caps were placed over the nozzles of each motor to secure the igniters in place. Finally, extra protection was provided to the exposed wiring for the airstarts. You should not leave igniter wiring for airstarted motors dangling from the bottom end of the rocket. This invites trouble in the form of burned-up wires that will prevent any airstarts. This was particularly important for our project, as the seven motors were packed very tightly in the 7.67-inch airframe. At launch, the three K550s would produce a very large, hot flame. So all exposed wiring was covered in heat-resistant tape and then secured to the aft end of the rocket with self-adhesive clips and more tape.

13-39

A look at the aft end of the rocket and the seven 54mm motor tubes that would hold the K motors.

The First Launch of the Rocket

The finished project weighed around 51 pounds on the launch pad and stood a little more than 10 feet tall. The airstart would go like this: At ignition, three K550s would light, followed by the airstart of two more K550s four seconds into the flight, and, then by two K185s eight seconds into the flight. One blacksky Timer 2 would handle the airstarts of the two K550s and the remaining Timer 2 would airstart the K185s.

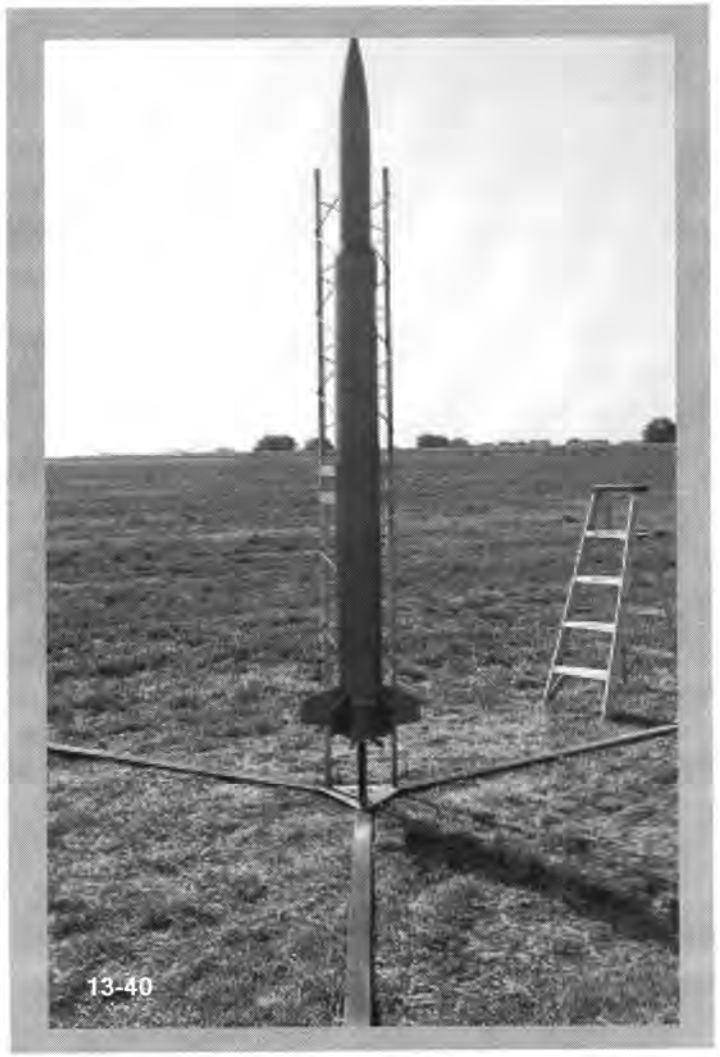
Be sure to consider the burn time of all the motors in the rocket when planning your airstarts. The timing delay of airstarted motors should not be too long. The rocket should still be in a solid, vertical trajectory when the extra motors come to life. If the airstart is delayed too long, the rocket may reach apogee and begin to turn over. This must be avoided.

In this case, the published burn times of the K550 and the K185 were 3.1 and 7 seconds, respectively. The timing of the airstarts allowed for a good boost phase, followed by a moment of coasting, and then renewed boost with a second moment of coasting, and then a third plume of white smoke.

At launch, the three K550s lit as planned, lifting the rocket effortlessly off the pad with a high-pitched whine. The motors burned out, and there was a brief coasting period–followed by the roar of two more K550s four seconds into the flight. At eight seconds, the final K185s roared to life. The total burn time was nearly 15 seconds, and the rocket reached an altitude just shy of 11,000 feet.

At apogee, the 16-foot military surplus main parachute deployed, setting the rocket down gently only a few hundred yards away from the launch pad.

Inspection of the rocket revealed that six of the seven K motors had burned. One K185 was still intact, right down to the tiny sliver of thermalite that had been placed in the top of the core prior to launch. Obviously, the igniter in the K185 did not fire. In fact, the igniter was gone.



13-40

The launch pad for the first flight: A pad with a big footprint and a unistrut rail attached to a radio tower. A ladder was needed to arm the electronics in the upper section of the rocket. The rocket weighed 51 pounds, loaded with seven K motors, on the pad.

In retrospect, we recalled that one of the red caps used to secure the igniters had been a little loose on the pad. Undoubtedly, it had fallen off during flight, and the igniter had simply fallen out–highlighting the importance of securing the igniter prior to launch.

For the next flight, a tiny spot of super glue was placed on each cap as it was secured to the nozzle of the motors.

This adhesive would keep the cap on the nozzle and would prevent the igniters in the airstarted motors from falling out of the motors under thrust of the three main K550s.

The Second Launch: LDRS20

The next launch of our seven-motor rocket was marred by a visit from a common high-power hobgoblin, drag separation.

At LDRS20 in Southern California, the rocket was once again loaded with seven motors–five K550s and two K185s. The firing sequence was the same. Three K550s would lift the rocket off the pad, followed by airstarts of two K550s at four seconds and two K185s at eight seconds.

Liftoff was spectacular. The three K550s lifted the rocket cleanly off the pad and into the desert sky. But then a strange thing happened. Almost immediately after the first three motors shut down, the lower, booster section of the airframe (holding all of the motors) and the upper airframe separated. And in the split second that it took the rocket to separate, the next two K550s roared to life.

The rocket careened all over the sky under the full thrust of the last two K550s. The upper and lower sections–now fully separated–remained connected by the long recovery harness as the main parachute deployed. It was quite the show as the rocket settled down for an uneventful landing. The last two K motors did not light, since the wiring connection had been broken when the rocket separated. The only real damage was a six-inch zipper in the booster section of the rocket, caused by early deployment under thrust.

At rest after the first flight. Initially, it appeared all seven motors had fired. Closer inspection revealed that one of the airstarted K185s had not fired, because the igniter had slipped out under thrust. Still, the rocket reached nearly 11,000 feet.

What happened? It seemed pretty clear that drag separation had caused the lower half of the rocket–which still contained four motors–to simply fall behind the upper airframe. When the thrust of the first three K550s suddenly stopped, the upper portion of the rocket simply pulled away from the booster.

This occurred, in retrospect, partly because of steps taken immediately prior to launch that were not taken at the time of the first launch.

As the rocket was being prepped at LDRS20, the coupler of the upper airframe was very tight as it was pushed into the booster. In fact we almost could not get the two sections together. We were concerned that it was so tight that it might not separate. To correct this problem, a thin sheet of household wax paper was wrapped around the coupler. The wax paper allowed the coupler to slide in and out of the lower booster with ease. Too easily, as it turned out.

This problem could have been avoided. Drag separation is not uncommon in high-power rockets, especially in rockets with large fins or, in this case, many fins. Four or five nylon shear pins placed in the rocket where the booster and the airframe meet would have kept both sections of the airframe together long enough for all of the motors to light. The shear pins would have then snapped apart after the ejection charges in that section of the rocket were fired much later in the flight.

Airstarts and Multi-Stage Rockets

A multi-stage rocket has two or more sections, each section containing its own motor. In most respects, the average multi-stage rocket has the same design and construction requirements as an ordinary airstarted rocket.

A two-stage rocket has two sections, the booster and the sustainer. The booster is the lower portion of the rocket. It may or may not be aerodynamically stable by itself. It has its own set of fins (usually), its own motor mount and its own issues of

High-power camera expert Doug Gerrard, left, and friend Dave Flynn with Flynn's two-stage rocket at DairyAire 2003 in Central California. The rocket carried one of Gerrard's 16mm movie cameras.

motor retention. It may or may not carry its own altimeter and recovery devices.

The booster carries the first motor (or motors) ignited on the pad. Once the booster is ignited, it carries the rocket into the air until the first motor burns out. At that point the booster will usually fall away from the rocket and the upper portion, or sustainer, will take over.

The sustainer is usually a rocket in and of itself: It has its own set of fins and, unlike the booster, its own nose cone. The sustainer carries the motor (or motors) that will thrust the rocket to its highest point. The sustainer must be aerodynamically stable, as discussed below.

"Code Red," a multi-stage rocket built by California FirefighterTony Alcocer and his son, AJ.

The Advantage of Multi-Stage Rockets

As Ray Dunakin noted in *Staging High Power Rockets*, "the advantage to staging is that the booster imparts speed and altitude to the sustainer, without requiring the rocket to carry the extra weight and drag [of the booster] all the way to apogee. This can result in higher altitudes for the rocket than could be achieved by a single motor, or even the same cluster of motors."

Ignition of the sustainer motor is carried out in the same, or similar, manner as ignition in any airstarted rocket motor. An on-board timer, often referred to as a stager, will ignite the sustainer motor during flight. Sometimes this is a certain time–as when the timer is programmed to fire the sustainer igniter four, five, or six seconds after takeoff of the booster. In other cases, the timer will not fire the sustainer motor until after the electronics detect actual burnout of the main motor. Some timers, like the G-Wiz flight computer, can do both.

Generally, observed Dunakin, staging at burnout of the booster will result in a *faster* flight than staging later in the flight (during coasting).

However, waiting a few seconds after burnout to stage the second motor should result in a higher *altitude* for the sustainer.

For newcomers to staging, Dunakin recommends staging at booster burnout: "If the rocket stages too soon, the worst that can happen is that the sustainer will achieve a lower altitude than planned. But if the sustainer ignites too late, it can go off when the rocket is at apogee or past apogee, resulting in the total destruction of the rocket and a risk of damage or injuries on the ground."

This is good safety advice to follow at least until you become fully familiar staging.

Aerodynamic Stability

Evaluating the center of gravity and the center of pressure in a multi-stage rocket is a little bit different than in a single-stage design. This is because in some respects the average two-stage rocket is really two rockets: The first rocket is the booster and sustainer together. The second rocket is the sustainer alone.

To ensure stability of your project, the center of pressure and center of gravity measurements must be made with the rocket in its multi-stage configuration (booster and sustainer together) and with the sustainer alone. This involves two separate measurements. First, the center of gravity for the enitre rocket must be one airframe diameter forward of the center of pressure for the entire rocket. Next, the booster must be removed and the same calculation must be made for the sustainer alone.

The reason for this is simple: At some point in the flight the sustainer will separate from the booster, and so the sustainer must be aerodynamically stable on its own.

But what about the booster? Does it have to be stable in and of itself? The answer to that question, in most cases, is no. Once the booster separates from the sustainer, its aerodynamic flying time is over. It simply falls away and begins its descent by parachute.

The determination of the center of pressure and the center of gravity in a multi-stage rocket is discussed in Chapter 1. Computer programs such as RockSim are the best way to locate the center of pressure on your rocket. And adding weight to the nose or foward end of the rocket is the easiest way to affect the center of gravity.

Motor retention is always a big issue for the sustainer in a staged rocket. Some rocketeers use set screws, while others use more traditional means to hold the motors in place. In this example, Richard Salinas uses a single bolt and washer secured to a wooden backing to hold in place four reloadable H motors.

Do not overlook this very important step, even in multi-stage rocket kits (which are presumably stable from the maker with the recommended motors installed). As G. Harry Stine noted in the *Handbook of Model Rocketry*: "I've seen just about everything happen to a model rocket in flight, but the most frightening is a two-staged model that lifts off, becomes unstable, thrashes around in the air 25 feet above the launch pad, stages and then becomes stable, usually pointed down! So check stability, please!" This is even more important in high power, since the motors and the rockets are so much larger.

Igniters in the Multi-Stage Rocket

As with any multiple-motor project, the use of quality igniters is especially important for the sustainer motor that is airstarted. If you are using electric matches, augment them (unless the sustainer motor is an H or smaller). Be sure the igniter will remain secure in the motor after takeoff. Use tape or a plastic cap or some other means of fastening the igniter to the motor.

The Interstage Coupler

The interstage coupler is that part of the rocket that connects the booster to the sustainer. The design of the interstage coupler is one of the more challenging issues in multi-stage construction.

In the typical in-line or series-staged rocket, with a booster directly below the sustainer, the interstage coupler is nothing more than a short section of airframe coupler tube that sits within an even shorter piece of regular airframe tube. See photo 13-45. The coupler is similar to two of the altimeter bays discussed in Chapter 9. In this photo of the booster section of a Public Missiles Systems two-stage rocket, the interstage coupler has been placed on top of the airframe. The coupler houses the timer or stager and is connected to the booster by a recovery harness. The recovery system for the booster is activated by motor ejection and a PML piston.

Another design for an interstage coupler is the rod type. See photo 13-46.

In this design, rods attached to the tip of the booster extend into sheaths or tubes affixed to the outside lower end of the sustainer. At separation, the rods slip out of their tubes, and the sustainer moves forward. The rod-style coupler joint is especially useful in modified rockets that were not originally intended to be multi-stage. In many rockets, the interstage coupler also functions as a payload bay for the timer/stager.

In this design, the bay must allow the igniter wire to pass from within the bay to the motor in the sustainer. At the same time, the bay must be protected from the exhaust flame of the motor directly above it. This is usually accomplished by installing a sturdy bulkhead and sealing all holes.

In the alternative, some rocketeers prefer to place the timer in the sustainer. This way, noted Dunakin, if the booster separates prematurely, it will not affect the ignition of the sustainer.

Recovery Issues

In multi-stage model rockets, tumble recovery is often used for the booster. This may work in lightweight rockets, but the better method in high-power rocketry is to provide for separate parachute recovery for the booster and, of course, the sustainer.

For the booster, you can install an altimeter bay if you have the room, or rely on motor-based ejection.

The sustainer can be built for single or dual deployment. Keep in mind that, if your multi-stage rocket works as planned, it will achieve some serious altitude. So install a beeper or transmitter in the sustainer to help you find the rocket after launch.

For more information on electronics and altimeter bays, see chapters 8 and 9.

Case History

Multi-stage CALIFORNIA

My name is Richard Salinas, and I live in Fresno, California. I am a member of the Tripoli Rocketry Association, and I have my Level Three certification. My home club is Tripoli Central California, and we launch at the Maddox Dairy in Riverdale.

Although I enjoy launching single-stage rockets, I wanted the extra challenge of a multi-staged and airstarted rocket project. There is just something special about working through the calculations to get the stages (and airstarts) timed right and getting the electronics to make it all happen. When everything works right, there is a great deal of personal satisfaction, and the crowd here appreciates it as well!

The rocket I built was a two-stage project made from scratch. My goal was to launch it with a K550 in the booster and four H180s in the sustainer. I would airstart the H180s two at a time.

The biggest challenge in construction was making the interstage coupler. I wanted a smooth transition that would separate easily, but it had to be strong, too.

I used a four-inch coupler tube as the main component for the interstage coupler. But the problem was how to get the coupler to fit into the aft end of the sustainer. As with most rockets, the sustainer would usually have a centering ring at the end. This ring would not allow a coupler to fit into the sustainer.

The fix was to eliminate the aft ring from the sustainer and replace it with a ring placed four inches higher up in the main airframe. Above this ring I added extra centering rings and expanding foam for strength. Probably overkill, but I wasn't going to take any chances.

To make sure that there would be drag separation before the first pair of sustainer motors lit, I added a plastic ring that attached to the interstage coupler on the outside. My thought was that this would add a little extra drag to the booster section and help separation go as planned.

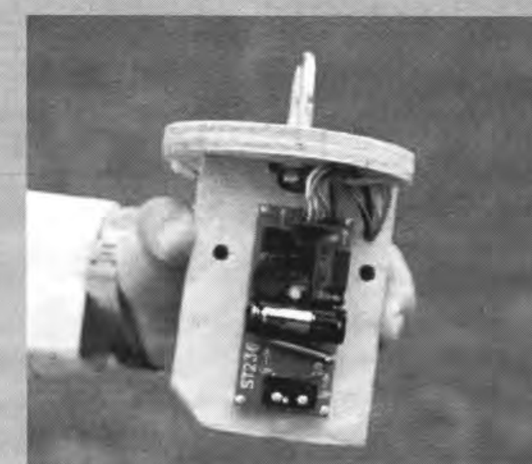
When the project was finished, the rocket stood more than nine feet tall and weighed about fifteen pounds, unloaded. The booster, which held no electronics, carried a six-foot military parachute that was deployed with motor ejection. The sustainer held an Olsen altimeter for the ejection charges and an Adept two-event timer to airstart the H180s. The sustainer also carried a Rocketman drogue parachute and a Rocketman 9c main parachute.

To help ensure that the sustainer motors lit on time, each igniter for the H180s was dipped in pyrogen.

The flight was terrific. I launched the rocket at a big three-day event, and there was a nice crowd. The weather was near perfect, and the Aerotech K550 lifted the rocket off the pad in a rush. There was a trail of thick, white smoke that filled the sky. The first two H180 motors in the sustainer fired at three seconds after booster burnout, and the second pair of motors fired about two seconds later. Recovery was perfect.

It was a fun project to put together and launch, and the challenge of it all keeps me interested in high-power rocketry.

My advice for others in high power is Do not be afraid to try different things. Just go for it, and challenge yourself. The sense of satisfation after a job well done is always worth it.



The DETAILS

Both Tripoli and NAR require basic construction information and anticipated performance data for the Level Three certification rocket. The data includes center of pressure and center of gravity calculations, sample construction photos, rocket weight and expected altitude, motor size, and deployment plans. Some of these details can be obtained from rocketry software programs, such as RockSim, Wrasp or SpaceCad. Copies of this information are provided to the certifying officer. The applications for Level Three can be found online at the web site for either NAR or Tripoli.

14

Level Three and Beyond

Welcome to the leading edge of high-power rocketry

The purpose of this chapter is to review and compare the requirements for Level Three certification between NAR and Tripoli. This chapter also provides practical information to help rocketeers reach Level Three safely and on their first attempt.

The Basics

Level Three is the pinnacle of high-power rocketry. It allows rocketeers to launch rockets equipped with M motors or larger and generally involves the most expensive and sophisticated rockets in high power.

14-1

Blake Prince, right, with son Wes and Blake's Level Three certification rocket at LDRS23.

The basic requirements necessary to achieve Level Three are substantially the same with both Tripoli and NAR. As a preliminary matter, the rocketeer must be a member of one of these two rocketry organizations. Membership is typically open to all adults, and the specific requirements for each organization can be found online at the website for NAR at www.nar.org or for Tripoli at www.tripoli.org.

Prior to a Level Three attempt, candidates must also attain Level One and Level Two certifications. As discussed in previous chapters, Level One is achieved by successfully launching and recovering a high-power rocket on an H-class motor, single-use or reloadable. Level Two

14-2

Once Level Three is attained, the only limit to a rocket's size or design is your imagination. Here, team leader Kimberly Harms stands next to a full-scale Honest John built by the Community Space Program in Washington state. This rocket weighed more than 700 pounds and flew in Northern Nevada in 2004.

is obtained by launching a rocket using a motor with at least 640.01 newton-seconds of impulse (usually a J motor or larger) and by passing a written examination. Once Level One and Level Two certification are attained, the rocketeer is eligible for a Level Three attempt.

The Paperwork

The first step in any Level Three certification attempt is to obtain the appropriate documents from either Tripoli or NAR. Both clubs offer their Level Three applications online, but there are significant differences in the paperwork, and the forms between the two rocketry organizations are not interchangeable.

The Tripoli application is known as the "Level 3 Data Capture Form." This form must be filled out prior to any Level Three attempt and submitted to two Tripoli advisory panel members (also called TAP officers) 30 days prior to flight. Both TAP members will sign off on the document if the rocketeer has satisfied the application and construction requirements for Level Three. One of the TAP members must also witness the successful flight and recovery of the rocket.

Locating TAP members is not difficult. A current list is available by logging on to Tripoli's website. If the Level Three flight is successful, the paperwork is submitted by the applicant to Tripoli headquarters for certification.

14-3

NAR follows a similar procedure but the paperwork is a bit more extensive. Currently, NAR requires completion of two forms. The first form is a two-page document known as the "NAR High Power Certification Application." The second form is a one-page supplement. Both forms are available online as are the rules and regulations for Level Three certification. The NAR paperwork must

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Case History

Level Three UK HYBRID

My name is Steve Gibbings, and I am a member of the East Anglian Rocketry Society (EARS), which is affiliated with the United Kingdom Rocketry Association–the British version of Tripoli and NAR. I am 37 years old, and I live in the village of Gravely near Hitchin, Hertfordshire.

My passion for rocketry began when I was only 13 years old, and I discovered an article on rockets in a back issue of *Scientific American* in the school library. Later, I found my way into model rocketry. From there I made the move to high power pretty quickly as my model rocket club also did high power. I was very impressed with the high-power rockets in the club and just had to have a go at a big kit--so I obtained my Level One.

Photo Courtesy of Bob Arnott

My Level Three project was built from scratch and would be powered by a hybrid motor. I chose a hybrid because it is a lot cheaper per flight once the ground equipment and basic motor system are purchased. I also enjoy the process of filling the nitrous tank and watching the gas vent on the pad just before launch of the rocket.

For my Level Three flight I chose a Hypertek 75mm M960. For the six-inch diameter airframe of the rocket, which I named Tinnitus, I used filament-wound fiberglass, which came from Hawk Mountain in the United States. Hawk Mountain also provided the fiberglass fins. Centering rings for the airframe and an aluminum back plate were purchased from Precision G10.

For recovery, I chose parachutes and recovery harnesses from B2 Rocketry and I picked up two RDAS flight computers from Pete's Rockets here in the UK.

As an extra bonus, I included an on-board video camera to capture the flight. When I finished the rocket, it stood nearly 12 feet tall and weighed more than 50 pounds on the pad.

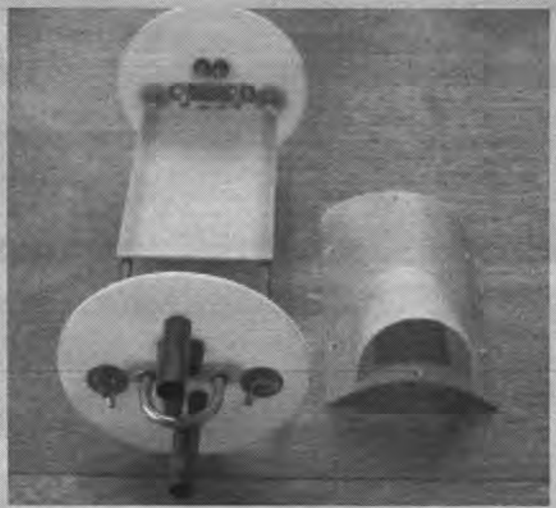
I faced a couple of big hurdles on the way to certification.

First, it was not that easy to get all of the materials. Although high-power rocketry in Great Britain is growing, it is not as large as the rocketry community in the U.S., and so the backup for parts and motors is not as readily available.

The second hurdle was more personal: I lost the use of one arm in an accident several years ago, and this made it necessary to think through every construction and launch task in a very detailed manner, and to run a few trials to make sure I could do everything. Fortunately, I also had the support of many friends in high-power rocketry, and they helped me along the entire path.

The easiest part of reaching Level Three was launch day! The launch was at the EARS site in Cambridgeshire in October 2003. The site is near Cambridge in a rural area where one of the local farmers has made a deal with the club and allows us to fly.

I had meticulously planned every step, and I had a lot of help once I had assembled the rocket. But I did have one little problem that almost stopped everything.



I had some Nox and cable tie problems on the pad, and the rocket suddenly shot up the rail about 11 feet–but luckily it never left the pad. The RSO did not have to treat it as a failed launch (which would mean I would have to wait another day) and so we re-packed everything and set it up again.

This time the rocket left in a rush. The 50-pound hybrid reached nearly 6,000 feet, and the RDAS units worked well. The B2 SkyAngle drogue and main parachutes brought it all back in perfect condition.

My advice on reaching Level Three? Listen to what others have to say, but be sure to research everything on your own before you actually start work. I researched and tested every component down to how long the batteries would last and still give a reliable current for the igniters. If you do not *know* something is safe and reliable, then do not use it.

be completed prior to flight, and the application is then submitted to a Level Three Certification Committee (L3CC) member, who signs the documents, certifying proper completion of the forms and appropriate construction of the rocket.

As with Tripoli, an L3CC member and another witness (who is a member in good standing of the NAR) must be present to attest to the pre-flight preparation, flight, and safe recovery of the rocket on launch day. The forms are then returned to the NAR for certification.

The applications for both Tripoli and the NAR require the rocketeer to provide basic construction information and anticipated performance data for the rocket and its flight. This data includes, among other things, information about the rocket's center of pressure and center of gravity, construction photographs (a sample or two), rocket weight, motor size, deployment plans and altitude calculations. Specifications for the rocket's anticipated performance, including velocity and altitude, may be obtained using readily available simulation programs, such as Winroc, RockSim, or SpaceCAD. Copies of the flight simulation and other launch characteristics are usually printed right off the rocketeer's computer and then handed to the TAP or L3CC member along with the application for certification.

Although the overall process is similar, there are significant differences in the application information that must be provided to both Tripoli and NAR in advance of a Level Three attempt.

For example, Tripoli's Data Capture Form requires the rocketeer to calculate and provide the precise thrust-to-weight ratio of the rocket with the anticipated motor for the Level Three flight. NAR does not specifically require this information on the application, although as a practical matter, rocketeers should make this calculation for every rocket flown, especially Level Three projects. A proper thrust-to-weight ratio helps ensure that the rocket will have a stable trajectory. NAR does require its Level Three candidates to provide information to their L3CC to indicate that the flight is likely to be stable.

Canadian rocketeers help load Rick Dunseith's N-powered (Cesaroni) rocket on the pad at LDRS23 in Geneseo, NY.

NAR, on the other hand, requires its Level Three applicants to calculate the rocket's anticipated descent rate. The descent rate must not exceed 20 feet per second for any component weighing more than eight ounces. Descent rate calculators are available online and are an important component to any launch. An improperly sized parachute can lead to a hard recovery and significant rocket damage, particularly with large rockets and in hard landing areas. This can turn an otherwise good flight into a Level Three failure. So even though this is not a requirement with Tripoli, calculating the descent rate is good practice prior to the

flight of any large project. For an example of completed Tripoli and NAR Level Three applications, see Appendixes 4 and 5.

The Reloadable M Motor

Choosing the right motor for a certification flight is the same as picking a motor for any high-power launch. Personal preference and familiarity with a given manufacturer play a role, as do price and availability of casings and reloads. Some rocketeers certify with smaller and less expensive--but very powerful--motors such as Aerotech's 75mm M1315 or the Animal Motor Works 75mm M1350, while others break the bank with upper-end M or even N motors on their first Level Three flight. No matter what motor you choose, there are some important rules to keep in mind.

Roger Noss with his L3 Talon 6 in Florida.

First, the motor in a Level Three certification flight must exceed 5,120.01 newton-seconds of total impulse. This means an M motor, or larger.

Next, motors must be approved by Tripoli or the NAR. Experimental motors are prohibited for a certification flight by both rocketry organizations.

Although there is no requirement that a particular manufacturer be chosen, Level Three attempts are commonly flown on motors from manufacturers such as Aerotech, Animal Motor Works, and

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The MOTOR

The motor for a Level Three certification flight must have a minimum of 5,120.01 newton-seconds of total impulse. There is no requirement that a motor be from a certain manufacturer. The most common motors used for Level Three certification flights are made by Aerotech, Animal Motor Works, and Cesaroni Technology. These three makers provide solid-fuel motors in the 75mm and 98mm diameter range. Hybrid motors can also be used to certify, provided they meet the minimum newton-second requirements.

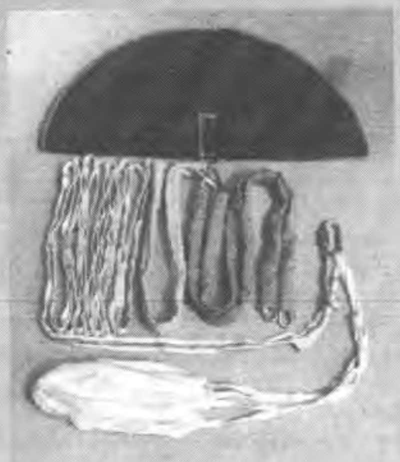
Case History

Level Three DOWN UNDER

My name is Scott McLeod, and I live in Fairfield, New South Wales, Australia. I am 37 years old. I fooled around with model rockets, on and off, through high school. The last model rocket I built was an Estes Goblin. For some reason I never flew it, and I drifted away from rocketry to cars and motorbikes.

Many years later I was inspired to fly the Goblin, which had sat on various bookshelves ever since I built it. I built some more rockets and joined Tripoli and a local club, the New South Wales Rocketry Association.

After my L2 flight I decided that I would take up the challenge of Level Three. Prefect David Wilkins of Australia had completed his Level Three at LDRS in Kansas and was also a TAP, which meant that it was indeed possible to certify Level Three in Australia now that it was confirmed we could get the big motors here.



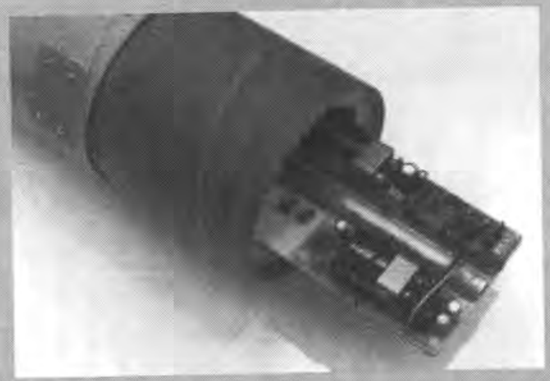
The L3 rocket was a modified LOC custom engineering K-Load kit that I modified for the flight. It was one of the few kits that had a 98mm motor mount and I liked the clean, simple styling. I drilled two vent holes in the main and drogue parachute bays to avoid premature separation of the airframe components during boost. I also used West System fiberglass for the airframe glass work. An Aero Pack motor retainer held the motor in place (with a Slimline motor adapter to reduce the 98mm mount to 75mm).

The paperwork seemed daunting at first, but after a while I saw it as a challenge to make my description of the rocket as complete as possible, and the characterization in the simulations as accurate as possible. During this time I had gained a lot of experience with RockSim, electronics, and also with construction methods on smaller rockets.

The flight would be from a farm near Serpentine, Victoria. This is a wonderful place to fly rockets! The waiver is more than 10,000 feet (with windows to 25,000 feet) and the land is as flat as a tack for as far as you can see. And best of all, the owners, the James family, really make us feel welcome there. It's a 600-mile drive each way, but it's worth it!

The day of reckoning was stressful. From first thing in the morning, it was blowing a gale like we'd never seen at Serpentine before. My friend, Les Morton, and I were dubious whether we would get to launch at all. I'd launched it on

the computer at up to 25mph, and I knew it would be okay, but when you have to make the call, it's still somewhat nerve-racking. I had an awful lot of time, money, and effort riding on this flight. I didn't want to let "go fever" overrule common sense. But I really felt that it would be okay.



When the Aerotech M1315 came up to pressure, the first thought that popped into my head was, "How can anything make that much noise and not explode?" quickly followed by "How come that flame is pink and green?" Of course, what I was seeing was an after-image on my retinas like the one you get from a photo flash. It really was *that* bright. I was delighted to see that my modified LOC/Precision K-Load held together through Max-Q and beyond. Now I just had to wait for an apogee event.

The main-ejection charge blew off the nose cone at 1,000 feet, deploying the pilot chute, which immediately dragged the R14 parachute into the air. Touchdown occurred just inside the fence of the same paddock we launch from, less than a mile away.

There was no structural damage of any kind, and apart from some question as to the effectiveness of the drogue in the prevailing conditions, David Wilkins was happy to sign off my Level Three Data Capture Form. (Kevin Harness had previously signed off my form after reviewing my documentation and construction photos via mail.)

I was very pleased with the altitude: The Missile Works RRC2 said 12,247 feet, and the Transolve P6 said 12,200 feet.

The most enjoyable aspects of certifying Level Three were not only the satisfaction of pulling off a successful flight of the biggest, heaviest, and most powerful rocket I'd ever flown, but also of becoming the first person to do so in Australia.

There are at least three more local Level Three projects underway at the moment, and I feel privileged to have helped open the door for others to attain this goal without having to travel overseas.

Photos courtesy Scott McLeod

The COST

The cost of a Level Three Certification project depends on the individual rocketeer. At a *minimum*, a Level Three reloadable motor, without the case, costs at least $250 to $350. The cost of the reload casing, closures, and electronics, can add several hundred additional dollars to the project (aside from the cost of the rocket itself). However, the project does not have to be expensive. Casings can be borrowed or shared among friends. And the cost of electronics and recovery equipment can be allocated among several rockets, making the total cost to reach Level Three a lot cheaper. See the next chapter for suggestions on how to build your Level Three project for around $300.

14-7

Cesaroni. These motors are usually in the 75mm to 98mm size and range in price from $250 for a lower-impulse M to more than $600 for a full N motor, reload only. Hybrid motors are also gaining in popularity for Level Three certification, provided they exceed the minimum size in newton-seconds.

Multiple Motors on a Certification Flight?

The use of clusters in Level Three certification is limited. In fact, NAR prohibits the use of a cluster to obtain certification. To certify Level Three for NAR, the rocket must be flown on one motor only.

The rules for Tripoli are slightly different. Although Tripoli does not allow clustering to reach the minimum requirement of 5,120.01 newton-seconds, clusters are allowed if the extra motors are necessary for the rocket to obtain the proper thrust-to-weight ratio for the flight.

For example, Tripoli would allow the use of three K700s around a central M1315 in a Level Three attempt if the rocket is too heavy to be safely lifted on the M1315 alone. The NAR has no similar allowance for cluster use.

Multi-stage flights, on the other hand, are prohibited by both Tripoli and the NAR for Level Three certification flight. There are no exceptions. Of course, once Level Three certification is obtained, clusters and multi-stage rockets with M motors or larger are allowed by both organizations.

Electronics and Recovery

Tripoli and the NAR both require that electronics be used to deploy the main parachute in a Level Three attempt. This is usually accomplished with an on-board altimeter.

However, NAR has an additional requirement for L3 deployment. To certify with NAR, the

Continued on page 266

Level Three at a Glance

ITEM	TRIPOLI	NAR
1. Certification officer	TAP Member	L3CC Member
2. Paperwork	Data Capture Form	NAR High-Power L3 Certification Application + Supp.
3. Paperwork deadline	30 days before flight	5 days before flight
4. Minimum motor size	5120.01 n-sec	5120.01 n-sec
5. Built from kit?	Allowed	Allowed
6. Electronic recovery	Mandatory	Mandatory
7. Redundant recovery	Suggested	Mandatory
8. "Safed" ejection	Not required	Mandatory
9. Descent calculations	Not required*	Mandatory (20fps)
10. Estimates re CG, CP, velocity, etc.	Mandatory	Mandatory
11. Thrust-to-weight calculations	Mandatory	Not required*
12. Minor damage	Discretionary	Discretionary

This chart is not intended as a substitute for the actual certification rules set forth by NAR or Tripoli. It is a quick reference guide summarizing the rules as they were posted at the time of publication. Always double-check the certification rules on the websites of NAR or Tripoli for the most recent updates.

*Although NAR does not explicitly require the thrust-to-weight ratio on its form (as does Tripoli), most L3CC members will require you to provide that ratio to demonstrate that the rocket is stable and will have a safe flight. The same is generally true for descent-rate calculations with Tripoli members who will certify Level Three.

Diagram 14-1

Case History

Level Three PERSISTENCE

My name is Andrew Tryon. I am 38 years old and I live in Washington. My interest in high-power rocketry began about eight years ago when a very good friend named Dave Eckhart invited me to a rocket launch. Dave has been flying rockets for decades and knowing of my interest in aviation and model building, he figured that I would be interested in model rocketry. I took to it like a duck to water.

I quickly progressed from the Estes kits to the more advanced PML kits. For me, rocketry was just an extension of my model building. I get as much enjoyment out of building them as I do flying them. After about four years I decided that it was time that I became "official," and I joined Tripoli.

Photo by Nadine Kinney

Level One and Level Two were slam dunks as I already had several proven airframes. However, Level Three proved much more challenging. Aware of my preference for kits, Dave suggested that I check out Maximum Thrust, and I quickly settled on their 10-foot-tall, 9.25-inch-diameter Hawk rocket, a 60-percent scale replica of an Army Hawk missile.

My guiding principles in the construction of this rocket were threefold: First, structural integrity. Second, electronic redundancy. Third, ease of access for the electronics bay.

The rocket was built with extra centering rings and double-thick reinforced bulkheads. It was covered in three layers of 6-oz fiberglass. This "over-construction" came at a cost in the form of extra weight, and due to the large amount of fin surface, the CP for this rocket was considerably forward. As a result, it took a 45-pound nose cone to obtain a proper CG. The total weight of this rocket, without a motor, was 105 pounds. This extra weight would come back to haunt me when I launched the rocket.

My first attempt at Level Three certification was in June, 2003, at Lucerne Dry Lake in California. The tower-based launch seemed to be plagued from the start. The Olsen FCP-M2 (primary) altimeter and the Missile Works RRC2 (backup) altimeter armed properly. However, the Missile Works remote-control deployment unit malfunctioned, blowing the deployment charge twice. The rocket was launched without it. The M2500 lifted the heavy rocket with ease. But the main chute deployed at apogee along with the drogue. Unfortunately, because I had anchored the nose cone to the reinforced bulkhead deep within the rocket, the rocket suffered two nasty zippers, thus failing to achieve certification.

In June 2004, I was back for another try. With the addition of a Giant Leap Rocketry anti-zipper ball, I was sure that the zipper problem was solved. To keep it simple, I eliminated the dual deployment. The boost on the M2400 was once again flawless. Unfortunately, the anti-zipper ball stretched enough to pull completely out of the rocket, allowing another zipper, resulting in a no-cert.

In November, 2004, I drove from my new home in Washington to Rocstock in California for another attempt.

To prevent another zipper, I put a metal band around the lip of the rocket and repositioned the anti-zipper ball. Acting on advice from Wedge Oldham, I increased the length of the recovery harness from 30 feet to nearly 78 feet. Acting on advice from Carl Delzell, I fan-folded my shock cord and wrapped a band of tape around it every three or so folds.

The third flight was a heart-stopper. The rocket lifted off on an M1939 and weather-cocked right off the rail. The rocket hit apogee and began to descend without deploying the parachute. The Hawk was one-quarter of the way down before the nose cone was blown off. It was nearly halfway to earth before the chute fully deployed and the rocket swung underneath it.

Was there any damage? Had the changes worked?

A group of my friends and several spectators reached the rocket before I did. I tried to judge their reactions, but to no avail. The Hawk had been dragged 4 or 5 feet and was half buried in sand. It was not until we lifted the rocket and dumped out the five or six pounds of dirt that we were able to tell that the rocket was completely undamaged! Despite the weather-cock, the rocket had achieved an altitude of 2,269 feet.

Later that day, after the flying was done, and my paperwork had been signed off, we popped the corks of several bottles of wine and toasted our success.

(Photos on this page courtesy of Andy Tryon.)

14-8

The view from below: Andy Tryon and crew lower his Level Three certification attempt Hawk missile onto the tower in preparation for launch. Level Three rockets may launch on towers, rods, or rails, depending on the preference of the individual rocketeer. Photo courtesy of Andy Tryon.

rocketeer must have a backup system for parachute deployment. This requirement helps ensure that, if the primary ejection charge fails for any reason, the parachute will still be deployed by the backup. NAR rules allow for the backup charge to be motor-based, although as a practical matter most backup systems for Level Three flights are controlled by on-board electronics. This is because most, if not all, commercial 75mm and 98mm motors are plugged, with no provision for motor-based charges.

Tripoli does not *require* backup systems for Level Three certification.

Instead, Tripoli's rules provide that backup systems are "strongly encouraged." Since Level Three rockets are generally large and expensive projects, common sense dictates that backup ejection charges always be used.

14-9

Gary Vielbaum of Burlingame, California, with his Level Three Black Brandt on M power.

"Safing" Ejection Charges

In an NAR Level Three certification flight, the rocketeer must be able to externally disarm all ejection devices in the rocket. This is also known as the ability to "safe" the ejection charges in the rocket.

This means that the rocketeer must be able to disarm the rocket's ejection charges by physically breaking the connection between the charge and its power source. This entails more than just turning off an on-board altimeter. Typically, safing is accomplished by wiring the ejection charge through a phono jack or external switch that can be armed or disarmed from outside the rocket.

The safing requirement is not found in the Tripoli Level Three certification rules, but it is not a bad idea for all high-power rockets. Ejection charges can be dangerous, and they have been known to go off

accidentally while the rocket was being loaded on the pad or during final assembly of the component pieces on the field. A safe switch is an extra bit of insurance that protects not only the rocketeer but also spectators in the area. The only drawback to "safe" ejection charges is that the addition of an extra switch in the altimeter/ejection charge circuit is one more point where failure can occur.

14-10

Keith Gaillard of New England with the altimeter bay for his Level Three rocket. His attempt was successful on hybrid power at LDRS23.

Team Projects and Kits

A group of individuals cannot certify Level Three with the same rocket. Both Tripoli and NAR require that the rocket be constructed by the certification applicant.

NAR's language is specific: The rocket must be "substantially built" by the certifying flyer. "Substantially built" means (1) fabrication of the engine mount with centering rings, if applicable; (2) alignment and mounting of the individual fins (prefabricated fin cans are specifically disallowed); (3) installation of attachment points for the recovery system; (4) mounting and installation of airframe electronics; and (5) final flight preparations, including pyrotechnic installation, recovery system packing, motor assembly, and motor installation.

Do these rules mean that Level Three certification rockets cannot be based upon or built from kits prepared by commercial manufacturers? The answer to that question is no.

There is no rule that Level Three projects be scratch-built. Indeed, NAR specifically provides that certification rockets can be built from commercially manufactured kits and may also "contain components built to the specifications of the certifying flyer but fabricated by others." These components include, but are not limited to, electronics, recovery systems, motor mounts, and fins.

Tripoli has no similar rule on this point, but there is nothing in the Tripoli Level Three rules that would

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Start EARLY

People who are serious about certification should present their paperwork to their TAP or L3CC member as far in advance as possible. This ensures that any glitches in the paperwork or the rocket can be corrected in time to launch on schedule. Candidates who are planning to certify Level Three at a large regional or national launch should also check with the local club to make sure the event will have the necessary equipment for their Level Three project. Do not wait until the last minute. You may end up disappointed.

Case History

Level Three NAR ORANGEBURG

I'm Mike Scicchitano, and I live in Florence, South Carolina. In February of 2003, I had a conversation with my high-power rocketry mentor, Rich Pitzeruse, discussing my National Association of Rocketry Level Three attempt at the August Freedom Launch in Orangeburg, South Carolina. While surfing the web one night, I came across the home page of Skunk Works Rocketry, where I fell in love with their 10-inch Bullpup kit. Rich and I decided it would be a good kit for me since it came with a fiberglassed body tube and a fiberglass nose cone. Now all I had to do was convince my wife. She agreed, so I placed the order that night.

This was by far the largest and heaviest rocket I had ever built, and there were several challenges I had to meet and overcome. The first challenge was to make sure the center of gravity and the center of pressure were in the right places on the rocket. During construction I had to add a lot of weight to the huge nose cone to ensure that the center of gravity would be at least 10 inches in front of the center of pressure. To accomplish this, I placed about 10 pounds of small sandbags into the tip of the nose cone. The sandbags were held in with fiberglass.

The next problem involved deployment and recovery. The rocket weighed in at 65 pounds, loaded, including the 16-pound nose cone. I needed to make sure that it all came back to the ground safely and with no damage. I decided to use dual deployment. At apogee, the rocket would split into two sections and drop drogueless. Then, at around 1,200 feet, two parachutes would deploy. The main parachute would be a large SkyAngle that would carry the main rocket body to the ground. A smaller SkyAngle parachute would drop the nose cone. A Missile Works altimeter and a borrowed RDAS would control four ejection charges, with eight grams of black powder in each charge.

Construction began in March and things really started to roll. Working in my garage during the hot and humid South Carolina summer months tested my building stamina. Many phone calls were made to Rich and other high-power friends, and throughout every step of this project I received great ideas and much support. I had originally worked with an NAR L3CC member from Florida who would come up to South Carolina to witness the launch. Unfortunately, something came up and he could not make it. But luck was on my side: Rich had applied to become an L3CC member and was accepted. So now my friend would be making the long drive from New York for the big launch over the Labor Day weekend.

I finished the rocket one week before the launch date. Rich drove twelve straight hours to arrive at my house on Friday night. I completed the electronic bay as I wired in my Missile Works RRC2 and an RDAS unit that Rich graciously allowed me to borrow for this important flight. The recovery system was packed, and the Bullpup was ready for flight the following morning.

We arrived at the launch site about 9 a.m. on Saturday. After setting up camp, I prepped the ejection charges, loaded the motor, and completed the final assembly. Rich and I headed to the away cell at about 11:30 a.m., where we discovered the pad from Hell! We had never used this launch pad before; it was missing some parts, and the rocket would just not fit. If you are going to do your Level Three flight, be sure you are familiar with the pad you are using before you arrive at the launch! After nearly three hours of pad work, it was finally time for the countdown and for the LCO to push the button.

At ignition, the Bullpup roared off the pad on a 75mm Animal Motor Works M1350. The flame from the motor was great. The rocket headed perfectly straight into the clear blue Carolina sky and reached an altitude of 3,400 feet. The recovery system deployed right on cue, and the rocket landed about 100 yards from the pad.

The whole project had taken months to complete and cost nearly $1200, but it was worth it! And it sure helps to have friends around when you need them.

suggest that a commercial kit could not be used for a Level Three certification attempt.

Nor is there a rule with either Tripoli or NAR that the certification rocket conform to a particular size or shape. Any safe design is acceptable, whether scratch-built or constructed from a kit. Depending on the objectives of the rocketeer, Level Three flights may take the form of minimum-diameter missiles, large and heavy projects, or anything in between.

Do the rules regarding team projects preclude or forbid rocketeers from assisting each other in certification attempts? No. It is common for people to give each other advice, expertise, and helpful suggestions at any stage in the process, particularly with Level Three projects. Rocketeers may loan one another electronics, motor casings, and other components for Level Three flights, and it is a great idea to check with more experienced flyers at every major juncture to ensure that you are on the right track with your own project. This includes asking questions even on the day of your Level Three certification attempt.

Level Three rockets often require a lot of help at the pad. Here, crew members help Jerry O'Sullivan place his multiple-M-motor Nike on the away cell during experimental days at LDRS23. The rocket carried three Loki Research M motors (this was not a cert flight).

Putting it All Together

Prior to the certification flight, the Level Three candidate must present the TAP or L3CC member with a written package containing all the required information about the rocket and its flight, including sample photos of construction and anticipated flight data. For Tripoli members, this must occur at least thirty days prior to flight. NAR requires its package to be presented to the certifying officer a minimum of five days prior to flight.

Rocketeers who are serious about certification should present their paperwork as far in advance as possible. This ensures that any glitches in either their paperwork or, more important, their rocket, can be corrected in time to launch on schedule. Candidates who are planning to certify at a large regional or national launch–such as LDRS–but wait until the last minute to submit their paperwork are asking for trouble.

"Start early with your L3CC or TAP certification team member," advises L3CC officer Stephen Lubliner of Arizona. "Show the member the proposed design and solicit comments. The L3CC

members I have worked with are looking out for the flyer's success."

Presentation of the package can be accomplished in any number of ways. There are no hard-and-fast rules. The first thing to do is to contact the TAP or L3CC member and ask if they have any preferences. If they do, follow them. If they do not, put yourself in their shoes.

Present them with something that you would like to be presented with if you were a committee member. Be neat and concise. If you can type your paperwork, do so. If you cannot, make sure your information is easily readable.

Remember, you want the TAP or L3CC member to see that you are careful, patient, and deliberate.

Do not rush through the construction of the rocket, and do not speed through the paperwork. Make a good impression, and if problems are discovered and the committee member suggests changes, make them. TAP and L3CC members are there for your benefit. They want to see you succeed, and, chances are, they have more experience than you do, so listen carefully to their advice.

A fisheye view of Philip Hathaway's Level Three certification Phoenix rocket on the pad in New York. The rocket was powered by an Aerotech M1419 and cleared more than 7,500 feet, giving the Maine resident his NAR certification. (Note the standoff just below the aft end of the rocket.)

Anticipating Problems before the Launch

Anecdotal evidence and a random survey of L3CC and TAP members reveal that the single biggest cause of unsuccessful Level Three certification flights is failure of the recovery system. Indeed, deployment problems may be the single largest cause of all rocket failures, Level One through Level Three.

Recovery failures include zippers, tangled or undeployed parachutes, and even lawn darts (no deployment at all). Unfortunately, many rocketeers spend a little too much time worrying about using an M motor for the first time and not enough time on the fundamentals of deployment and recovery.

L3CC member Kimberly Harms of Washington sends her L3 applicants a list of the important things to keep in mind for a certification attempt. The top three items? "1. Recovery. 2. Recovery. 3. Recovery." Although her list is tongue-in-cheek, Harms advises candidates seriously to spend plenty of time considering all aspects of deployment.

"Most Level Three failures result from recovery

Continued on page 274

Case History

Level Three CANADA

My name is Rick Dunseith, and I live in the suburbs outside Toronto. I started flying model rockets in the late 1970s and have remained involved in the hobby, on and off, ever since. In 1998, I chanced upon HPR on the Internet and was completely surprised by the advances that had been made in rocketry and the technologies that were now available.

I joined the Canadian Association of Rocketry, and later Tripoli, as I became very involved in high-power rocketry. It wasn't long before I was a regular at Canadian launches and launches in the United States. I soon certified Level One and then Level Two on my own scratch-built rocket designs.

I then spent a couple of years honing my construction techniques, improving my recovery designs, and becoming proficient in flight electronics. I had many successes–and a few failures–along the way. But I treated each failure as an opportunity to learn something new, and with each failure I was able to increase my knowledge and improve my rocketry skills.

Then one day, while watching my biggest rocket descend gently under chute, I knew I was ready to take the next step. I began planning my Level Three rocket.

I took my time, and over the course of 14 months I researched, planned, designed, simulated, constructed, and documented a vehicle that satisfied my TAP advisors. And I then built it: A seven-inch-diameter, ten-foot-tall, tube-finned rocket that would tip the scales at sixty pounds when fully loaded.

The rocket took to the sky in the fall of 2002, powered by an Animal Motor Works M1850 Green Gorilla motor. The flight was perfect, and over the next couple of years I launched the rocket on M power again and again. I also flew the rocket on an Aerotech N2000 and what a flight that was!

In 2004 I made the trek to New York for LDRS23. It was my first LDRS event, and I enjoyed every aspect of it–especially being part of the planning and organizing and being on the Big Freakin Rocket committee. It was also

great attending as a rocketeer. I enjoyed meeting some of the people whom, until that point, I had known only by their names and by photos in rocketry magazines and in postings on Internet discussion forums.

I brought my Level Three rocket–the Extreme Paralyzer–to LDRS with me. This time, the rocket was loaded with a Cesaroni Technology Pro-98 six-grain N2500. The rocket weighed eighty pounds on the pad. For electronics I had on board an RDAS unit for primary ejection and a Transolve P5 for backup.

The flight was great. The rocket rose to more than 7000 feet and reached a maximum velocity of 588 miles per hour during flight. The rocket pulled a maximum of 11.6g under 877 pounds of peak thrust.

For deployment I used a drogueless descent from apogee down to an altitude of 1200 feet, where the main deployed. Just in case, I had a backup-deployment charge set for 800 feet. The rocket settled down gracefully under two separate SkyAngle parachutes, not far from the launch pad.

Why do I do this stuff? As long as I can remember, I've been fascinated by the exploration of space and by all of our efforts to get there. I know I'll never be an astronaut or even involved in the space program, but by doing this stuff I feel, in at least some small way, connected to it all. (All photos taken by Mark Canepa at LDRS23 in New York.)

problems and not airframe failure during boost," says Harms.

L3CC member Rick Boyette of Florida agrees. "People tend to either under-design or make their recovery system overly complex," says Boyette, who encourages rocketeers to keep it simple. "I advise people to use an altimeter, with a backup timer, and not to mess around with dual deployment. Bring the rocket down in two separate pieces. This eliminates zippering and allows use of two smaller chutes as opposed to one big one." Many other L3CC members share Boyette's views.

TAP member Andy Woerner's experience in Southern California also favors single, rather than dual, deployment in Level Three certification flights. "Most of the failures I have seen are either airframe damage at ejection or failure of the deployment system," says Woerner. "Zippers seem to be the most common. I typically encourage candidates to use apogee-only deployment to less complicate the flight."

If certification flights are based on dual deployment, Kimberly Harms advises her candidates to put a lot of thought into it. "The most important thing is the altitude where the chutes come out," says Harms. "If you use dual deployment, you should not consider deploying the main at less than 1,000 feet. Make sure your electronics can do that. It takes a lot longer than you think to get large chutes fully deployed."


14-13

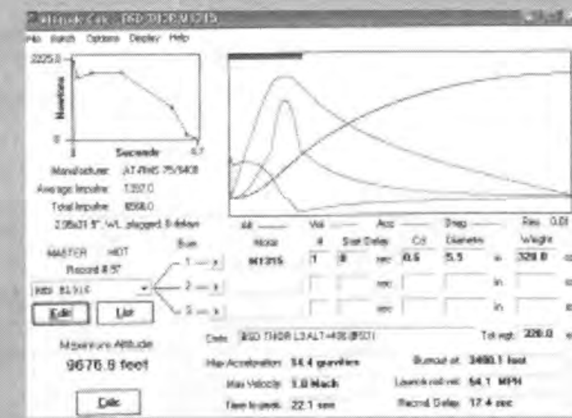
New Jersey resident and Tripoli member Dennis Lappert on a mechanized launch pad with his 82-pound SAAB missile. The rocket was equipped with a Loki Research M3210 demonstrator motor.

Deployment failures can be minimized by using familiar components, particularly when it comes to electronics. If possible, use altimeters or timers that you have used successfully in the past. If that is not feasible, then bring along a friend or someone from your local rocket club who is familiar with the electronics, to watch over your shoulder and provide advice. Level Three certification is not the time to be guessing about how to properly arm and use your new altimeter.

Stephen Lubliner has some additional advice when it comes to deployment and the use of electronics: Use different units in your rocket. "Some altimeter-based deployment systems may have a common software flaw where they improperly respond to pressure transients during transonic flight," says Lubliner, who believes that the safer approach is to use different systems to minimize the chances of a total failure.

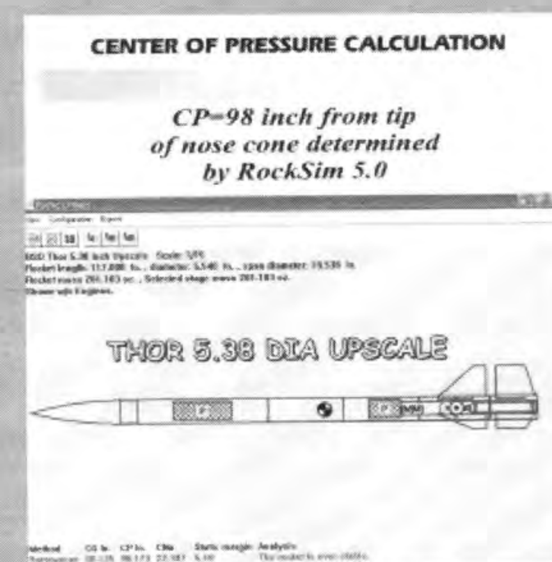
It is always a good idea to test your ejection

Continued on page 278



Level Three PAPERWORK

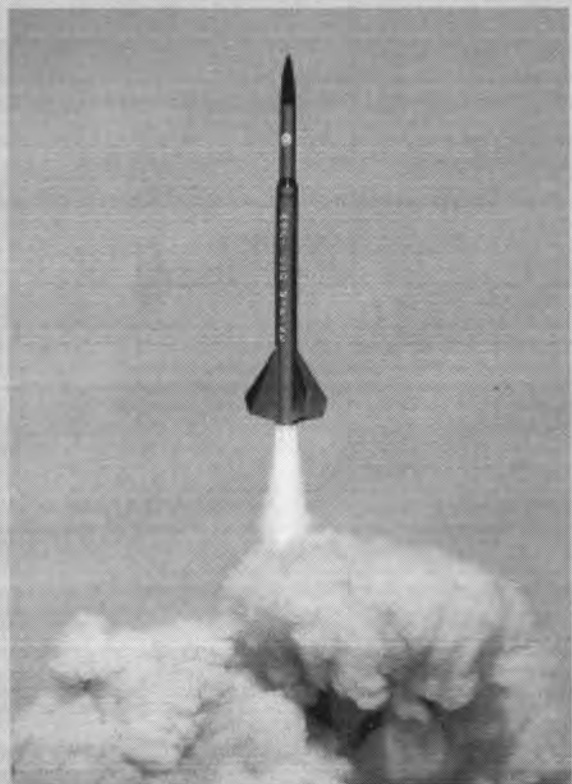
The supporting paperwork for a Level Three certification flight does not get much better than this. NAR member Craig Christenson used computer programs (such as RockSim) to submit all the necessary information to his L3CC member prior to flight. Not all Level Three paperwork submissions are this detailed, but Craig sets the standard. His rocket, a 5.38" Thor built from scratch, flew in Washington in 2002 on an Aerotech M1315. The 20-pound rocket reached 0.9 Mach, according to on-board blacksky altimeters. The rocket achieved nearly 10,000 feet. For a sample of a completed NAR L3 application, see Craig's paperwork in Appendix 3. Photos courtesy of Craig Christenson.



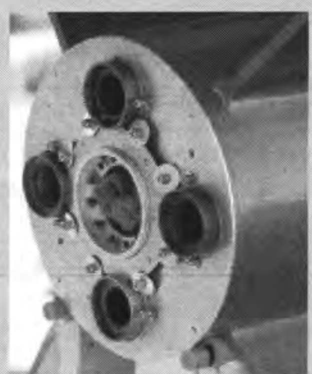
Case History

Level Three EXPERIMENTAL

At the leading edge of high-power rocketry, in places like the Black Rock Desert, you can see people push the envelope with scratch-built rockets powered by experimental motors. These rocketeers have achieved, and then moved beyond, Level Three. And at Tripoli's annual experimental launch, held in the early fall in Northern Nevada, they are out in force.



In September 2004, the team of Ron Weigel, Jerry Hughes, Jack Blair, and Woody Wood made the trek to Black Rock with a massive, 345-pound rocket that was 14 inches in diameter. It was one of several larger-than-life rockets at the launch. "More Bad Wiring" carried five Level Three-type motors: a central O5000, two three-inch M2200s, and two three-inch M1600s. The rocket stood more than 20 feet tall. The plan was to launch on the central O motor and two of the Ms, and then to airstart the two remaining Ms with an Olsen EZ-timer. Deployment for the massive rocket was critical, so the rocket was packed with not one, but four, Olsen M2 altimeters to ensure that the ejection charges fired.



"The ignition was perfect," recalled team leader Ron Weigel, "and the rocket flew out of a dust cloud with the O and two Ms blazing. The flame was at least ten feet long, a bright angry red, with three complete sets of mach diamonds. Soon the rocket was just a red glow at the end of a long stream of white smoke."

The airstart was next. "The main engines shut down, and the smoke trail became just a wisp for several seconds," said Weigel. "Then the second pair of Ms lit, and the trail became a dense white with a bright red glow at its apex." Soon the waiting for deployment began.

The rocket continued to climb and then turned over at apogee. Would the charges be enough to separate the 14-inch airframe? The ground

tests were successful, said Weigel, but now was one of the critical moments in the flight. "If the apogee charges do not deploy the drogues, all that will be left will be bags of debris."

The whooping and hollering over the success of the burn gave way to a quiet and uneasy anticipation as the rocket began its descent. The rocket had two mains–one for the booster and one for the upper section of the rocket. "Just one more hurdle," said Weigel. "The main needs to deploy." The wait for the mains seemed like it took forever–but the charges went off with a bang, and the rocket separated yet again. But it wasn't quite right. The main parachute from the upper section unfurled immediately, said Weigel, but where was the big main for the booster? "As it gets closer I can see the main chute flapping in the wind, but something is wrong," he said. "Open!–Open!–Open!" the four-man team chanted. But to no avail. The main parachute remained tangled, and the massive booster came in for a hard landing on the desert floor. "It's amazing how high something that big can bounce when it hits the ground," Weigel said later. That's why they call it experimental.

(Photos taken by Mark Canepa at Black Rock Desert in 2004.)

charges prior to flight to ensure that you have sufficient charge to separate the rocket. "Test the recovery system with live loads for the ejection," suggests TAP member Bill Cordova of New Mexico. "Make sure the ejection is energetic enough to throw every facet of the recovery system away from the rocket. Pack everything as you would for flight." Testing of ejection charges is essential for any high-power rocket. All testing should be done outdoors with plenty of room on all sides of the rocket. Also, remember to wear safety goggles for eye protection, and use plenty of common sense whenever working with black-powder charges.

Level Three Certification Day: The Launch

Bring a checklist. This is a requirement by both NAR and Tripoli for Level Three certification, and it is also good rocket practice.

For many rocketeers, Level Three certification is a stressful day. Sure, there are a lot of Level Two projects that are much more complicated than the average Level Three certification rocket. But the added pressure of reaching the highest level of high power can be daunting for even the most capable rocketeers. So bring your checklist to the field and use it. Do not leave it on the dashboard of your truck or tucked away neatly in your toolbox. Level Three rocketeers sometimes do the strangest things, and they usually occur in the absence of a checklist. And do not get rushed, as this usually leads to trouble. "I would advise against setting too firm of a timetable," cautions TAP member Daniel Gates of Minnesota. "You hear about people rushing to meet a self-imposed deadline and find that their haste has led to taking a shortcut or making an unintended omission."

14-14

Recovery problems are the biggest cause of Level Three failure. Remember the old adage: Keep it simple. Stick to systems you have used successfully in the past. And always ask questions. Photo courtesy of Andy Tryon.

Certification flights have failed because, among other things, the rocketeer neglected to attach his or her quick-link to the nose cone of the rocket, or because he or she forgot to turn on the altimeter.

L3CC member Charlie Barnett of Texas warns that you may need to use the checklist more than once on launch day, particularly if the rocket has to be removed from the pad prior to flight. This may occur where there are igniter problems or other difficulties on a busy launch day. "If you have to take the rocket off the pad," says Barnett, "go through the checklist again. You might be surprised by how many deployment failures are the result of not arming the rocket the second or third time it goes out to the pad." In addition, says Barnett, make sure that you have some mechanism (e.g. a flag) for ensuring that the rocket is armed before it is launched.

The Issue of Flight Damage

Although successful deployment and recovery are a fundamental requirement of certification, neither Tripoli nor NAR requires the rocket to be returned to the certifying officer in mint condition. Both TAP and L3CC members are allowed some discretion on the field in evaluating whether damage sustained during the course of a Level Three flight is significant or not. At a minimum, the rocket must be returned in a condition that would allow an immediate repeat flight without repairs. Minor cosmetic damage that would not prevent another launch is usually acceptable.

Some Final Advice

"Be realistic on your budget," says Stephen Lubliner. "An M1315 reload is $300. Most electronic modules are at least $100 each, and you will need two units. You might save on the cost of a reload casing by borrowing one from another rocketeer. I'd suggest a budget of at least $1,000 for a Level Three effort."

"Stay with what you know and have experience with," recommends L3CC member Fred Gruis of Iowa. "Try to stick with construction techniques and electronics that you have already had success with and are currently using. Do not make this an 'all new,' from the ground up, rocketry project."

Charlie Barnett agrees. "Take time to learn as you gradually move to Level Three," he suggests. "Do not jump from J to M. Visit with other regular L3 flyers about your project, and look carefully at their L and M rockets. The M project should be very much like your previous projects, so that very little new is introduced. You want the prep to be as routine as possible."

And ask questions all along the way. "Find people who fly a lot and are almost always successful," suggests TAP member Ed Dewey of Illinois. "Find out what kind of electronics they use and how they put things together. Have them take a look at your design and evaluate it." It is also important to keep in mind the practical aspects of a Level Three launch. For example, with a larger rocket, it will be important to have a larger launch pad and plenty of help in transporting the rocket to the pad. Do not assume that the club running the launch will have all of the equipment you may need on the day of your certification flight. Call ahead first. And bring plenty of help on launch day.

"Don't come alone," cautions Kimberly Harms. "You need helpers to get the rocket prepared, transported, loaded, tracked, and recovered. The TAP member who is watching your flight is not your ground crew, so do not expect them to be an extra set of hands for you. Get helpers–you will need them!"

Charles Barnett reminds his candidates that even if deployment is successful, the job is not over. Level Three attempts have failed because although the flight is otherwise successful, the rocket is never recovered. "Leave to recover the rocket immediately after it deploys," he warns. "Use a tracking transmitter if the rocket is going to a significant altitude. You only succeed if you find the rocket."

Building the rocket, preparing the appropriate paperwork, and getting it all in order for the certifying officer–not to mention getting the rocket to launch and recover–may seem like an impossible task, but taking it a step at a time will get the job done.

"Remember," says Harms, "the L3 project will be a major undertaking in time, effort, and money. But you will have something to look back on for years."

The L3 project will be a major undertaking in time, effort, and money. But you will have something to look back on for years.

Case history

Level Three LDRS23

My name is John Russo, and I have been active in both model and high-power rocketry for more than 25 years. I am a member of NAR, and I fly with local chapters in both Connecticut (NARCONN) and New York (Buffalo Rocketry Society/ BRS).

I obtained my Level One and Level Two certifications at the BRS field in Geneseo, New York, and when Geneseo was selected as the location for LDRS23, I knew it was time to prepare for Level Three.

After a slow start, I began work on my project in the spring of 2004. My goal was to scratch-build a Level Three rocket as inexpensively as possible without sacrificing any engineering integrity.

To help accomplish this, I made the 7.5-inch airframe from Public Missiles Systems phenolic (un-glassed) tubing, and I cut out the fins myself from craft plywood. At the end of April, the booster section was complete, less the paint.

Most of May was spent concentrating on layout work for the altimeter bay, along with preparing the NAR L3 certification package.

By the first week in June, NAR L3CC member Rich Pitzeruse had received and reviewed my certification package and was ready to sign off on my project. However, Rich was concerned that my un-glassed airframe might be susceptible to a zipper during deployment and recovery. So I spent additional time trying to make the rocket zipper-proof. It was time well spent.

For the drogue recovery harness, I added three foam pool toys, called Fa-Noodles, that attached to the harness and would prevent a zipper of the airframe. For the main parachute and recovery harness, we decided to use a piston. The piston would only reach, but not extend beyond, the edge of the airframe. This should prevent any zipper when the main was deployed. The anti-zipper devices were by far the largest engineering challenge, but they took the least time to fabricate. Even better, both anti-zipper assemblies cost less than $15.

It was now five days before LDRS23, and I had spent more than 200 hours on the project, with a total investment of $580. The rocket, called the Strato-Cobra, was now ready. On the second day of the big event, I prepped my rocket for flight. It took most of the morning and part of the afternoon, but by 3 p.m. it was time to head out to the away cells for setup on the pad.

The rocket was loaded with an Animal Motor Works M1850GG. The motor provided for a good thrust-to-weight ratio and I have been very impressed with the amount of white smoke and the brilliant green flame produced by the Green Gorilla motors. I held the motor in place with an Aero Pack retainer. Motor retention is one area where I do not try to reduce the cost!

On the pad, the rocket stood more than 14 feet tall and weighed 58 pounds. I had two PerfectFlite altimeters on board to ensure deployment.

The launch was perfect. The rocket reached more than 4300 feet, and it was recovered only a hundred yards from the pad. Rich Pitzeruse and I had an easy time carrying it back after the flight!

I do learn from other people's mistakes, and the number one piece of advice I have is that the nose cone on a Level Three rocket can't be put on too tight, especially if your main parachute is attached to the nose.

Be sure to test your pyrotechnic charges on the ground, and make certain that the nose cone does not come off early at apogee.

And have fun.

The COST

As we discussed in Chapter 14, the cost of your Level Three rocket does not have to break the bank. Although flyers can spend more than $1,000 on a rocket, it is easy to build a complete L3 rocket for a few hundred dollars. The key is to make use of your Level Two avionics and recovery equipment and to build some of the airframe components yourself. With a little planning, the entire airframe can be constructed for as little as $200-300. This chapter will show you how it can be done.

15

Building the Level Three Rocket

How to build a Level Three project for a lot less money than you think

There is no one recipe for a Level Three rocket. Level Three certification projects come in all shapes and sizes. They can be minimum-diameter, high-altitude flyers or large-scale models of famous rockets such as the V2 or Nike Smoke. They can also be built from kits.

Neither Tripoli nor NAR requires that a Level Three rocket be difficult to construct. Indeed, there are many Level Two rockets that are as complicated as, or even more than, the average Level Three certification rocket. Some people enjoy testing their limits all the time, and they approach Level Three by building the most sophisticated rocket imaginable. They may also choose to certify on an N motor, instead of an M. This is fine for them. But do not let someone else's choice for a Level Three rocket dictate the right choice for you. The key to enjoying Level Three is the same for all of high power: Stick to what you are comfortable with and do not move forward until you are good and ready. For most people, the Level Three certification flight should reflect the old adage: Keep it simple.

15-1

Tripoli member Rod Lovley built the entire airframe for his L3 project for less than $150.

15-2

Rocketeer Tony Nelson of Maryland holds the rocket designed for this chapter. The Level Three project features a 75mm and 98mm motor mount and cost about the same as an M motor reload (without electronics).

The purpose of this chapter is twofold: To show you how to build a simple Level Three rocket and to demonstrate how inexpensive such a rocket can be.

This rocket is not a kit, although in many ways it does resemble the traditional, three-finned rockets that come from kits. The rocket will house either a 75mm or a 98mm motor and will make use of components that are readily available from rocketry retail shops and home-improvement stores. The rocket will employ dual deployment. Except where noted, it is constructed with 30-minute epoxy.

In this example, we make use of many things that should already be part of the experienced Level Two flyer's inventory. You do not need any special construction skills or access to unusual equipment, but if you do have basic scratch-building experience and tools, you can save even more money.

15-3

Scott Eakins prepares his L3 rocket for flight while son Loren looks on. Eakins built the airframe for less than $100.

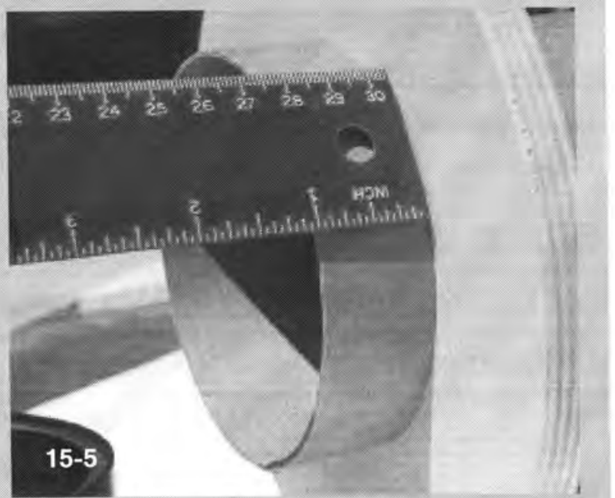
Our goal? To construct a reliable Level Three project that does not cost any more than an M motor reload. We will try to do this by using parts we have accumulated during Level Two flying days and by shopping around for less expensive–but high-quality–components.

Picking the Airframe

The airframe diameter we chose for this project was 7.51 inches. This size was picked for at least two reasons. First, it is readily available. Many rocket kit manufacturers and most rocket part retailers have some type of 7.51-inch airframe for sale.

Also, it avoids the need to scratch-build a custom nose cone, or buy a new one. One of our Level Two rockets was a Public Missiles 7.51-inch Patriot Missile, and we also had a 7.51-inch LOC Bruiser EXP. Both of these rocket kits have excellent nose cones suitable for a Level Three rocket. So the cost of the nose cone was

15-4



15-5

15-6

nothing–a big saving in any Level Three project. (If we had had to buy a new nose cone, the cost would have been about $75.)

The 7.51-inch airframe was purchased from Giant Leap Rocketry. Two four-foot-long sections of their 7.51-inch microseam tubing were ordered $37.95 each, for a total cost of $75.80. This tubing is a bit expensive, but it is strong and durable. It is also easy to sand and paint, and it can be fiberglassed for increased durability. Similar tubing is available from many other rocketry retailers.

Do all Level Three rockets have to be fiberglassed? The answer is no. Fiberglass increases the overall strength and durability of most high-power rocketry projects. It also provides a nice base–when properly sanded–for a good paint job. However, it is not necessary in all projects. This particular rocket was intended to fly once or twice a year on L or M power. As such, it would last plenty long without the addition of a layer or two of fiberglass cloth. If, on the other hand, you were planning on certifying Level Three with a minimum-diameter rocket on M or N power, fiberglass (even a fiberglass airframe), or some other strengthening material (such as Kevlar or carbon fiber) would be a must.

To save money on airframe tubing, many Level Three projects are built with Sono tube. Sono tube is used by construction workers to make cement forms. It is also great for rocketry projects. (The rockets in photos 15-1 and 15-3 were built from sono tube.) Even better, most 7.51-inch nose cones will fit on ordinary sono tube of similar size. So while our airframe tube had cost $75.80, we could have purchased the same amount of tubing at a home-improvement store for a mere $10. (Two four-foot sections at $5 per section–8-inch nominal size.)

Sono tube works well in high power, but it is softer and not as durable as microseam or phenolic tubing. Sono tube should be fiberglassed for use in any Level Three project. So in addition to the cost of the tube, you will need another $15 for fiberglass cloth and epoxy to cover the airframe, for a total cost of $25 for your basic airframe. You will need to do a

some sanding, but you save nearly $50. If you choose Sono tube for your rocket, take your nose cone to the store with you and test-fit it on the tube before purchase. (Sono tube is often supplied in several slightly different actual diameters within the same nominal size range.)

Motor Retention System

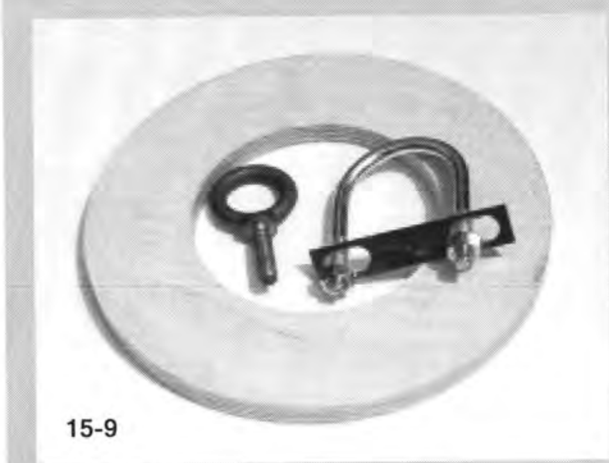
Actual construction of the rocket began with the motor housing and motor retention. We first needed a 98mm motor tube. The price for the tube was $19.95. The plan was to then install a motor retainer/motor adapter system that would allow the rocket to be flown with both 75mm and 98mm motors. This would let us fly on a less expensive 75mm motor for Level Three certification. To accomplish our goal, we returned to Giant Leap Rocketry and purchased their Slimline motor-retention package (for 98mm motors) and their 75mm motor adapter. (In the alternative, many rocketeers also use the Aero Pack line of motor retainers/adapters for Level Three projects.)

The Slimline is a lightweight, easy-to-use motor retainer that features a stainless-steel ring that holds the motor in place. The ring fits into a groove in Slimline's black metal base. The base is permanently affixed to the aft end of the motor tube. The motor slides through the base, into the motor tube, and the ring is then attached. See photos 15-4 through 15-6.

To install the Slimline base on our 98mm motor tube, we first did some test-fitting. Using the aft centering ring as a general guide, we placed the ring on the motor tube, with about one inch of the tube protruding through the ring. See photo 15-5. The Slimline base was then placed over the portion of the tube that was extended out of the ring, so the base actually abutted the aft ring. Next, we placed a 98mm motor casing into the motor tube. The aft closure of the casing slipped through the Slimline base, and the motor rested in the tube. We then placed the steel Slimline retaining ring in the base. It fit perfectly. See photo 15-6. The ring was then removed, and the motor was taken out of the tube.

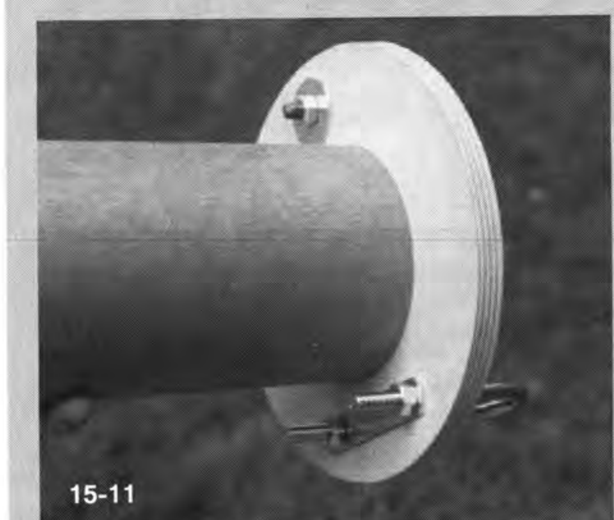
15-7

15-8



15-9

15-10



15-11

The aft centering ring was left in place. The Slimline base was taken off the aft end of the tube, and JB Weld was applied to the end of the motor tube. The base was then gently pushed back onto the aft end of the motor tube–again so it abutted the aft centering ring–and left to dry. Any excess adhesive was wiped away immediately.

The motor-adapter package was a 75mm motor tube with three centering rings and its own 75mm metal motor ring. This assembly slid into the 98mm main motor tube and was locked in place with the same retaining ring.

The total cost for our motor retention system, including the adapter, was $53.90.

Could we have saved more money on motor retention? Sure. In our alternative plan we could have used either a 75mm or a 98mm tube without any adapter package. In that scenario, all we needed was a couple of motor-retainer clips at a cost of about $7, total. For more information on motor retention, see Chapter 4.

The Motor Tube Centering Rings

The motor tube in almost any high-power rocket is held in place in the airframe by centering rings. For a Level Three project you should use at least three rings to anchor the motor tube.

The three centering rings were also purchased from Giant Leap Rocketry at a cost of $6.99 each, for a total of $20.97. The rings were 1/2" thick and made from Baltic plywood. If you are handy with a router, jigsaw, hole saw, or other woodworking tools, you can cut your own rings and save money. But for Giant Leap's price, we saved a lot of time for a reasonable amount of money.

The next step was to epoxy the centering rings in place on the motor tube. Be sure to sand all joints prior to applying the epoxy, and make sure there are fillets placed for all major connections (fins, rings, etc.). It is not necessary to go overboard with epoxy, but do not skimp, either.

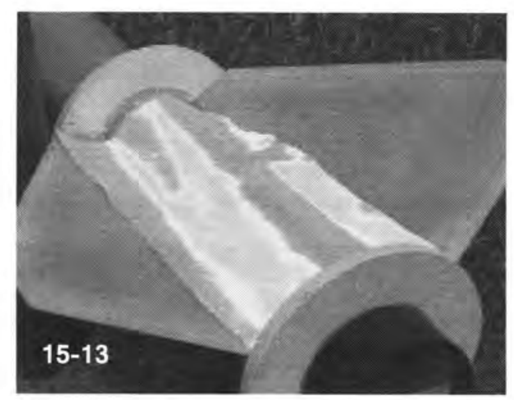
We started with the aft ring (which is already on the tube) and the middle ring. We slid the middle ring onto the motor tube, being sure to place it so

15-12

that the three rocket fins (discussed below) would fit between the aft and middle rings. All three fins were temporarily test-fitted between these two centering rings to make sure our distances were correct. See photos 15-7 and 15-8. A small amount of 5-minute epoxy was applied to hold the rings in place. The fins were then removed, and 30-minute epoxy fillets were placed all the way around the circumference of the motor tube–on both sides of the ring–where the centering ring and the tube met.

The Forward Ring

Next, the forward centering ring was drilled for a 5/16" U-bolt and a closed, forged-steel eyebolt. See photos 15-9 through 15-11. These attachments would be used to secure a recovery harness. After the nut and washers were threaded on, a small dab of epoxy was applied to the threads of the U-bolts and the threads of the 5/16" eyebolt to make sure they would never come loose. The total cost for both of these points of attachment was about $8.



15-13

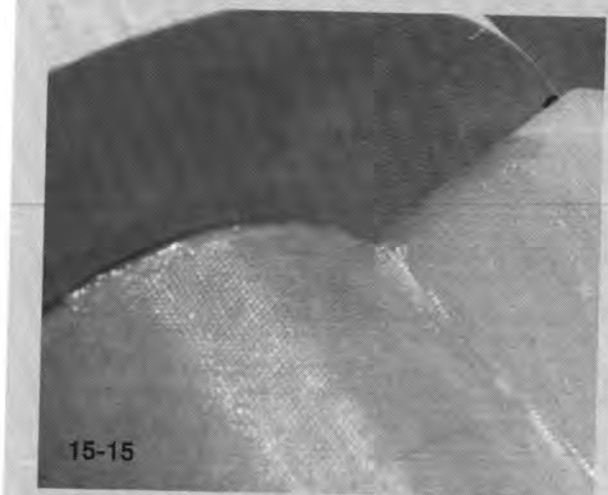
The fins were attached with epoxy, and then six-ounce fiberglass was placed in the valley between the fins to ensure a rock-solid foundation.

After the epoxy dried, the forward centering ring was placed on the motor tube, leaving 1/4" of the tube above the ring. Again, epoxy fillets were run around the joint where the tube and the ring met–both top and bottom--to complete the motor housing for our Level Three project. The finished housing is seen in photo 15-12.

Choosing and Installing the Fins

The three fins were next. Choosing the configuration for a rocket fin is really a matter of personal taste, and the size and weight of your rocket. Public Missiles, LOC, Giant Leap Rocketry, and others offer a wide variety of fins in various materials for almost any need. Some of these companies can also cut your own fin design out of plywood, fiberglass or other materials.


15-14


15-15

For our project, we picked a new design offered by Giant Leap Rocketry, and we spent extra money by choosing G-10 fiberglass (0.193-inch thickness) and by also asking Giant Leap to bevel the leading and trailing edges of each fin.

The total price for all three was $66, including the beveling.

How to save money here? Do it yourself. The fins were purchased from a rocketry retailer, but they could have been cut with a simple jigsaw out of G-10 fiberglass sheets or, in the alternative, they could have been made of plywood. The beveling also could have been done at home in your garage with a sanding block or a hobby sander. By doing it yourself, the total cost for three basic fins can be as little as $10.

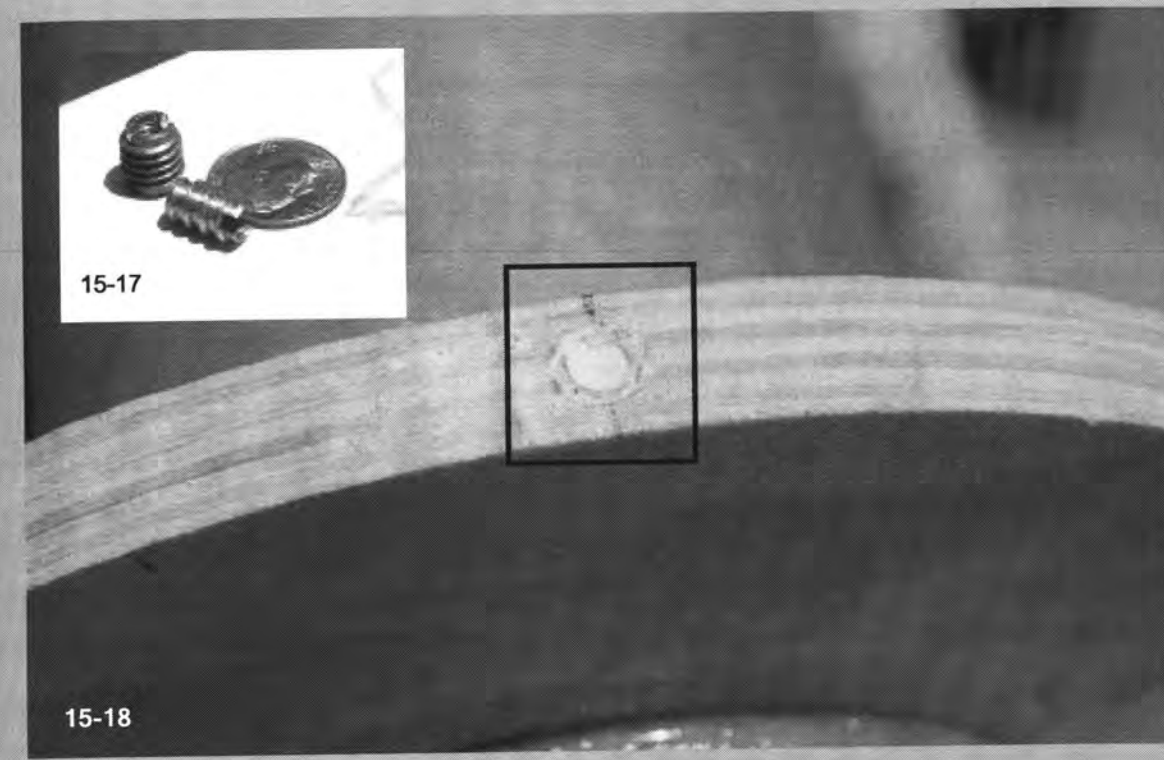
15-16

West System two part epoxy is excellent for fiberglass work on high-power rockets.

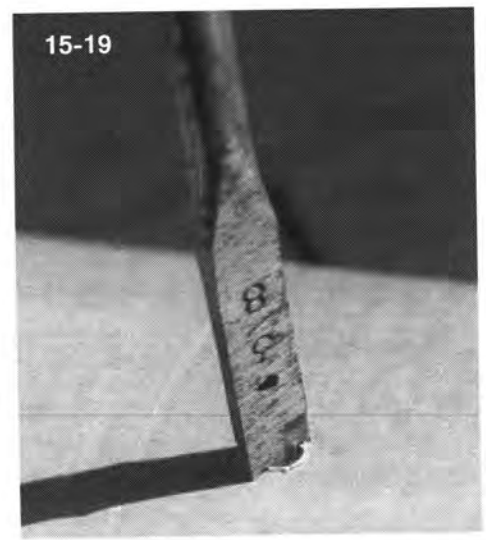
Each fin was tacked in place using quick-setting 5-minute epoxy. (The fin alignment was based on a simple three-fin guide pattern available from an old rocket kit.) Once the 5-minute epoxy had dried and the alignment of each fin had been double-checked, 30-minute epoxy fillets with were placed on the sides of all three fins where they met the motor tube and centering rings. For extra strength, a layer of five-ounce fiberglass cloth was placed in the valleys between all three fins. See photos 15-13 through 15-15. West System Epoxy Resin (two-part) was used to set the fiberglass in place. The cost for the fiberglass cloth, available at any hobby store, was $8.95 (with plenty left over for another project).

Installing Launch Lugs for the Project

The motor housing was almost ready to be installed in the booster. But there was one small step left. One of the questions facing any rocket builder is what type of launch lug to place on the rocket and how to attach them. For this rocket, we wanted the flexibility to launch the rocket with either simple rail guides or unistrut guides. This would increase the chances that at any given out-of-town launch we would be able to launch this rocket on the local club's equipment.


15-18

15-17

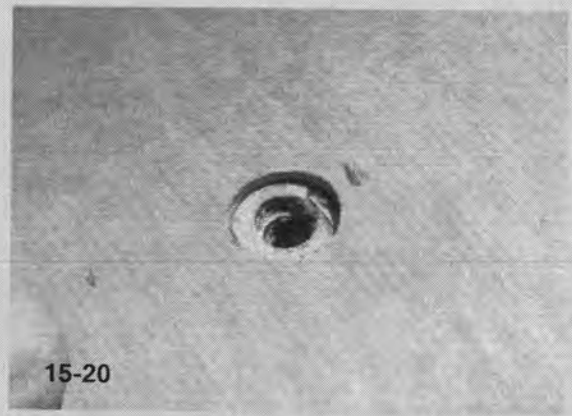

15-19

We based our design on a rocket we had seen built by some rocketeers from Alabama. Small barrel nuts would be installed in each of the three centering rings. See photo 15-17.

Pilot holes for the barrel nuts were drilled in the centering rings in a straight line from the aft ring to the forward ring (a T-square was used to accomplish this). Barrel nuts are threaded on both the outside and the inside and they have a slot on the end for a screwdriver. Each nut received a tiny dab of epoxy on the outside and was then screwed into its pilot hole until the top of the nut was flush with the ring. See photo 15-18. Care was taken not to get any epoxy on the inside threads. Careful measurements were then taken of the location of each nut, and a small mark was placed on the aft side of the bottom centering ring.

After the fin slots had been cut in the airframe (using a hobby knife–see Chapter 9) and **after** the motor housing had been set in place in the booster section (shown ahead), we went back to our measurements and drilled tiny holes in the airframe at locations corresponding to the center of each barrel nut. The holes were carefully widened until each barrel nut was exposed. See photos 15-19 and 15-20.

The end result? Our rail guides were removable and replaceable. They were also firmly at-



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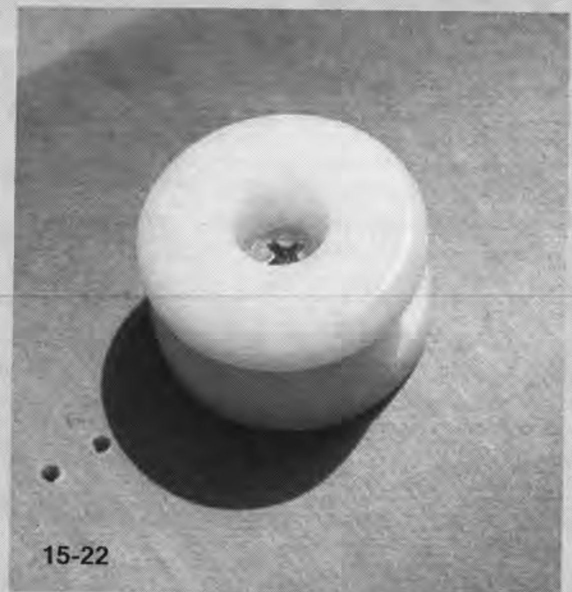
15-21



15-22

tached to the centering rings of the rocket with screws. As seen in photos 15-21 and 15-22, we could attach either ordinary rail guides or the much larger unistrut guides on the day of launch, depending on the launch equipment available. The price of this modification was low. The barrel nuts cost less than $2 for all three, and the two sets of rail guides were under $15, total.

Could money be saved here as well? Yes, by making your own rod-style launch lugs. As explained in more detail in Chapter 7, rod-type lugs attach directly to the outside of the airframe. For our project, a couple of lugs made from one-inch-diameter copper tubing or similar material (even heavy cardboard or phenolic) could have been utilized. The cost of a couple of four-inch-long lugs would be under $5.

Installing the Motor Housing in the Airframe

Three fin slots were cut in the lower half of the airframe, and the motor housing assembly (with the fins) was carefully placed into the rocket.

As explained in chapter 12, be sure to test-fit the motor housing in the airframe assembly a few times before you start placing epoxy. Make sure all of the appropriate marks line up and the fins fit easily. Also, use 30-minute epoxy for this step as it is very forgiving in the first five minutes, and you can make last-minute adjustments, if necessary.

After the epoxy was applied and the assembly had been installed, the entire booster section was inverted, and clamps were used to hold everything together while the epoxy set up. See photo 15-23.

Once the assembly had fully dried, the clamps were removed, and epoxy fillets were placed on both sides of each of the three fiberglass fins. See photo 15-24 for a look at the completed booster.

The Payload Bay

The payload bay in this rocket is the subject of one of our examples in Chapter 9 on altimeter bays. See that chapter (and Chapter 12) for instructions on cutting the removable hatch.

This rocket would have two payload bays separated by a removable bulkhead. The lower

15-23

payload bay would house the electronics and be accessed by a removable hatch. The upper bay would hold the main parachute and main recovery harness.

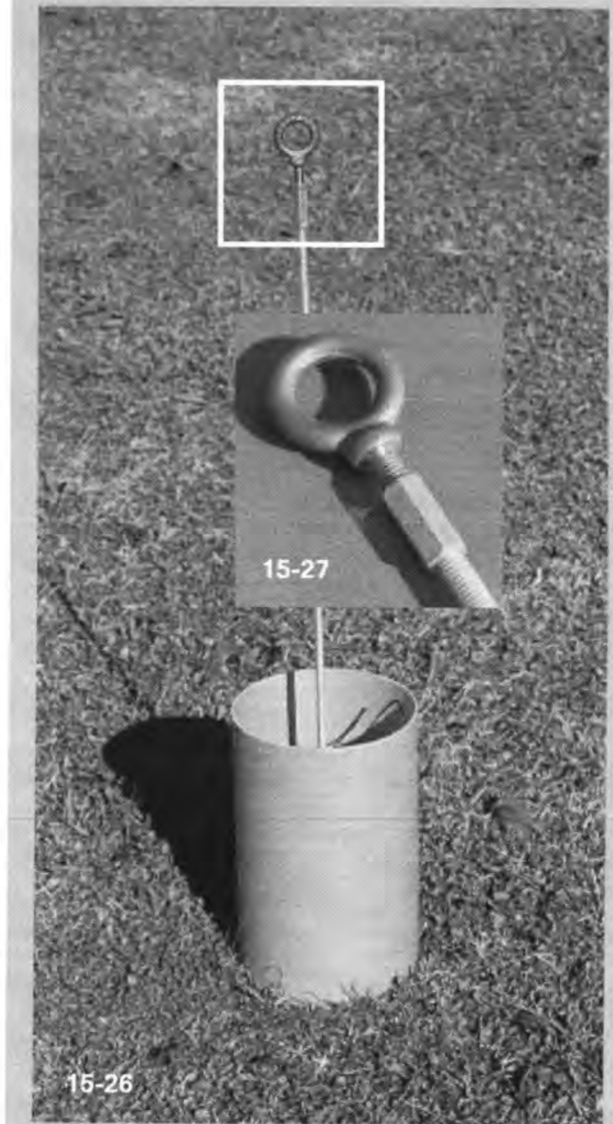
The bulkheads for the bays were 1/2" plywood for 7.51-inch tube couplers. They too were purchased from Giant Leap Rocketry at a cost of $6.45 each, for a total of $12.90. Both bulkheads would serve as mounting points for the upper and lower ejection-charge canisters and also for terminal blocks. See photo 15-25.

15-24

In the center of each bulkhead would be a single, closed 5/16" eyebolt to serve as a recovery harness point of attachment. The cost of the terminal blocks was about $8, and the two additional eyebolts were $4 each. The ejection-charge mounts and the terminal mounts were attached with machine screws and blind nuts. See photo 15-25.

The lower bulkhead plate, located at the aft end of the upper airframe in the tube coupler (photo 15-25), was installed using 30-minute epoxy fillets on either side of the coupler and fiberglass strips. Be sure to sand the inside of the lower coupler where the epoxy is placed as this improves the bond between the bulkhead and the coupler. Also, place small amounts of epoxy around all blind nuts to ensure that they do not come loose during flight. A little grease placed inside the blind nut will help ensure that the epoxy does not accidentally creep onto the threads of the nut.

15-25



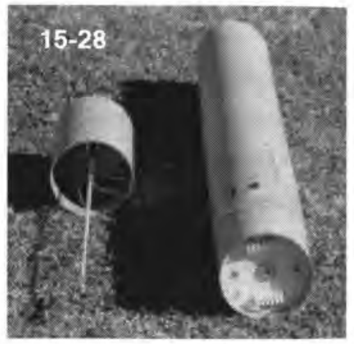
15-27

15-26

The upper bulkhead was removable. As illustrated in photos 15-26 and 15-27, the bulkhead was attached to a section of coupler tube with epoxy. On the top side of the bulkhead we placed ejection charge-holders and an eyebolt. On the bottom side of the coupler (attached to the threads of the eyebolt) was a length of 3/8" all-thread rod that ran from the upper eyebolt to the eyebolt in the lower bulkhead. The eyebolts were connected to the all-thread rod with threaded couplers, as seen in photos 15-26 and 15-27. This design allowed the upper bulkhead to be anchored by the lower bulkhead when the upper coupler/bulkhead assembly was placed in the payload bay. The upper coupler assembly would be stopped by the coupler used for the altimeter-bay hatch.

The Nose Cone

The nose cone can be one of the big-ticket costs for any Level Three rocket project. As noted above, we picked our airframe partly because we had PML and LOC nose cones that would fit our rocket. See photo 15-29.



15-28

By doing this, we saved at least $75 on the cost of the project. Even without recycling the nose cone, there have been a number of magazine articles on building your own nose cone from scratch. So if you have the patience and the skill, this is another area where a do-it-yourself weekend can save money on a Level Three rocket.

The LOC nose cone we launched with was a 7.51-inch cone. The shoulder had been partially sawed off so we could add two pounds of lead weight to the tip of the cone. (For photos of this type of modification, see chapters 12 and 13.) We cut a small bulkhead for the nose cone with a jigsaw out of 3/8" thick plywood, and we sanded the edges smooth. The bulkhead fit into the cone over a threaded rod that extended from the tip of the cone (embedded in epoxy and surrounded by lead weights) back to the shoulder. An eyebolt was attached to the lower end of the rod as a point of attachment for the upper recovery harness.

15-29

We saved money on the project by using a nose cone from rockets we already owned. Both of these cones would work fine with either eight-inch nominal sono tube or the 7.51-inch tube we purchased from Giant Leap Rocketry. The cone on the left is a Public Missiles cone. The one on the right is from LOC/Precision.

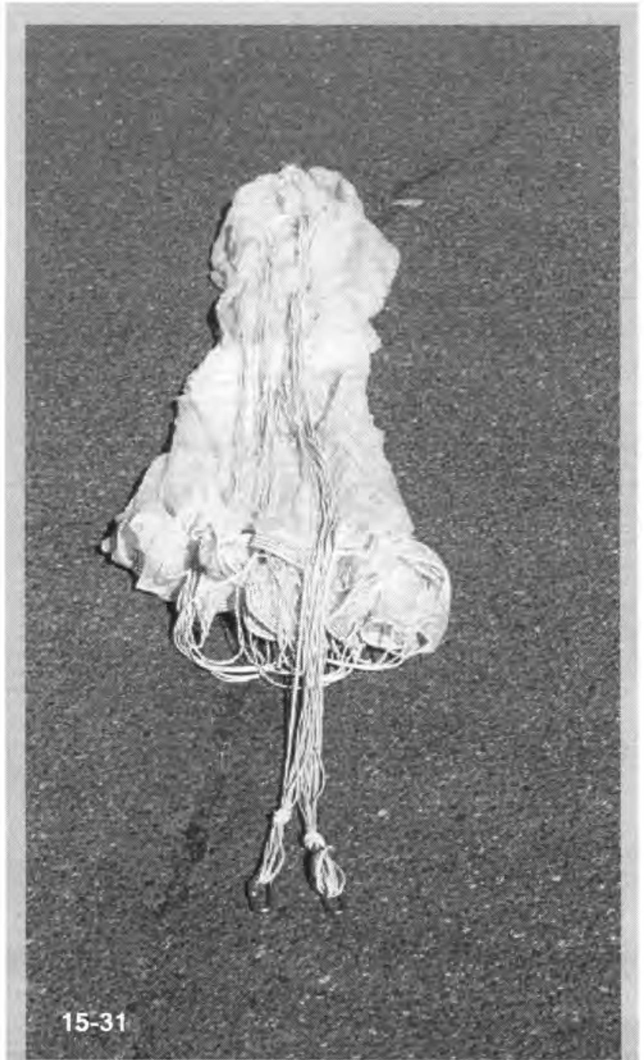
Putting Together the Recovery System

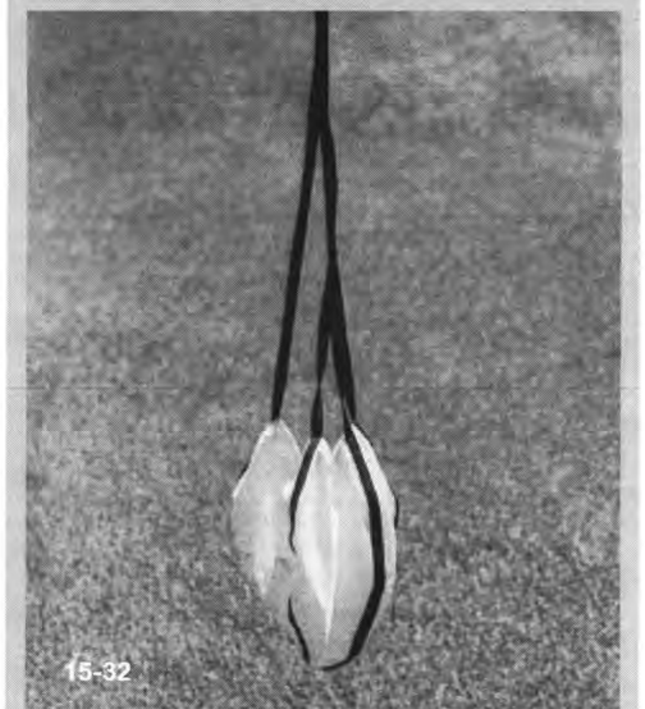
This is a dual-deployment rocket. A drogue parachute will be deployed at apogee, and the main parachute will be deployed at a lower altitude. Two separate recovery harnesses will be needed. One will connect the booster section to the upper airframe (for the drogue), and the other will connect the upper airframe to the nose cone (for the main). The recovery harness for both sections is one-inch tubular nylon, available from retailers such as Magnum Rockets for as little as 45 cents per foot. See photo 15-30. For a little more strength, 5/8" tubular Kevlar line is also available, at around $1 per foot. For our rocket, a total of 46 feet of tubular nylon was used for the drogue and main harnesses. That much cord would usually run around $20. But we already had it in our Level Two inventory, so it cost us nothing.

15-30

Most Level Two flyers already have a working recovery harness. If not, a good harness is still inexpensive.

Quick-links (5/16") were used at each end of the recovery harness to easily attach and remove the lines from the rocket. The links were attached to the tubular nylon by creating a loop at each end of the line. The loops were made by folding a few inches of the line over on itself and using epoxy and fishing line to make each loop permanent (see Chapter 10). The Quick-links then allow the user to transfer the recovery harness from one rocket to another–another cost benefit in the long run. The price of the four Quick-links for our rocket would be about $10, but we had those parts, too. The recov-


15-31


15-32

ery harness had a sleeve of Nomex at the end nearest the ejection charges. The sleeves are sold in various lengths and slide over the tubular nylon and further insulate the nylon from damage caused by repeated exposure to ejection-charge gases and flame.

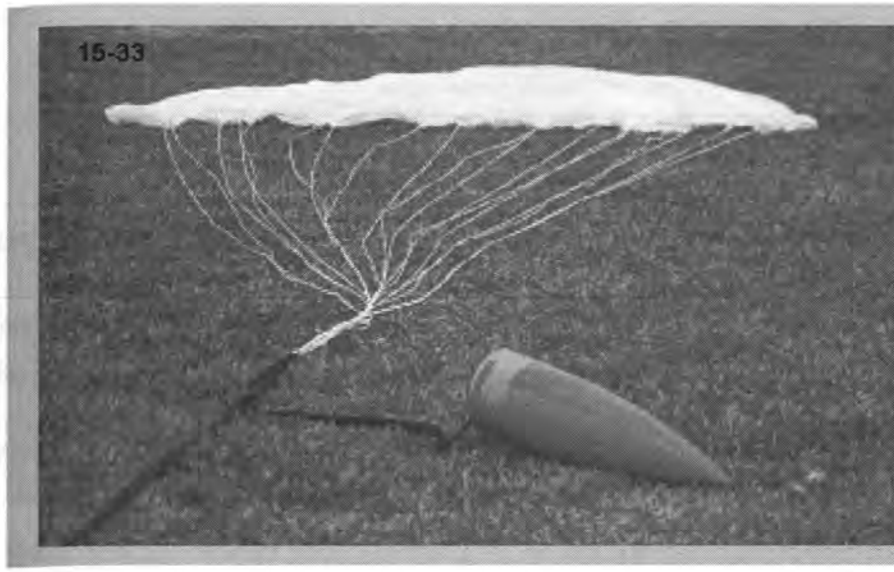
To protect the parachute, a 24-inch by 24-inch piece of Nomex was also attached to the recovery harness. The Nomex cloth was placed between the ejection charge and the parachute. The cost of the Nomex sleeve was $9.75. The cloth was $11.75. Again, since these pieces are reusable, we saved money by utilizing Nomex already in our toolbox. For more information on recovery harnesses, see Chapter 10.

A Word on Parachutes

Level Three rockets are usually larger than other projects, and special consideration must be given to the selection of a parachute. As set forth in Chapter 10, the ideal descent rate is typically somewhere between 15 and 25 feet per second. For a large, heavy Level Three rocket, it is probably even better to keep the rate at under 20 feet per second, depending on ground conditions. Be sure to use a parachute-descent calculator (available for free online) to get a good idea what size parachute will work for your rocket.

You can spend a lot of money on parachutes. Several manufacturers produce quality high-power rocketry chutes that can cost you $200 or more. A good parachute is worth every penny. But to save money, shop online and look for bargains. Check out Internet auctions for military-surplus parachutes or for a rocketeer who is selling an old chute. We purchased three 16-foot military parachutes a couple of years ago for $40 each. We would use one of those for this rocket, thereby saving a lot of money. See photo 15-31 and 15-33. We also had a Rocketman drogue parachute, purchased for about $30, already on hand. See photo 15-32.

Do you have to use a drogue parachute? The answer is no, even if you are planning on dual deployment. This brings up another cost-saving


15-33

device. If you have wide open space, with few trees or cornfields at your launch site, you can save money by deploying a single parachute at apogee and not using a drogue. The rocket may drift a lot farther, but if visibility is not a problem, you can recover the rocket a mile or two downrange.

On the other hand, if you are on a smaller field and you are using dual deployment, you can simply separate the rocket at apogee and not attach a drogue–depending on the size of the rocket and your comfort with the descent rate.


15-34

Electronics in Your Project

This is another area where we saved money. If you have spent some time flying Level Two, you should already own at least one or two altimeters and know how to use them.

For this project we used one blacksky Altacc, one Missile Works RRC2 and one Olsen altimeter. (We could have just as easily used Adept, Transolve, Loki, Perfectflite, or G-Wiz products, to name a few.) The altimeters cost us nothing, since we made that investment long ago. If we had not, two good altimeters for a Level Three rocket could cost $200 to $300, total. (We used three altimeters because we had them, and to compare their altitude calculations.)

The altimeters were mounted to the wall of the airframe around the

The WORK

If you're good with tools and raw materials, and you are able to do some of the work yourself, you can save a lot of money on a Level Three project. But if you are pressed for space or lack the tools necessary to cut centering rings, bulkheads, and other parts, you can simply pick up the phone and order the parts from one of several vendors. Public Missiles, LOC/Precision, Giant Leap Rocketry, and others offer a wide variety of parts and services at reasonable prices. In addition to standard sizes, rocket vendors can also do custom work. So don't be afraid to ask.

circumference of the altimeter bay. Both units would have ejection charges for main and apogee deployment, for a total of four ejection charges. Two safety switches (for electronics or ejection charges, or both) were installed on the outside of the bay. The switches were purchased from Aerocon Systems for $6.95 each and were flush-mounted against the airframe wall.

The ejection canisters were made by SafeEject. These handy metallic canisters can cost up to $20-25 each, but we had accumulated three or four over the last few years. So the cost was nothing for our Level Three project.

In the alternative, you can make your ejection canisters out of schedule 40 PVC pipe or related materials. For less than $5, you can easily make four ejection cans from scratch. See Chapter 6.

Conclusion

As Diagram 15-2 illustrates, the retail cost of this Level Three project, if we had to buy everything new, excluding the electronics (and epoxy/adhesives), would be nearly $700. Electronics could easily add another $300 to the project.

However, by using the parts we purchased new and the parts we already had from our Level Two rockets, we spent only $316.52. Not bad for a functional Level Three rocket that included ready-made bulkheads, centering rings, and fairly expensive fins. Our cost would have been less had we not purchased the motor adapter, and had we used Sono tube for the inner coupler instead of the more expensive phenolic tubing. We also would have saved money by making our own fins out of plywood.

The rocket is test-fit on the launch pad before launch day. Be sure the rocket's rail guides allow for smooth movement of the rocket on the rail and that there are no nose cone clearance issues.

Even without having the inventory of Level Two parts, and using our suggested alternatives (i.e sono tube airframe, cutting your own fins, bulkheads, etc.) this rocket could have been made for as little as $319.95. This price includes the purchase of a new nose cone, recovery harness, and a $50 military-style parachute.

If you already have these items in your Level Two inventory, and you have the skills to construct your own nose cone, the total price could drop to as low as $100-150. Sure, it is some work. But in the end you can say you did it all on your own.

As far as electronics are concerned, you need to invest in an altimeter at the Level Two stage. So you should have at least one, if not more. If needed, you could buy another for Level Three, or borrow one for the flight.

If you do borrow an altimeter or buy a new one for the flight, be sure you are fully familiar with it before the launch. Do not read the instructions on the altimeter for the first time in the back of your truck while you are awaiting launch.

In any event, there are plenty of ways to save

Component	Retail Cost	Our Cost	Alternative Cost
1. Airframe/7.51"(8')	$75.80	$75.80	$25.00 (Sono Tube)
2. 98mm Motor Tube	$19.95	$19.95	$19.95
3. Slimline Motor Retention/Adapter	$53.90	$53.90	$7.00 (Retainer Clips)
4. Centering Rings 1/2" Wood (3)	$20.97	$20.97	$5.00 (Do-It-Yourself)
5. Bulkheads 1/2" Wood (2)	$12.90	$12.90	$5.00 (Do-It-Yourself)
6. 3/8 Eyebolts (5)	$15.00	$15.00	$15.00
7. G10 Fins (0.193) Cut/Beveled	$66.00	$66.00	$10.00 Plywood (Do-it-Yourself)
8. Rail Buttons (3)	$15.00	Inventory	$15.00
9. Coupler Tube (4')	$52.00	$52.00	$5.00 (Sono Tube)
10. 7.51" Nose Cone	$75.00	Inventory	$75.00
11. Recovery Harness Tubular Nylon(40')	$20.00	Inventory	$20.00
12. Parachute	$150.00	Inventory	$75.00 (Internet or Military)
13. Ejection Cans	$80.00	Inventory	$5.00 (PVC Cans)
14. Nomex Cloth	$20.00	Inventory	$20.00
15. Quick-Links (6)	$18.00	Inventory	$18.00
Total cost of rocket (excluding electronics and epoxy/adhesives)	**$694.52**	**$316.52**	**$319.95**

Diagram 15-1

money on your Level Three project and cut corners--without sacrificing safety, design, or the appeal of your rocket. This was just one way to do it. Attend a few launches and talk to Level Three flyers on your own. You will learn other shortcuts and also build a great-looking rocket for certification.

The Launch of the Rocket

The launch of our test project went forward at the Florida Winter Nationals in 2005. The rocket weighed nearly forty pounds when loaded on the pad with an Aerotech 75mm M1315, held in with the Giant Leap Rocketry motor retainer and adapter. We used three different altimeters, and six charges, to control (and ensure) deployment: an Olsen M2, a Missile Works RRC2, and a blacksky Altacc.

The M1315 lifted the rocket cleanly off the pad to 7,448 feet. Deployment of the main 16-foot military parachute was right on schedule (1,750 feet per the Olsen) and the rocket touched down gently with no damage.

The Motors

You may certify Level Three with any commercial motor that has been approved by Tripoli or NAR. This includes both solid-fuel reloadable motors and hybrid motors. But it does exclude experimental motors. The reloadable motor must exceed 5120.01 newton-seconds in total impulse, and it must be assembled by the person who is seeking certification. The most common motor diameter sizes for Level Three flights are 75mm and 98mm. Generally, the 98mm motors have more total impulse, but they are also more expensive.

16

Building Your First Level Three Motor

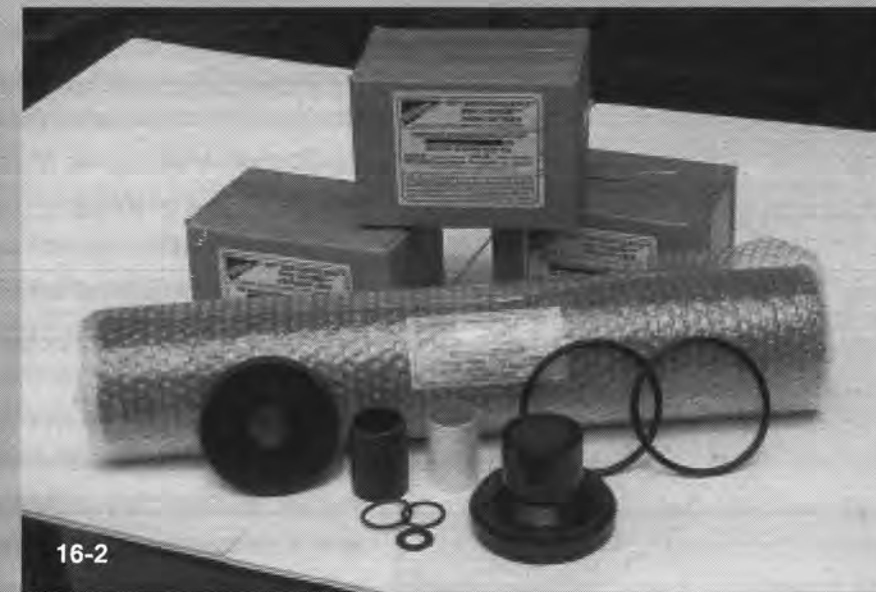
Loading the biggest motors in high power can be quick, fun and easy

There are a number of high-power reloadable motors that are appropriate for Level Three certification. The majority of these motors are in the 75mm and 98mm range. These motors are sometimes referred to as three-inch (75mm) or four-inch (98mm) motors. The foremost manufacturers of three-inch and four-inch motors are Aerotech, Animal Motor Works, and Cesaroni Technology.

16-1

As discussed in previous chapters, Level Three motors generally do not have motor-based ejection charges. The forward closure is often plugged on these motors, although some motors have a smoke charge in place of a delay grain. The smoke charge makes it easier to track the rocket at the high altitudes that M and N motors are capable of reaching in the right rocket. As for the ejection charge, it is assumed that any rocket using these large motors has on-board electronics to take care of deployment and recovery. So no black powder is supplied with these motors.

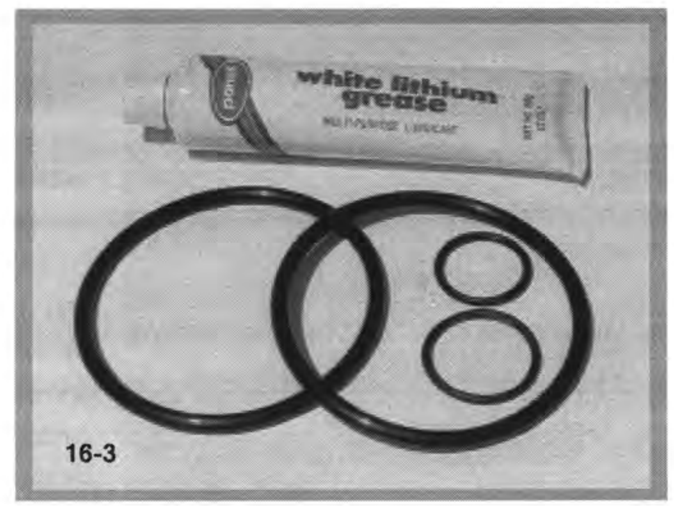
The great thing about most Level Three motors is that, even though they are much more powerful



16-2

This is what they look like: A reload kit for a 98mm Aerotech M1419. The boxes contain the three large fuel grains. The liner is wrapped in bubble wrap. This motor reload fits into a 98/7680 motor casing. Both Animal Motor Works and Cesaroni also make solid fuel Level Three certification motors.

than smaller motors, they are just as easy--if not easier--to load. The average M or N motor has the same number of parts as the smaller reloads. In fact, an Aerotech M motor has fewer parts than an Aerotech H motor. So if you have mastered the fundamentals of reloadable motors in Level One and Level Two, you will have no problem moving up to three- and four-inch motors when you are ready.



16-3

The selection of M and N motors has also expanded in the last few years. Animal Motor Works offers the widest selection in the 75mm category, with at least seven motors. In the 98mm range, Aerotech offers the biggest selection, with six motors. Ellis Mountain still makes a 76mm (not 75mm) motor and Cesaroni makes a 98mm M and has recently released a 150mm O motor for production. Hybrid motors are also available in the M range.

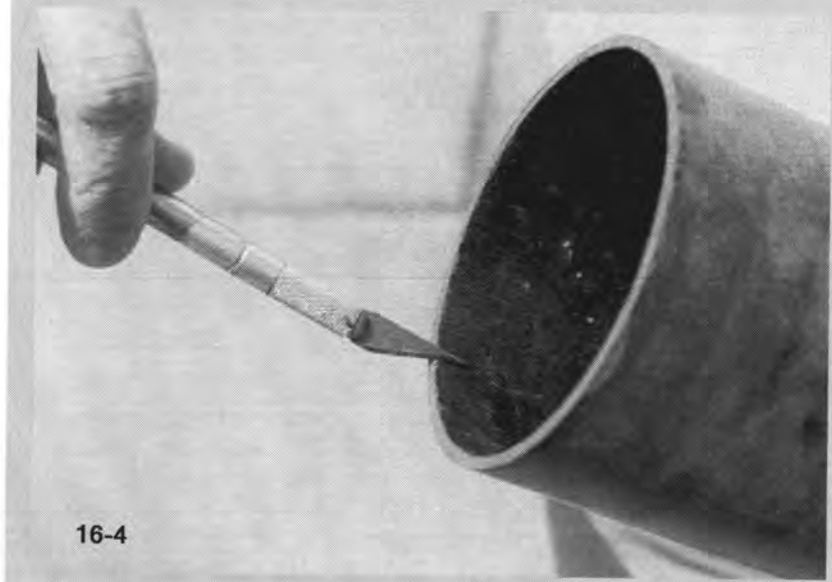
Unfortunately, as with smaller motors, the reload packages are gnerally not interchangeable among the manufacturers. So if you are flying an Animal Motor Works M motor, you will need an AMW casing. For an Aerotech motor, you need an Aerotech casing, and for a Cesaroni motor, a Cesaroni casing.

The purpose of this chapter is to illustrate the assembly of a four-inch motor.

The Aerotech 98mm M1419

One of the most popular Level Three reloads is the Aerotech M1419. With an average thrust of 1419 newtons and a burn time of close to six seconds, this 98mm motor produces a huge column of thick white smoke and is excellent for Level Three certification. The reload currently retails for nearly $400. See photo 16-2.

The M1419 is a three-grain motor with a total weight of nearly 15 pounds loaded in the casing.


16-4


16-5


16-6

The casing for the motor is the 98/7680, available from either Aerotech or Dr. Rocket. In our example, we will be using the red Dr. Rocket case.

Assembly of the Motor

For assembly of this motor, you will need Super Glue or 5-minute epoxy, a piece of sand paper (80-320 grit), a hobby knife, and some grease. To prepare for assembly, debur the inside edges of both ends of the motor liner with your hobby knife (a piece of sandpaper will also work here), as illustrated in photo 16-4.

Once this is done, test-fit the forward insulator disc and then the nozzle on both ends of the liner. If either part does not yet fit perfectly, then keep deburring the liner until it does. Also debur the inside edges of the black smoke charge insulator, as seen in photo 16-5. Then, test-fit the smoke charge into the insulator.

Now apply grease to the four o-rings in the Aerotech kit. The important thing is to coat each o-ring with some grease–but not too much. Do not use any more grease than is required to give the o-rings a shiny appearance. And be careful that the grease does not pick up any dirt or debris in the process. Do not put the grease away yet.

Pick up the smoke-charge insulator again, and put some grease on the outside of the insulator, as shown in photo 16-6. Now, do the same thing with the 98mm motor liner. Again, it is not

necessary to use too much grease on either the insulator or the liner–just enough to give both a shiny appearance. The grease on both parts aids in the disassembly of the motor after launch.

The Forward Closure

Actual assembly of the M1419 begins with the forward closure. You may recall that, in smaller Aerotech motors, the forward closure contains the delay grain element and the ejection charge. This is not the case in the M1419.

There is no ejection charge in the M1419. Instead, the forward closure contains a smoke charge.

As illustrated in photo 16-7, the forward closure of the 98/7680 casing has a recessed well for the smoke charge.

Hold the closure in one hand with the open cavity facing skyward. With the other hand, pick up the black smoke charge insulator and place it into the well, as illustrated in photo 16-7. The insulator should be fully seated against the forward end of the cavity.

The smoke-charge insulator will receive two o-rings and a fiber washer. See photo 16-8. The rings will be placed into the insulator prior to insertion of the charge.

The inner and outer o-rings are placed into the insulator first. Then place the fiber washer on top–and actually between–them. See photos 16-9 and 16-10. All three parts should be nearly flush against the bottom of the cavity in


16-7

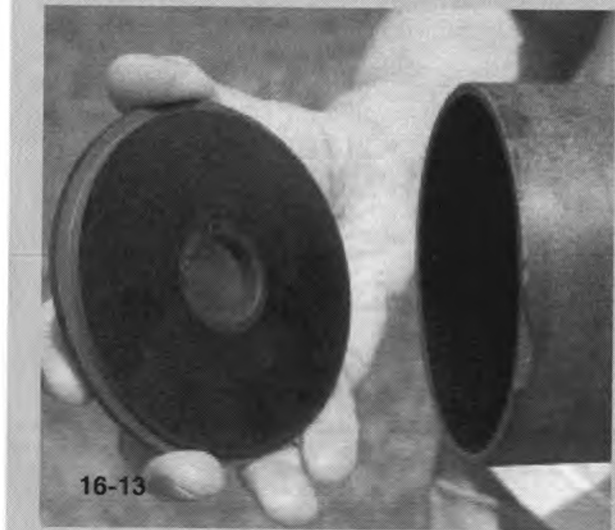

16-8


16-9


16-10


16-11


16-12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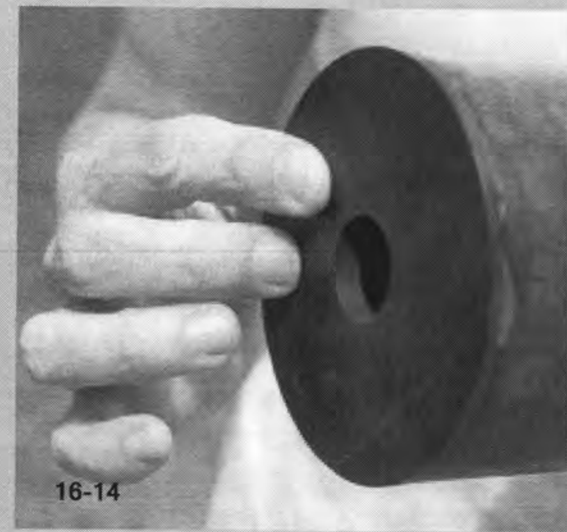
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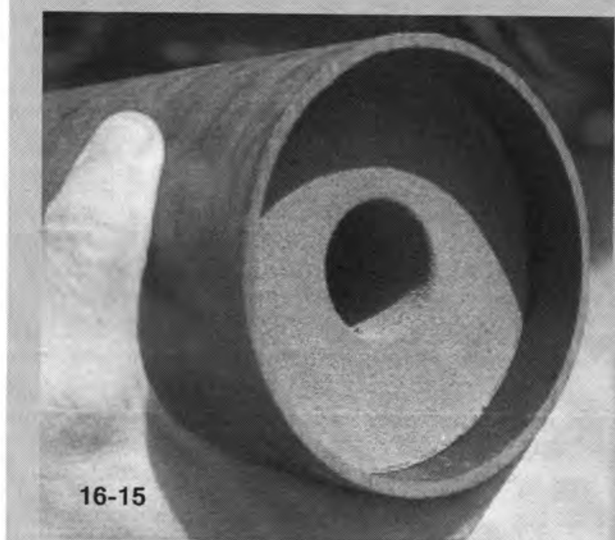
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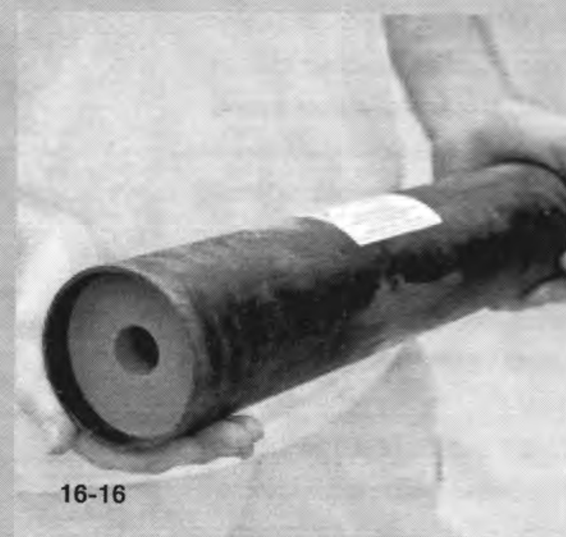
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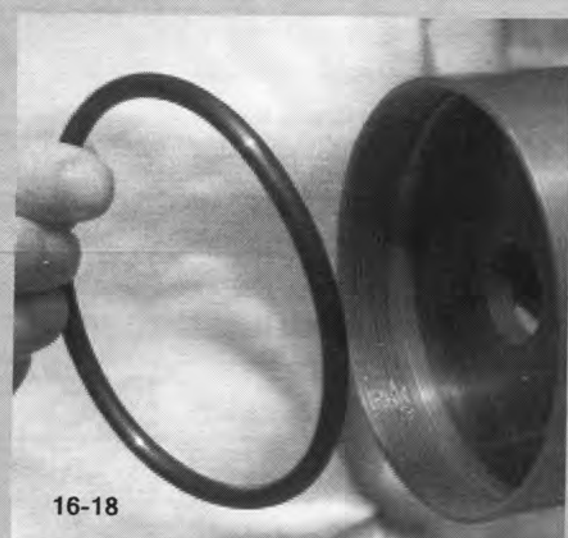
16-17


16-18

the forward closure. Now, place a liberal amount of grease on one end of the smoke charge. See photo 16-11. Then place the charge into the forward closure, greased end first. The charge should be fully seated against the o-rings and washer.

As noted in Aerotech's instruction sheet and illustrated in photo 16-12, the smoke charge element will protrude above the black smoke charge insulator by 1/32" to 1/64". This is normal. Do not try to squeeze or force the element all the way into the forward closure.

Set the forward closure assembly aside for a moment.

Installing the 98mm Propellant Grains

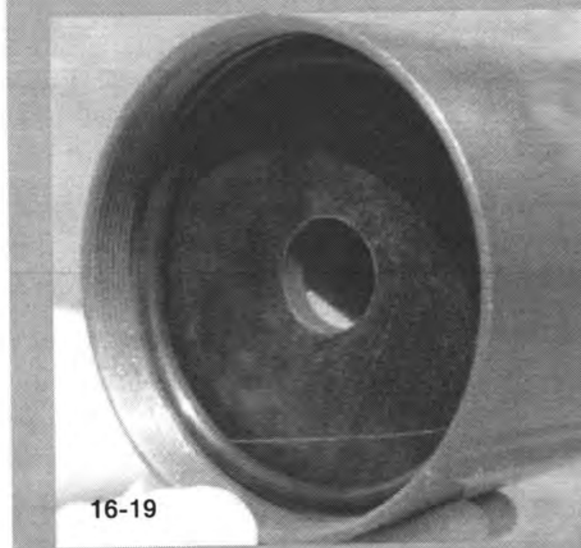
It is time to assemble the motor liner and insert the propellant grains into the liner.

First, once again test-fit the black forward insulator disc on one end of the motor liner. If the disc does not fit, take out your hobby knife, and gently debur the inside edge of the liner to allow a good fit for the insulator. Once the proper fit is obtained, remove the insulator disc, and place a small amount of Super Glue or 5-minute epoxy on the reduced-diameter flange of the insulator. Then reattach the insulator to the liner. See photos 16-13 and 16-14. Be sure to wipe away any excess glue or epoxy where the insulator and the liner meet.

Once the adhesive has dried, turn the motor liner around and carefully slide in all three of the M1419 propellant grains. With the inside of the liner filled with the three grains and the outside of the liner coated with a small amount of grease, push the entire assembly into the 98/7680 motor casing. The liner assembly should be equally recessed from either end of the case. See photos 16-15 to 16-17.

Next–and as illustrated in photo 16-18–pick up the greased forward o-ring, and place it into the forward bulkhead against the previously attached forward insulator disc. See photo 16-19.

With the o-ring in place, pick up the forward closure assembly. Place a small amount of grease on the threads of the closure, and then carefully thread it into the motor case by hand until it is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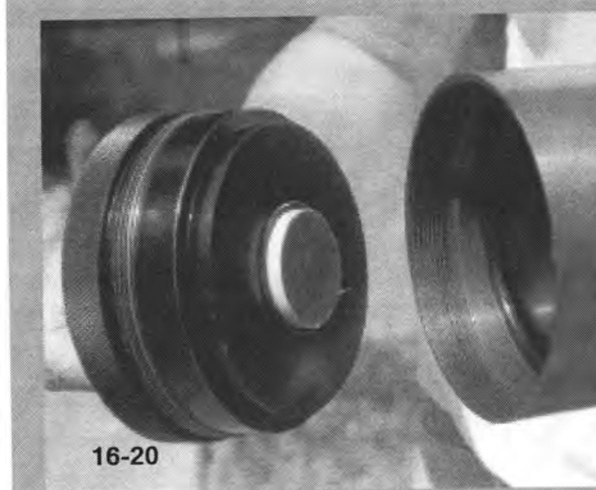
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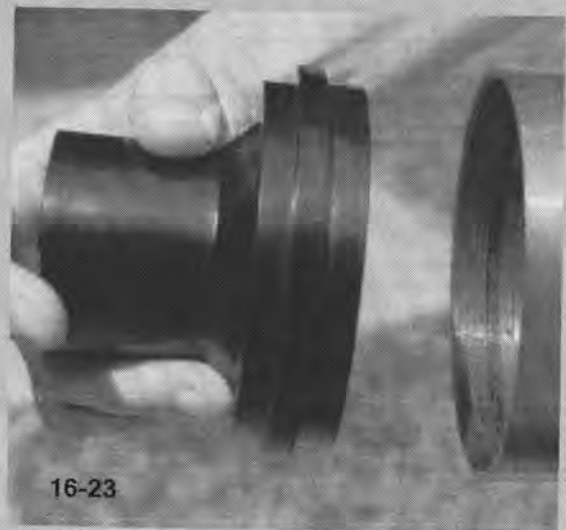
16-21


16-22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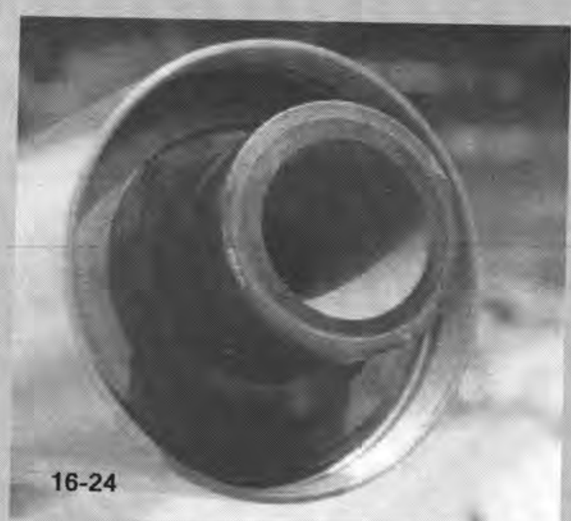

16-24

seated against the end of the 98/7680 case. See photos 16-20 and 16-21.

Placing the Aft Closure and Nozzle

As illustrated in photo 16-22, the 98mm nozzle in the M1419 is sturdy and large. Keep in mind that, as with most Aerotech motors, the nozzle is used only once, then it is discarded (It is helpful though to keep an old nozzle in your rocketry box to test-fit custom igniters, as discussed in Chapter 5.)

At this point in the assembly, one end of the motor case should still be open. Pick up the black exhaust nozzle and place it into the open end of the case until it is fully seated on the liner. Be sure that the shoulder and groove on the forward side of the nozzle (the side facing the case) fully engages the motor liner. If for some reason it will not fit, then remove the liner assembly and the grains, and once again debur the inside edge of the liner. See photos 16-23 and 16-24.

There is still one large o-ring left. Place this o-ring into the groove between the exhaust nozzle and the case, as shown in photos 16-25 and 16-26. Again, be sure the o-ring fully seats against the nozzle.

Now pick up the remaining closure for the case. Place a small amount of grease on the threads of the aft closure, and gently tighten the closure onto the case by hand. See photo 16-27.

As pointed out by Aerotech in their written instructions for assembly, there is often "considerable resistance" to threading the aft closure for the last 1/8" to 3/16". This resistance occurs as the closure is tightening against the o-ring, which in turn will prevent any gases from escaping during flight. It is normal for a gap of between 1/16" and 1/32" to remain between the closure and the case after tightening. Do not try to eliminate this gap, as you may damage the o-ring.

One the aft closure is tightened, the aft end of the rocket should appear as shown in photo 16-28.

The M1419 is now ready to go. This motor should be tightly secured in any rocket. Without a good means of positive motor retention, it may fall

out of the aft end of the rocket after the fuel is consumed. (See Chapter 5 for a discussion on motor retention.)

The igniter for the M1419 is installed on the pad after the rocket is in the vertical position and after the electronics in the rocket are armed. Be sure that the alligator clips on the pad are cold (the system is off) when you place the igniter into the aft end of the motor.

Also, and as pointed out in Chapter 5, be prepared to use an igniter that is attached to a thin wooden dowel so the igniter head has no problem extending the full inside length of the propellant grains. Keep in mind that an electric match by itself will probably not produce enough of a spark to ignite the average 75mm or 98mm motor. So use a pyrogen-tipped igniter or modify your electric match with suitable propellant (see Chapter 5).

This is a powerful rocket motor. As always, carefully read the Aerotech instructions that come with the M1419 before you begin assembly. If any of the instructions are not clear to you, ask for help or contact Aerotech. As you can see, this is not a difficult motor to assemble, but all the parts are important, and each step must be followed to ensure a successful launch. And be sure to adhere to the safety rules of either Tripoli or NAR with regard to pad placement and safe distances.

Remember that the *minimum* safe distance for an M motor launch is 300 feet from any spectators or other rocketeers. Also be sure to clear any flammable materials, such as weeds or dry grass, from around the rocket's launch pad. The M1419 produces a large flame and can easily set fire to combustible materials nearby.

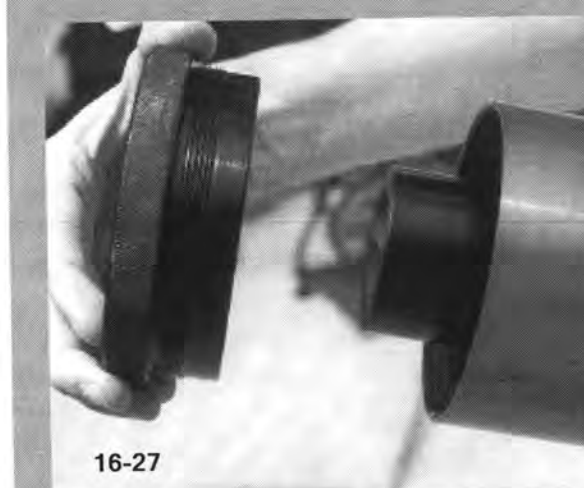
Cleanup after the Launch

After flight, clean up the remains of the M1419 as soon as feasible once the motor fully cools. The metal motor case will remain hot for up to an hour, if not longer. So do not rush in too quickly.

However, do not wait until the next day or the next launch, either. The debris of the M1419 can be corrosive and may adhere to the casing and the

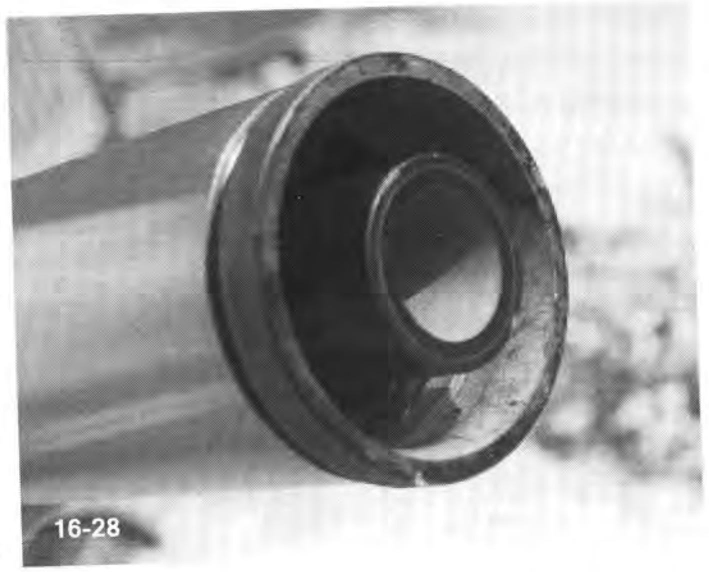

16-25


16-26


16-27

forward and aft closures if not completely cleaned in a reasonable amount of time. A 75mm or 98mm casing and closures are a significant part of your investment in high-power rocketry. Treat them properly, and they will last for many, many flights.

If you applied grease to the components during assembly, the closures should come off pretty easily, and the entire motor liner should simply slide out of the case. If the liner needs a little prodding, gently push it out with the end of a piece of wood, such as a broom handle. An old, discarded liner works well for this task, too. Be sure to wipe clean the inside surfaces of the case and the closures. For more information on motor cleaning, see Chapter 17.


16-28

Conclusion

There are few things at a local or regional launch that command the attention of the entire crowd like a three-inch or four-inch motor. These motors are produced not only by Aerotech, but also by Animal Motor Works and Cesaroni Technology (including Hypertek hybrids), and others. These motors are powerful and expensive and can lift large rockets 10,000 feet into the air–or higher (the altitude record for a single M motor is more than 25,000 feet, on a minimum-diameter rocket).

By reading the manufacturer's instructions and asking questions along the way, you will find that your use of high-power motors like the M1419 can be a fun and rewarding experience.


16-29

Manufacturer	Motor	Size	Case	Total Impulse	Burn Time
Aerotech	M1550R	75	75/6400	5600	3.6
AMW	M1350WW	75	75/6000	5725	4.2
AMW	M1480RR	75	75/6000	5790	3.9
AMW	M1850GG	75	75/6000	5920	3.3
AMW	M1900BB	75	75/6000	6008	2.8
AMW	M2200SK	75	75/7600	6325	2.8
Aerotech	M1315W	75	75/6400	6713	4.9
Ellis	M1000P	76	76mm	7320	7.3
AMW	M3000ST	75	75/7600	7370	2.5
Cesaroni	M2505P	98	Pro98	7450	2.9
Aerotech	M1419W	98	98/7680	7680	5.4
Aerotech	M2400T	98	98/7680	7716	3.2
AMW	M2500GG	75	75/7600	7800	3.1
Aerotech	M2000R	98	98/10240	9218	4.6
Aerotech	M2500T	98	98/10240	9671	3.8
Aerotech	M1939W	98	98/10240	10,481	5.4
Aerotech	N4800T	98	98/15360	13,347	4.4
Aerotech	N2000W	98	98/15360	19,361	6.9
Cesaroni	O5100P	161	Pro150	29,990	5.8

Diagram 16-1

Note: The information contained in this table is for quick reference only for solid fuel motors. (For hybrids, see the Hypertek web site for a current listing.) It was compiled from data on the web sites of the various manufacturers and the Tripoli Motor Testing pages at www.tripoli.org. Always check with either Tripoli, NAR, or the manufacturer for the latest information on any Level Three motor you intend to use for the first time. New motors are often added to the certified list, and old motors may be dropped. In addition, there are some minor discrepancies regarding published burn times and average thrust for some of these motors. Total impulse is measured in newton-seconds.

17

Cleaning Reloadable Motors

Keeping your motor casing and closures clean will help them last a long time

The Tools

It doesn't take much to clean a high-power motor. A wire scrub brush, some Handi-wipes or similar cloth, and a bit of newspaper will do the trick. Household cleaners such as Formula 409, Simple Green, or white vinegar will remove stubborn debris. Disposable gloves are helpful to keep the gunk off your skin. With a little practice, most high-power reloadable motors can be cleaned in 10 minutes, or less. Ideally, clean the motor within a day of launch.

Reloadable high-power motor casings and closures are among the most significant investments a rocketeer will ever make in this hobby. The casings and closures will last for dozens of flights–if not longer–if they are cared for properly.

The basic cleaning procedures for high-power motor casings are the same for most brands, although Cesaroni Technology motors are the easiest to clean, because they have fewer parts. In a Cesaroni motor, the entire reload slides in and out of the casing and is discarded, with very little actual cleaning required. In the first example in this chapter, we will clean an Aerotech 98mm M1419.

This California flyer knows that a good bottle brush is great for cleaning motors.

Cleaning the M1419

Cleaning a motor casing actually begins with a few steps taken prior to launch. If the o-rings and the motor liner were properly greased when the motor was loaded, cleanup should proceed smoothly. This is especially true for Animal Motor Works and Aerotech motors. The liner will slide

A sign of things to come? At LDRS23 in Geneseo, New York, one group of young rocketeers took advantage of the general dislike for cleaning motors. Actually, cleaning high-power motors is not difficult as long as you do it promptly and follow a few basic rules. Although at these prices, who would want to?

out of the casing with a minimum of effort, and all the remaining pieces should come apart easily. In lieu of grease, some rocketeers use WD40 on the motor liner and inside the case during assembly of the motor.

The first rule of maintaining casings and closures is prompt cleanup of the motor within a reasonable time after recovery of the rocket. But always wait until the motor cools down before attempting to handle the case. High-power rocket motors generate tremendous amounts of heat during flight. Motor casings can remain *very* hot to the touch for 30 minutes or more after recovery, especially large motors like the M1419. So be careful when removing any casing from a rocket that was recently recovered and, when in doubt, use insulated gloves.

As illustrated in photos 17-3 through 17-5, an old newspaper or other paper material is helpful in cleanup of the M1419. Place the paper flat on the ground or other hard surface, and then set the motor in the middle. Now remove the forward and aft closures. All that should remain of the propellant inside the case will be fragmented pieces of ash and other fine materials.

This is all that is left of the fuel grains after the launch and recovery of the 98mm M1419.

Tip the hollow case on end, tap it with a rubber mallet or other tool a couple of times, and any loose debris inside the casing should slide out onto the paper. Be careful if you are cleaning the motor in windy conditions, as the particles and soot will blow around.

Once the casing is empty of ash and particle debris, push out the motor liner. The liner should come out easily if it was greased prior to flight. If it gets stuck, use a small piece of wood or other object to push it out of the case. A used liner of the same size is an excellent tool for this job. So if you can, save an old liner for each motor diameter that you commonly use in high-


17-4

power rocketry. It may come in handy at cleanup time. Once the liner is out, set it aside, and inspect the case for damage, dirt, and debris. Usually, there is some residue in the case. See photo 17-6. It can be cleaned using a bottle brush or, if you can get your hand in position, with a damp cloth or cleaning wipe. Simple Green and Formula 409 work well here, as does the miracle worker of solvents, WD40.


17-5

Simply spray or apply the cleaner to the inside of the case, work the bottle brush in and out a few times, and then run a cleaning cloth through from one end to the other. If the motor is particularly dirty, you may have to repeat this process.

On long motor casings it can be difficult to get the dirt and grime out of the middle of the case. Try spraying the inside of the case with WD40 and let it rest on some newspaper for a few minutes. Then, crumple up some extra newspaper and place it into the opening of the casing at one end. Run a broom handle through the case, pushing the newspaper the entire length until it comes out the other end. This usually cleans up the hard-to-reach spots.

Be sure to clean the threads of the case. Tiny dirt particles left behind in the threads can cause damage the next time the casing is used. See photo 17-7. So wipe down the threads firmly to remove all dirt and debris. If the debris is hard to remove from the grooves, try using an old toothbrush or similar soft brush to do the job. You can also soak the closures in hot water or white vinegar for problem areas.

The M1419 has an aft and a forward closure. The forward closure holds the smoke charge, and there is usually some residue left after flight. See photo 17-8. The closure should be wiped clean–inside and out–with Wet Ones or a similar cleaner. The aft closure is easier to clean because it is essentially a hollow ring that can be wiped down easily.

Photo 17-4 illustrates the disposable remnants of the M1419. Again, it is not a bad idea to keep an old liner around if you have the space. It is also a good idea to keep a spare nozzle in each common motor size as well. Old nozzles should not be reused, but they can be helpful if you need to test-fit a homemade or modified igniter in a similar-sized motor.

Otherwise, dispose of the entire mess. If you cleaned the motor out on newspaper, simply roll up the paper so it wraps around the debris, and throw it away.

Cleaning the Aerotech J350


17-9

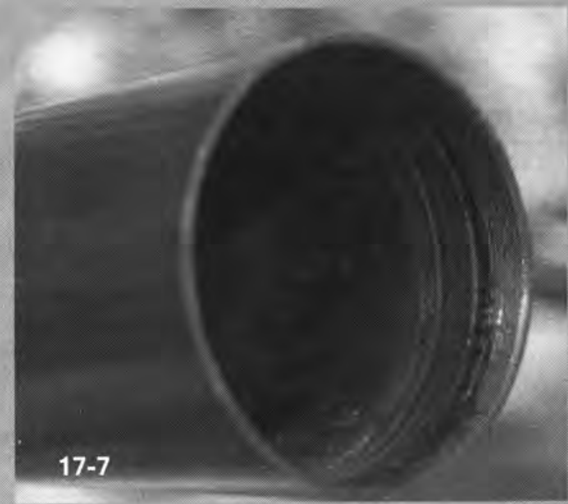
If you wait too long to clean the motor, you may need help getting the closures off the case. Here, Vise-grips are used to remove the forward closure on the J350.

Our second example illustrates the cleanup of a 38mm J350. This Aerotech reload was packed in a Dr. Rocket motor casing, and, for test purposes, we did not clean it out for several months after flight.

The first thing we had to do was remove the forward and aft closures. Since the motor had been sitting for so long, it took a pair of Visegrips to dislodge the forward closure. See photo 17-9. The aft closure came off with less effort. Occasionally, it is very difficult to remove the closures, even if you do not wait. This can occur if you forget to place any grease on the threads prior to flight.

One Internet method suggested to free up


17-6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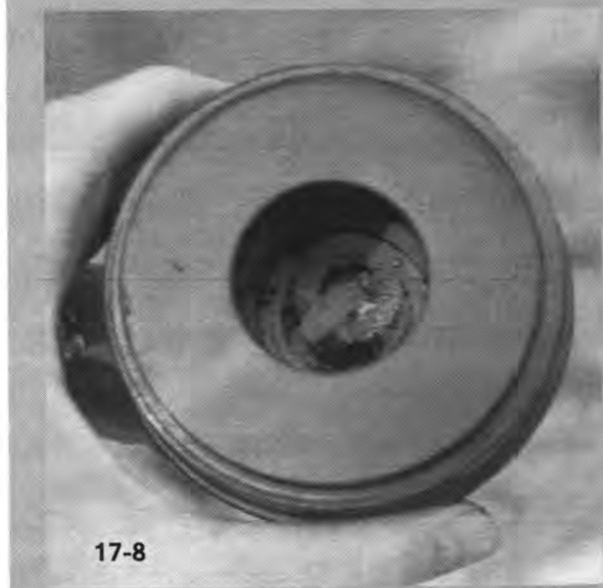

17-8

Old PARTS

Not all parts from a reloadable motor should be thrown away. Keep at least one used motor liner for every diameter motor you own. The old liners can be used to force out stuck liners in future motors. Old nozzles may also come in handy for test-fitting modified igniters. In AMW motors, the nozzle, snap rings, and steel washers are reused. Some AMW motors also reuse their nozzles. O-rings in all motors should be used only once. After that, throw them away.

17-10

stuck closures involves a freezer and hot water. Take the entire motor and place it in the freezer for an hour or so. Then remove the motor and run hot water over the case and closures in the sink. This may loosen the closures, and with a pair of pliers or Vise-grips you should be able to finish the task.

Removal of the motor liner was difficult because the casing had not been cleaned promptly. Eventually, using a large wooden dowel, we were able to get enough force on the liner to push it out of the motor case. Photo 17-10 shows the debris from the motor after the closures were opened and the motor liner was removed. The inside of the case was not too dirty, but the residue had been sitting for a while, so we used a bottle brush and Formula 409 to thoroughly clean and rinse it.

17-11

The delay element in this forward closure was stuck and hard to remove.

The forward closure was difficult to clean because we could not remove the delay element. But with a little patience and a pair of needle-nose pliers, the element was retrieved, and the inside of the closure was cleaned up with a Wet Ones cleaning cloth. See photos 17-11 and 17-12.

This motor had been flown in a rocket with dual deployment controlled by on-board electronics. There was no motor-based ejection charge. Hence, there was no black powder in the forward closure. Instead, grease was placed in the closure prior to flight. The well had been sealed with a sticker.

The seal was removed and, as illustrated in photo 17-13, the grease was also cleaned out of the well with a Wet Ones cloth.

The used nozzle is shown in photo 17-14. As you can see, the J350 nozzle is worn and caked with debris. It should be discarded. The nozzle's aft closure is cleaned with cloth.

Keep in mind that not all motors use disposable nozzles. Animal Motor Works, for example, uses graphite nozzles that last for many flights.

When a reusable graphite nozzle is removed, it should be immersed in water for several minutes to dissolve any residue. See photo 17-15. When you pull it out of the water, check for any debris that remains, especially in the throat of the nozzle. Use a small hobby knife to gently scrape away material that was not removed in the water.

Animal Motor Works cautions in its motor instructions that the nozzle should not be stored in the casing unless it is greased. Storage of an ungreased nozzle in the case can lead to case corrosion. Many rocketeers simply clean the nozzle and then

17-12

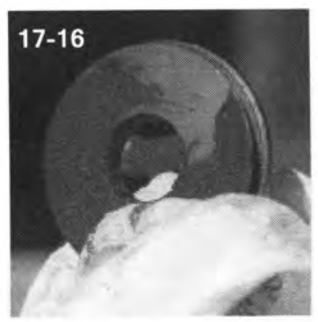
17-13

17-14

17-15

store it alone, wrapped in a clean cloth in a dry environment. This should keep the nozzle in good condition over time.

The Aerotech J350 has an aluminum seal ring. The red ring in our example was completely black and covered in debris that was hard to remove, but eventually the dirt came off with a little elbow grease and a lot of Formula 409. See photo 17-16.



17-16

When all of the parts were thoroughly cleaned, the seal ring was placed into the case, and the forward and aft closures were threaded on. We also placed a tiny bit of grease on the threads of the closures to keep the threads lubricated.

Cesaroni Technology Motors

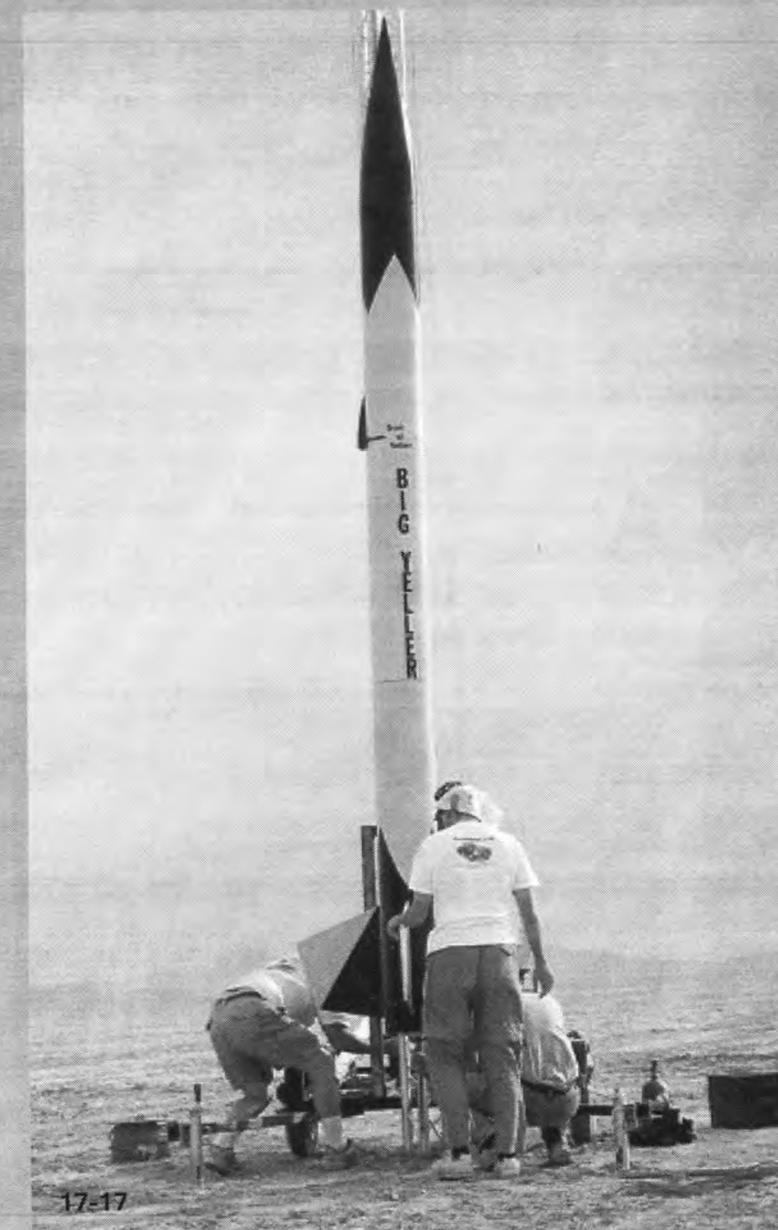
As stated above, Cesaroni Technology motors are the easiest to clean among high-power reloads. The typical Pro-series motor has virtually no internal parts. The nozzle, fuel grains, and motor liner are one assembly. There are no separate forward or aft closures. After flight, the entire inside of the case is removed and discarded. The case is simply wiped down and is ready to be loaded again immediately.

Motor cleanup is often done at the field, sometimes between launches. Since it is important to keep your hands clean while loading a new motor, always wash up after motor cleanup.

There are many personal products available at any supermarket or drugstore that offer waterless cleanup on a dirty launch field. Purell hand cleaner will clean up dirt, grease, or oil from your hands without any water. Wet Ones and similar wipes will do the same.

Prompt motor cleanup is good practice and will ensure that your casing and closures last a long time. Most high-power motors can be completely cleaned in ten minutes or less if you do not wait too long. The first few hours after a flight are the best time to clean the case. In fact, Animal Motor Works notes in some of its instructions that the motor is easiest to clean about thirty to sixty minutes after flight, when it is still slightly warm to the touch. This is good advice. However, even up to twenty four hours after launch will do.

But do not wait until the next launch.



17-17

Rocketeers prepare "Son of Big Yeller" on a launch pad in the Black Rock Desert in Nevada in 2004. The rocket was launched on a Richard Hagensick experimental O motor.

The DESIGN

Software programs such as RockSim and SpaceCAD allow you to design your own rocket on your home computer before you begin building. These and other programs help scratch-builders to visualize the construction of a rocket right down to the fins and centering rings inside the airframe. Programs can also run flight simulations with the motors of your choice to evaluate performance prior to any actual flight.

18

Introduction to Scratch Building

With a little time and practice, some people can make anything fly

An entire book could be devoted to the art and science of scratch-building in high-power rocketry.

The purpose of this concluding chapter is to provide a brief overview of some of the basic elements of scratch-building and to give aspiring rocket builders a preview of the skills necessary to build, from raw materials, their own rocket.

18-1

Rocketeer Jim German with his tetrahedron on M power at the 2003 Freedom Launch.

Designing a Rocket

The design of a scratch-built rocket is limited only by the imagination, skill, and pocket-book of the builder. A scratch-built rocket may be based on science fiction stories, or theoretical space-craft, or even the real thing. At national launches, such as LDRS, scratch-built rockets now include incredible replicas of rockets flown by the United States, Russia, and China.

Scratch-builders also like to create upscaled versions of their favorite model rockets built by companies like Estes or Quest. It is not uncommon to see rockets, such as a 100-pound upscale Estes

18-2

Scratch-builders construct everything from ordinary looking rockets to wild spacecraft. Here, master rocket builder Ed Miller of Pennsylvania with his scratch-built UFO Flying Saucer at LDRS23 in New York. The saucer flew on M power (see photo below.)

Mosquito, that fly on multiple M motors, or Fat Boy rockets that are increased to 7.5 inches in diameter and fly on K motors.

Some scratch-built rockets do not resemble conventional rockets at all, and you may see 170-pound flying tetrahedrons, giant beer bottles, flying saucers, oversized crayons, and large spools of wood.

18-3

No matter what the shape or ultimate design, creating your own rocket from scratch does require a certain level of proficiency beyond that of the novice rocketeer. Scratch-building a high-power rocket is best attempted by those who have gained at least some experience in the construction and flight of high-power kits of proven design and safety. That said, there are a number of resources available to help you get started.

The Internet, Magazine Back Issues and Rocketry Software Programs

One of the best places for scratch-building research is Rocketry Online. This web site contains many links to technical articles describing scratch-building techniques as well as examples of step-by-step construction projects. Rocketry Online also links to web sites that illustrate scale rockets and offer photographs and drawings of military and civilian spacecraft and missiles.

Additional resources include the high-power magazines, starting with *Extreme Rocketry*, *High Power Rocketry*, and *Sport Rocketry*. These magazines regularly include stories on the construction of rockets and many scratch-building tips and techniques.

The bibliography to this book cites a number of

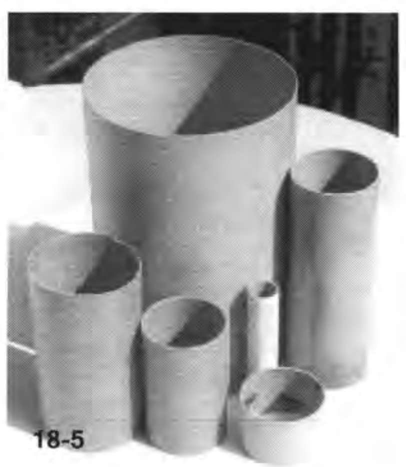
Scale ROCKETS

Where do you find scale-rocket information and data for real rockets? The best resource is probably Peter Alway's book *Rockets of the World*, available from Saturn Press. This book contains detailed drawings and measurements of hundreds of rockets from many nations, including scores of U.S. military and space vehicles. Another resource is NAR Technical Services (NARTS), where scale drawings of some rockets are also available online. Of course, you can also search through libraries and government archives. But, in many cases, Alway and NARTS have done that work for you.

18-4

how-to construction and painting articles by people such as Brad Vatsaas (*Extreme Rocketry*) and Ed Miller (*High Power Rocketry*), who provide tips on scratch-building techniques. Many back issues of these magazines are still available.

There are also computer programs available to help with the design and engineering. For example, SpaceCAD and RockSim produce their own software packages that assist in the construction and design of model and high-power rockets, including parachute selection and calculations of center of pressure and center of gravity. These programs and others allow the scratch-building rocketeer the opportunity to design and build a rocket on the computer and then virtually launch it with flight-simulation programs. The flight programs can give you a pretty good idea as to whether your particular design is airworthy or not.



18-5

Scale Projects

Scratch-built projects are frequently large rockets scaled down, which means the builder has taken drawings and measurements of life-sized rockets and reduced them proportionately to a size suitable for hobbyists.

For example, a builder may wish to take a full-size Pershing missile and reduce it to a high-power rocket with the common body tube

diameter of six inches. With a little online research or a trip to the local library, the builder can obtain the rough measurements of the actual Pershing and all of its external parts (fins, nose cone, etc.) and then scale those dimensions down to a much smaller airframe.

Rocketeers may also design rockets upward in size. It is becoming increasingly popular to upscale model rocket kits to sizes that can handle high-power rocket motors. In either case, the builder must use the same basic math to convert a rocket to another size. The equations are simple.

18-6

Upscaling model rockets is popular in high power. Here, Woody Hoburg makes ready his spectacular 100-pound upscaled Estes Mosquito. Note the smaller (but still upscaled) Mosquito in the foreground. Hoburg's rocket flew on multiple M motors.

Let's consider an uncomplicated example. Assume the builder wants to make a high-power scale rocket based on a military missile. The first step is to obtain the dimensions of the actual rocket, including the height and diameter of the airframe and the dimensions of the fins and the nose cone. Assume for the purposes of our example that the height of the rocket is 20 feet and the diameter of the airframe is 24 inches.

The next step is to choose the diameter. Usually this comes down to choosing which common high-power rocket-tube diameter is right for the scale model. This is an important consideration. There are several common airframe sizes available from rocketry retailers. By choosing one of the common sizes for your project, you increase the availability of parts for the rocket, which, in turn, should make construction flow smoothly. Of course, there are also Sono tubes and other potential airframes available at home-improvement stores. Sono tube is available in a wide variety of diameters. A Sono tube that has been fiberglassed will work fine for high-power. The bottom line is to pick some airframe tube size–whether a common one or not–that you are sure you can obtain once construction begins.

For our example, we picked a common 6-inch-diameter airframe. Once the size was chosen, the scale factor can be obtained. If we are going from a 24-inch-diameter rocket (the actual missile) to a 6-inch scaled model, we simply divide 24 by 6 to obtain a scale factor of 4. The scale factor is then used for all other measurements of the rocket. The height of the original rocket is 20 feet. Using the scale factor, we divide 20 by 4 to obtain a height for the high-power rocket project of 5 feet. So the scale rocket will be six inches in diameter and five feet in height.

A similar process is followed to upscale a smaller rocket into a larger rocket. But instead of dividing by the scale factor to downsize, the builder multiplies by the scale factor to upsize. For example, if the model rocket is only 2 inches in diameter and the goal is to build an upscaled version that is 16 inches in diameter, divide 16 by 2: The scale factor is 8. If the model rocket is 2 feet tall and the scale factor is 8, you multiply the scale factor by the model rocket's height to reach an upscaled height of 16 feet.

Building Materials for the Scratch Builder

The materials used today in high-power rocketry include Kraft paper, phenolic tubing, Quantum tubing, sono tube, fiberglass, Kevlar and even carbon fiber.

Kraft paper and phenolic tubing are probably the most common types of airframe material used for model rockets and for basic high-power rockets. These materials are suitable for scratch-built rockets as well. Kraft paper and phenolic tubing are available from many rocketry retailers. The tubing is usually sold by the foot and is available in all of the popular airframe sizes and all of the major motor sizes, too. Quantum tubing is a hard plastic-type tubing that is sold by Public Missiles Systems and also comes as standard airframe material in some Public Missiles rocket kits. Quantum tubing is strong and easy to paint.

Airframe tubing is also available in fiberglass and carbon fiber. Both of these materials are popular in high-power, as they are suited for rugged use and can withstand almost any high-impulse motor. Carbon fiber has the added advantage of being lightweight–an important quality in rockets seeking high altitudes. The only real drawback to either fiberglass or carbon fiber is expense. Both types of airframe tubing are expensive. For example, a 6-inch-diameter piece of phenolic tubing that is 48" in length costs less than $40. The same section of tubing in fiberglass (not cloth--actual fibergalss tubing) can cost more than $150. Carbon fiber is even more expensive.

One of the most popular–and also the cheapest–airframe tubes is ordinary Sono tube. Sono tube is used in the construction industry for making concrete forms. It is available at home-improvement stores in sizes beginning at around eight inches in diameter, and can cost as little as $10 (or less) for a four-foot section. Sono tube is used in many large rocket projects for high-power airframes up to 36 inches in diameter. But it is not used without some modification.

18-7

Tripoli member Rod Lovley of California turned ordinary 10-inch Sono tube into the beautiful rocket below. The airframe was fiberglassed. The nose cone was scratch-built, and the fins were cut out of sheets of G-10 fiberglass.

18-8

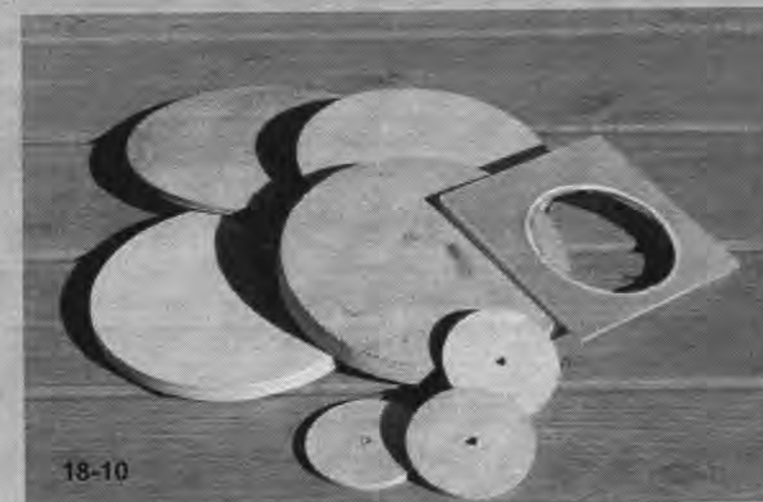
Stock Sono tube has a tendency to dent or deform easily–especially under the rigors of repeated high-power rocket launching. For this reason, rocketeers apply fiberglass cloth to Sono tube to increase its strength and overall durability. Fiberglass cloth and epoxy may be obtained at hardware stores, hobby shops, home-improvement centers, boat stores, and rocketry outlets. Fiberglass cloth comes in many weights and is usually labeled as two-ounce, six-ounce, ten-ounce, etc. Cloth weights between two and six ounces are common in high-power rocketry.

In lieu of fiberglass cloth, rocketeers can also cover their airframes with Kevlar or carbon fiber. As set forth above, these materials are more expensive than fiberglass, but they provide maximum strength when it is needed.

The application of fiberglass to Sono tube or other rocket

Continued on page 324

18-9



18-10

18-11

Case History

Scratch-built FLORIDA

My name is Rick Boyette, and I have been a member of NAR and Tripoli for many years. I fly out of Tripoli West Palm in Florida.

I've always been a scale-model fan, and I'm also drawn to unusual subjects. Several years ago I was at a hobby shop and saw a 1:48 scale plastic model kit of the Long March 2E Satellite Booster.

Made by Shanghai Dragon of China, the plastic model is 42 inches tall. It is unique and very impressive. I bought the kit but never got around to building it, so it languished in my closet for more than a year.

As I was cleaning out my closet, I came upon the kit and it got me to thinking that maybe the Long March would make for an interesting scratch-built project. I checked the measurements of the main rocket booster and the four strap-on boosters on the model and discovered that LOC/Precision 5.5-inch and 7.5-inch stock tubes were a very close match. I then began thinking about how a large scale model could be built.

The five separate nose cones would be the first challenge. I have a lathe that I could turn the smaller cones on (for the strap-on boosters), but the large main nose cone would be too big. So I called Chuck Sackett in Orlando. He does a lot of custom nose cones. He always enjoys a challenge, so he agreed to do all five nose cones for $500, which sounded like a good deal to me. The cones were turned on a lathe out of solid cedar, then hollowed out. I then scanned the kit decals and enlarged them 274 percent to create the authentic rocket insignia for the Long March.

The design of the rocket posed several additional technical challenges. One of these challenges was how to attach the strap-on rocket boosters. I decided to use two pairs of 12-inch-long all-thread rods with crossing brass tubing attached with epoxy in the main booster. Each pair of opposing strap-on boosters is held in place with wing-nuts on the all-thread rods. The bottom of each booster is secured with a 3/8" bolt. It was a bit tricky to get it all aligned, but it was worth the effort.

Another major challenge was the clear Lexan fins. Lexan is heavy and nothing sticks to it well. I used material that was ¼-inch thick and cut the Lexan with my radial arm saw. The fins had to accommodate the canted motor-mount tube, so I made a template out of scrap plywood and fiddled with it until I was satisfied it would work. I then slotted the template for the centering rings. One of the rings is a standard center-hole ring. The other ring has the hole offset to within half an inch of the edge.

To lock the Lexan in place, I glued parallel strips of spruce to the motor-mount tube and drilled a series of holes in the Lexan to allow epoxy to flow through.

The rocket was launched at LDRS23 in Geneseo, New York, in July 2004. But to get it there, I had to ship it from my home in Florida. That took some more planning. The more components you can break it down to, the better. It's usually cheaper to send two smaller boxes than one huge box, because then the oversize charges kick in. I shipped three boxes and took one on the plane with me. It was over the size limit by a few inches, but they did not charge me the usual surcharge. I guess I looked pretty pitiful. The total shipping charge was about $60, UPS Ground.

The biggest challenge at launch was to get all five motors to light. The rocket carried a central Aerotech L952 and four Cesaroni Technology Pro38 I205s. It weighed in at more than 70 pounds, loaded with motors on the pad.

The launch was spectacular and all of the motors did light–but unfortunately booster number two came apart several hundred feet in the air, and the rocket then shredded.

Still, it was a great project and I plan on building it again.

airframes is not difficult, but it does take practice. There are books, magazines and even videos available from fiberglass suppliers that will help introduce the builder to fiberglass. Fiberglass makers such as West System produce brochures, pamphlets and videotapes to accompany their products, which makes the job a little less messy and a lot more fun.

Fiberglass work should always be done with proper ventilation and, on large projects, with as much help from friends as possible. Always read and follow the manufacturer's label and instructions. Typically, the surface of the airframe is roughed up with sandpaper, and the fiberglass cloth is cut to length (with some overlap) to fit a portion of the body tube. The cloth is then set against the airframe and fiberglass epoxy is applied with a brush or roller. The epoxy permeates the cloth, and excess epoxy is wiped away. After several hours, the cloth and epoxy bond to the airframe for a very strong surface. Ridges, air pockets, gaps, and other imperfections in the cloth or epoxy are sanded smooth or filled to prepare the surface for paint.

18-12

18-13

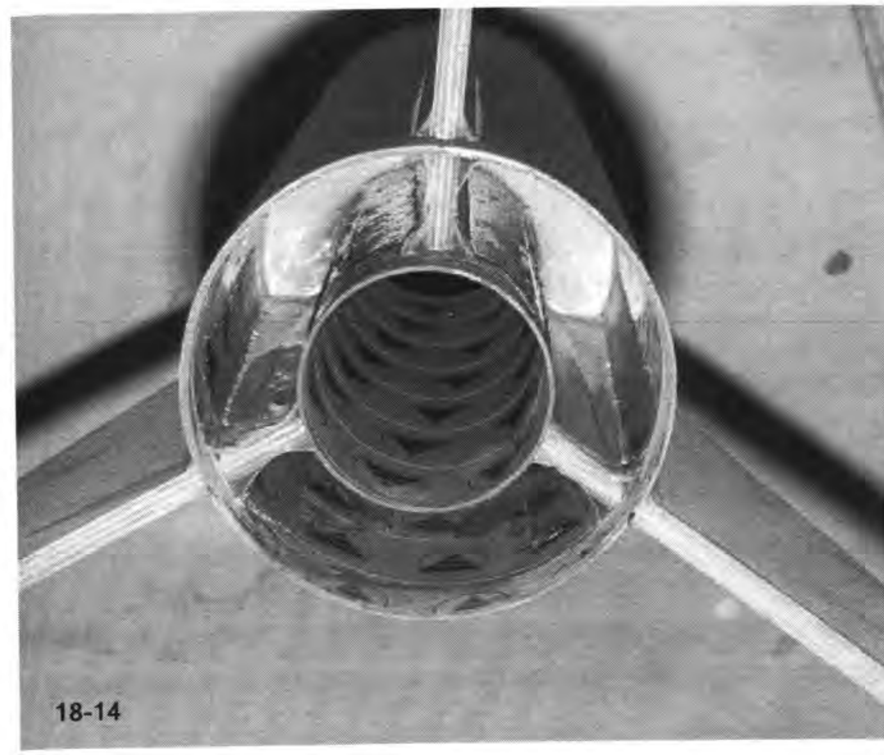
East Coast flyer and long-time rocketeer John Ritz built this flying tetrahedron from scratch. It launched on an Aerotech M1939.

The use of fiberglass in a very large rocket project was the subject of an article written by Ed Milller and others, "Mercury Redstone: Glassmeister's Delight," which appeared in the December 1999 issue of *High Power Rocketry*. This is a good informational story about the building of a very large rocket–thirty feet tall and 24 inches in diameter–with lots of fiberglass. In addition, Brad Vatsaas has written several articles for *Extreme Rocketry* magazine exploring the use of fiberglass in high-power rockets. These resources and the materials available from fiberglass makers should provide a good foundation for getting started with fiberglass.

Joining your local NAR or Tripoli rocketry club will also introduce you to rocketeers in your area, some of whom will be familiar with fiberglass techniques.

Making Your Own Bulkheads and Centering Rings

High-power rockets use centering rings to hold and align the motor mount in place, and they use bulkheads to separate internal rocket compartments from each other. In most rockets, bulkheads and centering rings are made from either aircraft-grade plywood or G-10 fiberglass sheets. Suitable plywood can be found at hobby stores or even home-improvement stores. G-10 fiberglass sheets are available from several rocketry distributors online. Bulkheads and centering rings can be cut by using standard-size hole cutters (used for cutting or drilling doorknob holes) or, for larger rings, a circle cutter. See photos 18-9 through 18-11. A circle cutter is not easy to use on larger-diameter bulkheads, and also requires access to a drill press. A router is also a tool for cutting bulkheads and centering rings, as demonstrated in a step-by-step article by Brad Vatsaas in the September/October 2003 issue of Extreme Rocketry.



18-14

A view of through-the-wall fin attachment in Richard King's upscaled Fat Boy rocket. Note that the wooden fins go through the airframe and attach directly to the motor tube. The fins are joined to the rocket with fiberglass inside the airframe and epoxy fillets outside the airframe. This 7.5-inch-diameter rocket, aptly named "Got M?," flew on an Aerotech M2400.

18-15

Scratch-builders who cannot manufacture these items at home can order them from rocketry shops such as Giant Leap Rocketry, LOC/Precision, or Public Missiles Systems, according to the specifications provided by the builder. These shops–or even a local carpentry shop–can make rings of all sizes, usually for a reasonable price.

If you do your own work with bulkheads and centering rings, be sure to keep your common sense on board, especially when building large projects. And when in doubt, overbuild the rocket with heavier, not lighter, parts.

At a West Coast launch a couple of years ago, one of our Level Three flyers had scratch-built a 24-inch-diameter rocket that he intended to fly on multiple 98mm motors. At ignition, the 14-foot-tall rocket rose off the pad with a combined average thrust of more than 5,000 newtons. It looked great, at least for the first few hundred feet. But only a second into the flight, all of the motors ripped through the rocket lengthwise–from bottom to top–continuing skyward as the broken airframe crashed to the ground.

What happened? Inspection of the debris after flight revealed that the aft plywood centering ring (the ring with the multiple motors) was simply torn apart under thrust. This was not surprising, at least in retrospect. The centering ring was barely a

Continued on page 328

Bowling ball CONTEST

Each year at LDRS, the Arizona High-Power Rocketry Association (AHPRA) sponsors one of the great scratch-building exercises in all of rocketry: the Bowling Ball Loft contest. Rocketeers from all over the country compete to see who can design a rocket that will lift an eight-pound bowling ball to the highest altitude on an I motor (or, in some cases, a 16-pound ball on a K motor).

This event attracts those who have the utmost scratch-building skills, as it requires a lightweight rocket airframe that is capable of sustaining the thrust of an I motor, while at the same time being strong enough to carry a heavy ball thousands of feet into the air.

The rules for the contest are set by the AHPRA. The bowling ball must be drilled and attached with a safety line to a parachute. Parachutes must provide a descent rate of no greater than 21 feet per second, and altitudes are recorded by barometric altimeters.

The overall weight of the rocket is a critical factor in the contest. "I dumped my altimeter because it weighed three ounces," said one contestant in 2004. "The new one weighs only half an ounce." Some rocketeers go even further: "I took the terminal blocks off my altimeter and soldered the wires directly to the board to save more weight," said another one.

Contestants build airframes out of lightweight materials such as carbon fiber

and launch their rockets out of towers, off rails, or out of tubes. In 2004, bowling-ball rockets weighed as little as eight ounces (without the ball), and the winning rocket propelled the ball to more than 2,700 feet.

Why do they do it? "I didn't like it at first," said Richard Hagensick of Minnesota, "but somehow I became intrigued about how light you could build the rocket and have it survive the flight." Drake Damerau of Pennsylvania liked the challenge, too. "Someone told me I couldn't do it successfully, and that's really all it took," he said, and then added: "Science rules!"

Geoff Elders, the winner of the I motor event in 2004, launched his bowling-ball rocket out of a 10-foot-tall PVC tube. The tube provided for a "cannonball effect." he explained. "No friction is the key to this event," said Elders, whose rocket reached 2,755 feet--a new I motor bowling-ball record.

But for how long?


18-16


18-17


18-18

quarter of an inch thick. The thin rings were no match for the thrust of the multiple motors.

Cutting Your Own Fins

Fins are also made of wood or G-10 fiberglass. The fin design and the number of fins used will change from rocket to rocket. But there are a few common tricks to keep in mind.

Several popular techniques are used to attach a fin to the airframe of a high-power rocket. One of the best is known as *through-the-wall* construction. See photo 18-14. With this technique, the root edge of the fin fits though a slot in the outer body tube and attaches directly to the motor housing. Epoxy is applied to the root edge (and on both sides of the root edge) where it touches the motor housing, and also on both sides of the fin where it passes through the body tube, inside and outside. This construction method provides for a rock-solid fin attachment on those rockets with a large-enough diameter.

Fins may also be attached using wooden or metal guides into which the fin will slide. The guides are actually hardware tracks for sliding doors or windows (or simply stock aluminum). The tracks are attached to the airframe with epoxy or screws or both. The fin then fits into the track and is secured by a nut and bolt or other fastener. This method of fin placement has the advantage of making the rocket a little easier to transport, because the fins are entirely removable. See photo 18-15.

Yet another common method of fin attachment is with the fin canister, also called a fin can. A fin can is a cylindrical mold with the fins made part of the can. The mold or fin-can tube is made of fiberglass, plastic, or even metal. The fin can with the fins attached fits right onto the end of the airframe tube. Fin cans are often used in high-performance, minimum-diameter rockets because they are easy to attach, they keep the diameter of the airframe to a minimum, and they are virtually indestructible. Fin cans are available through rocketry retailers and manufacturers in most common airframe sizes.


18-19

Mark Polansky's "Blastoff Brew" with Lexan fins and three J motors.

Always use epoxy or a similar adhesive when attaching the fins to the airframe or motor housing. Ordinary glues will not withstand high-power motors, and fins attached with these glues will tear off the rocket.

If you are concerned about the strength of the attachment between the fins and the airframe, consider applying a layer of fiberglass between each pair of fins–particularly on high-thrust motors. The layer can start halfway up one fin, cross over the body tube and finish halfway up the adjacent fin. This will ensure that the fins will remain with the rocket under even the most stressful situations.

As illustrated by photos 18-16 through 18-18, the fiberglass cloth is cut to size and placed in the valley between any two fins. The fiberglass resin is applied, and the cloth adheres to the airframe and fins. Excess fiberglass that hangs over the edge


18-20


18-21

can be cut with a sharp blade or utility knife, and the fiberglass can then be hand-sanded or sanded with a palm sander. If you do use a power sander, be careful not to sand right through the fiberglass.

And avoid using large fins that have too thin a cross-section. This may lead to fin "flutter" during flight. Fin flutter means the fins will start whipping back and forth. The result is loss of stability and likely destruction of the rocket. Back in 1999, one of our local flyers scratch-built a beautiful upscale Estes Fat Boy rocket on a 7.5-inch airframe. The rocket was powered by a cluster of a central K700 and two outboard I motors. The fins were very large, and made of extremely thin G-10 fiberglass. At takeoff, the Fat Boy began climbing, and almost immediately the large, thin fins began to move–and then whip–back and forth. The rocket lost stability and shredded in flight.

The Nose Cone for Your Project

Nose cones and rocket transitions are made of plastic, fiberglass or even wood. They can be molded out of foam or purchased in standard sizes from rocket makers. In many projects, the nose cone is where additional weight is added to move the center of gravity forward of the center of pressure. Fishing weights, sand, or any weighty objects (that will fit) can be placed in the very tip of the cone. The weight can be secured by epoxy, fiberglass or even foam.

18-23

Rocket designer Dick Mooradian of California with the upscaled version of his own Super Sonic Stealth rocket design.

Points of Attachment

All points of attachment for recovery systems should be bullet-proof, especially on large projects. Do not use open-ended eyebolts on anything other than model rockets or the very lightest of high-power rockets. High-power rockets should be built with closed eyebolts, U-bolts or pipe clamps. To skimp here invites trouble. As set forth in Chapter 7, use Kevlar or tubular nylon for recovery-harness material. Do not use elastic strap or bungee cords (except on model rockets or lightweight high-power projects).

Launch lugs

As explained in more detail in chapter 7, there are several types of lugs used in high power today. These include rail buttons, rail guides, metal lugs, wooden lugs, or even cardboard lugs. If possible, secure rail guides or unistrut buttons in a bulkhead or centering ring. Be sure the lug or button you choose for your project will work with your own rail or rod, or the equipment owned by the local rocketry club. Do not assume that the local club will have every type of launcher. Ask first.

Parachutes

Parachute selection should be guided by the weight of the rocket, the size of the airframe, and a descent rate between 15 and 25 feet per second. Keep in mind that the harder the ground you fly above, the slower your rocket's descent rate should be. If you are using a drogue parachute on a large rocket, do not use an ordinary parachute. Practical drogue parachutes are reinforced and are much sturdier than the typical parachute of comparable size. Always protect the parachute from ejection-charge gases, and inspect the parachute carefully after each launch for damage to the canopy or lines. For detailed discussion on parachutes, see Chapter 10.

Motor Selection

Most high-power rocket kits are supplied with a list of suggested motors for flight. For a scratch-built rocket the builder has to decide what motors are suitable. When getting ready to launch your vehicle for the first time, be sure to consider the 5:1 rule of thrust-to-weight (discussed in Chapter 1). Also, be sure that the center of gravity is at least one body tube diameter forward of the center of pressure. If it is not, then make the appropriate modifications to the rocket to ensure that it is stable for flight.

These matters are best dealt with during construction of the rocket–do not wait until the day of the launch. Use a computer-simulation program to test the motor you choose for your project.

Join a Rocketry Club

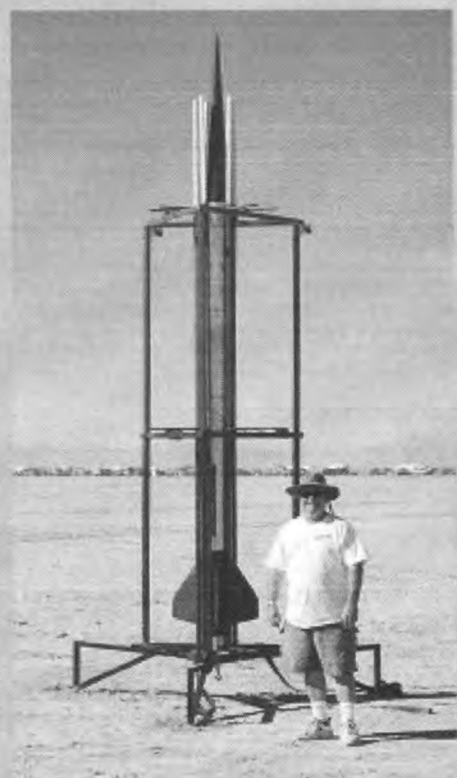
High-power rocketry clubs are a great way to share information and ideas about scratch building. There is a good chance other high-power enthusiasts are in your area and share your love of building a rocket from scratch. So contact the local chapter of NAR or Tripoli and find those new friends today!

18-24

18-25

Minimum DIAMETER

A minimum-diameter high-power rocket is one in which the airframe is just large enough to accommodate its motor. "Large enough" in this case refers to the diameter, not the length, of the rocket. Minimum-diameter enthusiasts can be found in almost any rocketry club.



At first glance, their rockets may seem simple, uncomplicated. But appearances can be deceiving. These rockets, many of them scratch-built, are some of the most complex vehicles flown in high power, and the altitude records for almost every motor class (A-N) are held by minimum-diameter flyers.

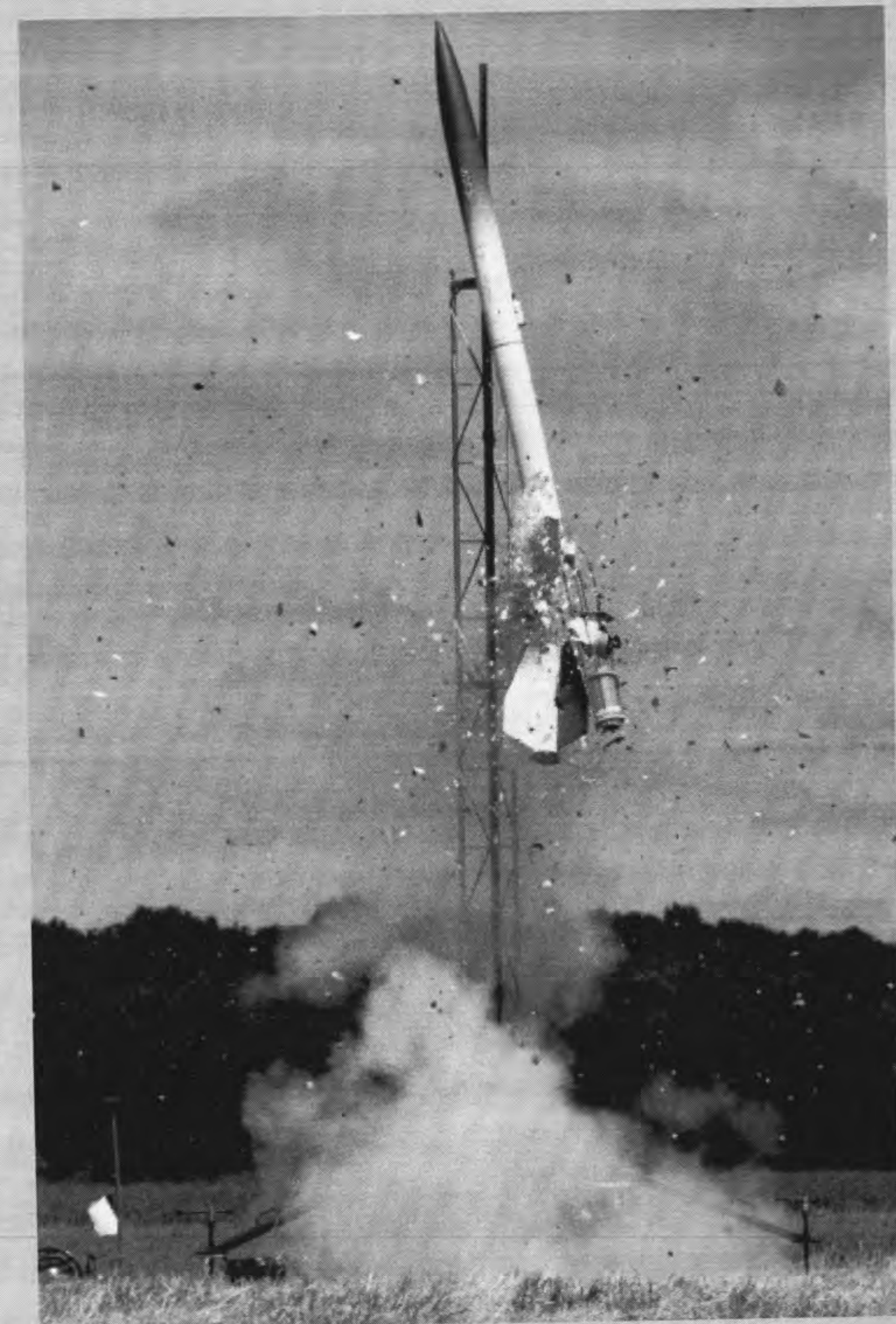
When the airframe diameter is the same size as the motor, your choice of building materials is critical if the rocket is going to hold together. Many high-altitude flyers use Kevlar, carbon-fiber, or other composite materials to build sturdy, yet lightweight, airframes for the rockets. These rockets must be fashioned to hold all of the same parts as large rockets–but in only a fraction of the space. To reach the highest altitude possible, a rocket needs to withstand the three primary forces that act upon a rocket during flight: gravity, thrust, and drag. Special planning must also be given to altimeter selection and altimeter-bay design, to fin type and nose-cone configuration, and to how the recovery harness will be mounted in the rocket.

William J. Inman, the current holder of several altitude records and a minimum-diameter expert, launches all of his record-holders from a tower to eliminate launch lugs and reduce a rocket's coefficient of drag.

In his article, "10 Ways to Get Extreme Altitude," (*Extreme Rocketry*, March/April 2000), Inman also cites the importance of boat-tails, a smooth airframe surface, and a small, compact airframe as three of the factors he looks for in a high-altitude contender.

How well do Inman's theories work? Pretty well, considering the fact that he has pushed a rocket on a G motor to nearly 8,000 feet, an H motor to more than 10,000 feet, and a J motor rocket to nearly 17,000 feet! The current altitude record for an N motor (one of the few records Inman does not hold) is well over 35,000 feet.

Pictured above left: Rocketeer Greg Davis stands in front of a minimum-diameter Q-powered rocket at Black Rock in 2004.



Robert Utley's "Sky in my Eye," a camera-equipped, M-powered (experimental) scratch-built rocket suffers a mighty CATO on the pad at LDRS23 in Geneseo, New York in 2004. Despite the CATO, most of the upper airframe survived intact. For additional photos of this beautiful rocket, see the Introduction.

The Rocketry Toolbox

The motto "Be Prepared" is a good rule to follow in high-power rocketry. A well-stocked rocketry toolbox that contains all of the range essentials is a must for any serious high-power enthusiast. Rockets and rocket motors invariably need some type of help out in the field on launch day. Whether it be a small amount of epoxy, a piece of tape to hold on a nose cone, or a C-clamp for a launch-pad standoff–you need these and other items in your toolbox every time you launch. And don't forget purely personal items--plenty of water, good sunscreen, and a pair of sunglasses for most events. And a heavy coat in the winter.

Over the years, there have been several articles written on range essentials in each of the major rocketry magazines. So there is certainly no consensus on the subject. Go to a launch. See what the experienced rocketeers have in their toolboxes. And then start working on your own.

Here's our two cents' worth:

Water. This is the most important item in your toolbox. Dehydration can be a serious problem out in the field. Most high-power rocket launches are held in remote areas–a long way from the nearest convenience store (unless you're lucky enough to launch in Geneseo, NY, or Orangeburg, SC). Walking back and forth between your car and the launch pad, and recovering your rocket after flight, is going to make you thirsty.

Bring several bottles, and help out that guy who is dying of thirst because he came unprepared. It's ususally the new guy–who ended up staying at his first launch too long because it was so much fun.

Food. Another no-brainer, but you would be surprised at the number of people who spend a day at the range without eating a thing. For most of us, several hours of building, launching, recovering and socializing, is going to run us low on fuel. And when you are low on fuel, the chances for errors (e.g. forgetting to arm your altimeter before flight) will increase. Bring something to eat. Snacks, sandwiches, beef jerky, anything. You'll be glad you did.

Sunscreen. Some type of sunscreen or sunblock is a must for most launches, especially out in the desert in the West. Several hours in the bright sun–even in winter months–can leave you with a nasty burn if you are unprotected.

Black powder. This is an essential for any launch. Black powder is used in ejection canisters and in the forward closure of some reloadable motors for motor ejection. It's cheap, but it needs to be stored according to the warning labels on the can.

Masking tape. Someone is always looking for tape at every launch. Masking tape is used as an ejection-charge seal, for nose cones, for airframes, and

even at the launch pad. Tape will help increase the friction fit of a single-use motor in the motor tube. It will also hold in your igniter at the pad. A good piece of tape will help keep the battery in your electronics secure. The list goes on. Be sure to bring a roll of tape.

New batteries. Always have new spare batteries in your toolbox for the electronics that you use. Whether it is an altimeter, timer, stager, or other on-board device, never use anything other than a new battery for launch. If you are a photographer at these launches, be sure to have a set of extra batteries for your camera, too.

Arming screwdrivers. Most high-power electronics are armed with tiny screwdrivers, sometimes called jeweler's tools. They are available at any hardware or home-improvement store, and they are inexpensive. Try to pick up a couple of sets–that Phillips screwdriver is used a lot and can easily get misplaced.

Pliers and cutters. These are essential hand tools. You will need wire cutters to strip insulation off igniter leads. Pliers are useful for launch-pad work, and a good set of diagonal cutters is always handy. If you are using reloadable motors with snap rings, be sure to include a nice pair of snap-ring pliers, too.

Grease. Most reloadable motors need some small amount of grease to aid in both assembly and disassembly. Don't leave home without it. And for cleanup and general-purpose use, bring along a small can of the miracle fluid–WD40. It can clean up just about anything, including the inside of your motor casing.

Gloves. Handling the residue of your reloadable motor after flight can be messy business. The same is true for handling epoxy and other adhesives. Bring along some disposable gloves to help out. Also, if you are one of those indispensable rocketeers in your club who arrive early to help set up (or leave late to help tear down), don't forget a good pair of work gloves for handling launch-pad equipment.

Hat. A personal safety item for the summer months at most launches, a hat or cap will keep your head in the shade and prevent sunburn on your face. It is a must for any desert launch.

Blue Thunder. Great stuff for motors that just won't light. Blue Thunder is made by Aerotech for some of its motors. It ignites quickly and makes for a big spark. It is a good way to augment an igniter for use in a 54mm, 75mm, or 98mm motor. It is also helpful for motors used in a cluster or for airstarts. Attach small slivers to your

igniter with tape, sewing thread, or even CA (super glue).

Epoxy and CA glues. For work at the last minute or for small, emergency repairs, CA or 5-minute epoxy works well. Hopefully, you will never need the stuff on the field. But you never know.

First-aid kit. Most clubs should have their own first-aid supplies on the field. But you should be prepared, too. Small kits are available almost everywhere–some for as little as $10. It's a good thing to have for cuts and scrapes that sometimes occur out in the field. And it takes up very little space in your toolbox.

Extra igniters. You need just one igniter for every motor, right? Well, maybe. Invariably, igniter losses occur. This can happen for a number of reasons: The igniter may refuse to light, the igniter may light but the motor won't ignite, or you may just lose it on the walk out to the pad.

Whatever the reason, always arrive with more igniters than you need. This also means, of course, always buy more igniters than you need. Don't be cheap here. Igniters are about the least expensive item in your rocket, so buy them in packages of ten, at least. (The average high-power rocketry igniter costs less than $2.) You will not regret it. And you will also be able to save

somebody's day when they arrive with a lousy igniter–or no igniter at all.

Sandpaper. This is a must. Put a small piece of coarse sandpaper (120-220 grit) in your pocket when you arrive at the launch. Hopefully, you will not need it. A piece of sandpaper will allow you to clean the launch rod or rail of residue before you place your rocket on the pad. It will also help you clean up the alligator clips of the launch-control system. These clips can get really dirty after repeated launches, making it difficult for your igniter leads to get a good connection.

Sunglasses and safety goggles. More necessary personal items. You will be looking up into the sky all day–be sure to protect your eyes from the sun. And when you are prepping ejection charges, it is good practice to put on safety goggles. Ejection charges occasionally go off unexpectedly, so protect yourself.

Walkie-talkies. Not just a luxury item. A pair of walkie-talkies is great to have when hunting for a downed rocket or simply to monitor local launch operations (many large launches use them to communicate with away pads). The price of walkie-talkies has dropped sharply in the last few years, and it is possible to get a nice set with a range of 3-5 miles for well under $100. Some units sell for as little as $29.95 a pair.

Binoculars. Not a necessity, but really

nice to have. Helps you keep track of that rocket that drifted a lot farther away than you planned.

Electronics and motor instructions. Always bring them. If you have used an altimeter or timer many times, you may not need the written instructions. Bring them anyway. Sooner or later you will forget something, and having the instructions close at hand may make the difference between a good flight and a big disaster. This item takes up almost no room in your toolbox.

Launch-pad standoffs. Also known as an ordinary C-clamp, this is a really good item to have. Many launch pads, especially rails, have no built-in standoff to allow room between the aft end of a rocket and the blast deflector. So people are often seen hunting around at the pad for anything to use–rocks, pieces of metal, even Coke cans. Be prepared. A C-clamp will attach to most pads in less than a minute.

Cleaning supplies. These include personal-cleaning items as well as cleaners for your motor hardware. Handi-wipes, Wet Ones, or similar cleaners are great for cleaning up your hands before, during, and after loading motors. They also work pretty well for cleaning motor casings after flight. For heavy-duty cleaning, bottle brushes and cleaners like Formula 409 or Simple Green work well, too. And don't forget a trash bag to haul the stuff out.

Cordless drill. Another one of those things that is not a real necessity, but it's sure nice to have in a pinch. A good cordless drill has a million uses. On the rocket field it can be used to drill vent holes or static port holes in rocket airframes or to quickly attach things to those really big projects. If you already have one sitting in the garage, throw it in the car on launch day.

Identification. Don't forget your Tripoli or NAR ID card. If you are planning on launching your own rocket, you will need the card to get past the RSO table. This is especially true if you are traveling to a large regional launch or somewhere other than your local launch site.

A cheap camera. This is another one of those items that is not a necessity, but is helpful if you bring it. Even if you do not want a single memory of your own launch or the launch of a friend, you may still see something out there worth recording. It may be an interesting or unusual altimeter bay design, or a unique rocket that you may want to copy, or a launch pad that you would like to build yourself. A cheap camera is easy to use and handy for preserving those little details that you will surely forget with the passage of time.

Hobby knife. A hobby knife is also an important part of the toolbox: a simple blade for cutting Blue Thunder propellant or for stripping wire or taking off the rough edge of motor liners. No rocketry box should be without one. Even better: bring at least two.

Rubber boots. The cheap kind. For marching through the swamp or rain-choked field where your rocket landed. Put them in your vehicle and forget about them. Most of the time you will not need them. But when you do, you'll be glad you packed them away.

Ladder. This is for the rocket with the electronics bay way up high. If you have built a large project, and you need a ladder to reach your altimeter bay, then bring one to the launch. Do not assume that the local club will have a six-foot ladder on hand, and do not plan on standing on a bucket, or some friend's shoulders, to arm your electronics. It takes up a lot of space, but that's what the roof of your car is for.

Flashlight. This isn't a necessity item, but it's very useful for peering into the depths of your rocket or altimeter bay to get a good look. Of course, if you are at a regional launch and there is camping involved, the flashlight is a must-have item.

Box full of little stuff. High-power rockets are filled with little parts--things like eyebolts, quick-links, terminal blocks, switches, motor-retention clamps, and screws. Always bring some backup parts, if you can. A small storage box with multiple little compartments is a great way to haul this stuff around. Sooner or later, the little stuff breaks or gets lost, or you need another one for some unforeseen reason. Be ready with replacement parts on the field.

Box full of big stuff. Large, heavy-duty plastic storage bins are a great way to transport all of the essentials of a rocket launch. These plastic bins are inexpensive (under $10) and can take a beating. You can fit rocket parts, parachutes, food, extra clothing, and even the little rocket box into these large bins. They also seal up well with nearly waterproof lids that may come in handy in that surprise rain shower or, if you are launching in the desert, the occasional sandstorm.

Tent/canopy. Absolutely vital if you are going to spend any serious time at a launch. Protects you and your equipment from the sun and other elements. Buy one that sets up and takes down quickly. And don't forget a table to go under it.

Don't forget the toolbox. There are a lot of toolboxes out there. The one you choose will depend on whether you are traveling light, in a car, or with a lot of equipment, in a truck or trailer. Shop around. There are a lot of boxes that are durable and strong, yet weigh very little. Don't haul around an industrial-strength box that weighs a ton unless you have to or you are lucky enough to have more room than you know what to do with.

Some toolboxes come with multiple compartments or drawers to help arrange all of those little parts. And some boxes come with a handle and wheels to save your back and help you move them around a lot easier. Some rocketeers convert old fishing-tackle boxes into a rocketry toolbox, and this seems to work fine, too.

Did we miss anything important? Drop us a line at www.modernhpr.com and we'll try to include additional items in the next edition of Modern High-Power Rocketry.

Appendix 1

Troubleshooting chart

Problem	Possible Causes
Motor fails to ignite	Igniter head has fallen out of the motor Igniter leads have shorted out on the pad Igniter is defective Igniter has fired--possible motor problem Igniter has fired--not enough spark Launch control box/main battery problem
Motor lights--rocket fails to leave pad	Launch lugs are too tight Launch lugs are improperly aligned Rod/rail needs to be cleaned
Motor CATO at ignition	Improper assembly of motor Defective motor
Shred	Too much motor for the rocket Too little rocket for the motor Motor CATO Improper adhesives used in assembly Fins too large or too thin--fin flutter
Cruise missile flight	Rocket not stable Nozzle failure Wind-caused instability
Drag separation	Airframe components/nose cone too loose Shear pin failure
Ejection charge fires too early/too late	Improper delay time chosen Improperly assembled motor Electronics/altimeter problem Static portholes insufficient/improperly sized Ejection charge leak from canister Defective motor/delay grain
Lawn dart	Electronics failure Ejection charge failure Airframe components too tight Insufficient ejection charge
Electronics failure	Operator error Electronics turned off Weak or loose battery Improper static porthole sizes Loose switch/electrical connections
Damaged parachute	Insufficient wadding or other protection Too much ejection charge

The majority of high-power rocket launches are successful. Occasionally, however, problems occur before, during, or after launch. This table is a quick-reference guide for some of the more common problems.

Brian Weese launched this beautiful replica of the mighty Saturn V on an Aerotech 54mm K550 at the Maddox Dairy in Riverdale California in 2003. The 7.51-inch-diameter scale rocket was nearly eight feet tall.

Appendix 2

NAR High-Power Rocketry Safety Code

1. **Certification**. I will fly high power rockets only when certified to do so by the National Association of Rocketry.

2. **Operating Clearances**. I will fly high power rockets only in compliance with Federal Aviation Regulations Part101 (Section 307, 72 Statute 479, 49 United States Code 1348, "Airspace Control and Facilities," Federal Aviation Act of 1958) and all other federal, state, and local laws, rules, regulations, statutes, and ordinances.

3. **Materials**. My high power rocket will be made of lightweight materials such as paper, wood, rubber, and plastic, or the minimum amount of ductile metal suitable for the power used in performance of my rocket.

4. **Motors**. I will use only commercially-made, NAR-certified rocket motors in the matter recommended by the manufacturer. I will not alter the rocket motor, its parts, or its ingredients in any way.

5. **Recovery**. I will always use a recovery system in my high power rocket that will return it safely to the ground so it may be flown again. I will use only flame-resistant recovery wadding if wadding is required by the design of my rocket.

6. **Weight and Power Limits**. My rocket will weigh no more than the motor manufacturer's recommended maximum liftoff weight for the motors used, or I will use motors recommended by the manufacturer of the rocket kit. My high power rocket will be propelled by rocket motors that produce no more than 40.960 Newton-seconds (9,204 pound-seconds) of total impulse.

7. **Stability**. I will check the stability of my high power rocket before its first flight, except when launching a rocket of already proven stability.

8. **Payloads**. My high power rocket will never carry live animals (except insects) or a payload that is intended to be flammable, explosive, or harmful.

9. **Launch Site**. I will launch my high power rocket outdoors in a cleared area, free of tall trees, power lines, buildings, and dry brush and grass. My launcher will be located at least 1,500 feet from any occupied building. My launch site will have minimum dimensions at least as great as those in the Launch Site Dimensions Table. As an alternative, the site's minimum dimensions will be one-half the maximum altitude of any rocket being flown, or 1,500 feet, whichever is greater. My launcher will be no closer to the edge of the launch site than one-half of the minimum required launch site dimension.

10. **Launcher**. I will launch my high power rocket from a stable launch device that provides rigid guidance until the rocket has reached a speed adequate to ensure a safe flight path. To prevent accidental eye injury, I will always place the launcher so the end of the launch rod is above eye level or I will cap the end of the rod when approaching it. 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 motor exhaust from hitting the ground directly. I will always clear the area for a radius of ten feet around my launch device of brown grass, dry weeds, or other easy-to-burn materials.

11. **Ignition System**. The system I use to launch my high power 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 a distance from the high power rocket and launcher as determined by the total impulse of the installed rocket motor(s) according to the accompanying Safe Distance Table.

12. **Launch Safety**. I will ensure that people in the launch area are aware of the pending high power rocket launch and can see the rocket's liftoff before I begin my audible five-second countdown. I will use only electrical igniters recommended by the motor manufacturer that will ignite rocket motors within one second of actuation of the launching switch. If my high power rocket suffers a misfire, I will not allow anyone to approach it or the launcher until I have made certain that the safety interlock has been removed or that the battery has been disconnected from the ignition system. I will wait one minute after a misfire before allowing anyone to approach the launcher.

13. **Flying Conditions**. I will launch my high power rocket only when the wind in no more than 20 miles per hour and under conditions where the rocket will not fly into clouds or when a flight might be hazardous to people, property, or flying aircraft. Prior to launch, I will verify that no aircraft appear to have flight paths over the launch site.

14. **Pre-Launch Test**. When conducting research activities with unproven designs or methods I will, when possible, determine the reliability of my high power rocket by pre-launch tests. I will conduct the launching of an unproven design in complete isolation from persons not participating in the actual launching.

15. **Launch Angle**. I will not launch my high power rocket so its flight path will carry it against a target. My launch device will be pointed within 20 degrees of vertical. I will never use rocket motors to propel any device horizontally.

16. **Recovery Hazards**. If a high power rocket becomes entangled in a power line or other dangerous place, I will not attempt to retrieve it. I will not attempt to catch my high power rocket as it approaches the ground.

Appendix 3

Tripoli High-Power Safety Code

1. Only a person who is a certified flyer shall operate or fly a high power rocket.
2. Must comply with United States Code 1348, "Airspace Control and Facilities", Federal Aviation Act of 1958 and other applicable federal, state, and local laws, rules, regulations, statutes, and ordinances.
3. A person shall fly a high power rocket only if it has been inspected and approved for flight by a Safety Monitor for compliance with the applicable provisions of this code.
4. Motors
    1. Use only certified commercially made rocket motors.
    2. Do not dismantle, reload, or alter a disposable or expendable high power rocket motor, not alter the components of a reloadable high power rocket motor or use the contents of a reloadable rocket motor reloading kit for a purpose other than that specified by the manufacture in the rocket motor or reloading kit instructions.
5. A high power rocket shall be constructed to withstand the operating stresses and retain structural integrity under conditions expected or known to be encountered in flight.
6. A high power rocket vehicle intended to be propelled by one or more high power solid propellant rocket motor(s) shall be constructed using lightweight materials such as paper, wood, plastic, fiberglass, or, when necessary, ductile metal so that the rocket conforms to the other requirements of this code.
7. A person intending to operate a high power rocket shall determine its stability before flight, providing documentation of the location of the center of pressure and center of gravity of the high power rocket to the Safety Monitor, if requested.
8. Weight and Power Limits.
    1. Ensure that the rocket weighs less than the rocket motor manufacturer's recommended maximum liftoff weight for the rocket motor(s) used for the flight. During pre-flight inspection, The Safety Monitor may request documentary proof of compliance.
    2. Do not install a rocket motor or combination of rocket motors that will produce more than 40,960 newton-seconds of total impulse (4.448 newtons equals 1.0 pound).
9. Recovery.
    1. Fly a high power rocket only if it contains a recovery system that will return all parts of it safely to the ground so that it may be flown again.
    2. Install only flame resistant recovery wadding if wadding is required by the design of the rocket.
    3. Do not attempt to catch a high power rocket as it approaches the ground.
    4. Do not attempt to retrieve a high power rocket from a place that is hazardous to people.
10. Payloads
    1. Do not install or incorporate in a high power rocket a payload that is intended to be flammable, explosive, or cause harm.
    2. Do not fly a vertebrate animal in a high power rocker.
11. Launching Devices
    1. Launch from a stable device that provides rigid guidance until the rocket has reached a speed adequate to ensure a safe flight path.
    2. Incorporate a jet deflector device if necessary to prevent the rocket motor exhaust from impinging directly on flammable materials.
    3. A launching device shall not be capable of launching a rocket at an angle more than 20 degrees from vertical.
    4. Place the end of the launch rod or rail above eye level or cap it to prevent accidental eye injury. Store the launch rod or rail so it is capped, cased, or left in a condition where it cannot cause injury.
12. Ignition Systems
    1. Use an ignition system that is remotely controlled, electrically operated, and contains a launching switch that will return to "off" when released.
    2. The ignition system shall contain a removable safety interlock device in series with the launch switch.
    3. The launch system and igniter combination shall be designed, installed, and operated so the liftoff of the rocket shall occur within three (3) seconds of actuation of the launch system. If the rocket is propelled by a cluster of rocket motors designed to be ignited simultaneously, install an ignition scheme that has either been previously tested or has a demonstrated capability of igniting all rocket motors intended for launch ignition within one second following ignition system activation.
    4. Install an ignition device in a high power rocket motor only at the launch site and at the last practical moment before the rocket is placed on the launcher.
13. Launch Site.
    1. Launch a high power rocket only in an outdoor area where tall trees, power lines, and buildings will not present a hazard to the safe flight operation of a high power rocket in the opinion of the Safety Monitor.
    2. Do not locate a launcher closer to the edge of the flying field (launch site) than one-half the radius of the minimum launch site dimension.
    3. The flying field (launch site) shall be at least as large as the stated in Table 1. *or* Not less than one-half the maximum altitude expected, calculated, or simulated, or as granted by an FAA waiver or the authority having jurisdiction.
14. Launcher Location
    1. Locate the launcher more than 1,500 feet from any occupied building.

2. Ensure that the ground for a radius of 10 feet around the launcher is clear of brown grass, dry weeds, or other easy-to-burn materials that could be ignited during launch by the exhaust of the rocket motor.

15. Safe Distances
    1. No person shall be closer to the launch of a high power rocket than the person actually launching the rocket and those authorized by the Safety Monitor.
    2. All spectators shall remain within an area determined by the Safety Monitor and behind the Safety Monitor and the person launching the rocket.
    3. A person shall not be closer to the launch of a high power rocket than the applicable minimum safe distance set forth in Table 2.
16. Launch Operations.
    1. Do not ignite and launch a high power rocket horizontally, at a target, or so the rocket's flight path goes into clouds or beyond the boundaries of the flying field (launch site).
    2. Do not launch a high power rocket if the surface wind at the launcher is more than twenty (20) miles per hour.
    3. Do not operate a high power rocket in a manner that is hazardous to aircraft.
17. Launch Control.
    1. Launch a high power rocket only with the immediate knowledge, permission, and attention of the Safety Monitor.
    2. All persons in the launching, spectator, and parking areas during a countdown and launch shall be standing and facing the launcher if requested to do so by the Safety Monitor.
    3. Precede the launch with a five (5) second countdown audible throughout the launching, spectator, and parking areas. This countdown shall be given by the person launching the rocket, the Safety Monitor, or other flying site operating personnel.
    4. Do not approach a high power rocket that has misfired until the safety inter-lock has been removed or the battery has been disconnected from the ignition system, one minute has passed, and the Safety Monitor has given permission for only a single person to approach the misfired rocket to inspect it.

TABLE 1: LAUNCH SITE DIMENSIONS

Installed Total Impulse(N-sec)	Equivalent Motor Type	Minimum Site Distance(feet)	Equivalent Distance(miles)
160.01 - 320.00	H	1,500	.28
320.01 - 640.00	I	2,500	.50
640.01 - 1280.00	J	5,280	1.00
1280.01 - 2560.00	K	5,280	1.00
2560.01 - 5120.00	L	10,560	2.00
5120.01 - 10240.00	M	15,480	3.00
10240.01 - 20480.00	N	21,120	4.00
20480.01 - 40960.00	O	26,400	5.00

TABLE 2: SAFE DISTANCE

Installed Total Impulse(N-sec)	Equivalent Motor Type	Minimum Safe Distance(feet)	ComplexMinimum Safe Distance(feet)
160.01 - 320.00	H	50	100
320.01 - 640.00	I	100	200
640.01 - 1280.00	J	100	200
1280.01 - 2560.00	K	200	300
2560.01 - 5120.00	L	300	500
5120.01 - 10240.00	M	500	1,000
10240.01 - 20480.00	N	1,000	1,500
20480.01 - 40960.00	O	1,500	2,000

Tripoli member Peter Carvajal arms the altimeter on his Public Missiles Systems Amraam on K-power at the Florida Winter Nationals in 2005.

Appendix 4

NAR Sample Level Three Form

NAR HIGH POWER LEVEL 3 CERTIFICATION APPLICATION

APPLICANT AND MOTOR INFORMATION (completed by applicant)

Name: CRAIG CHRISTENSON (First / Last) Birth Date: 07/29/60

Address: [redacted] Phone: [redacted] Day?

BENTON CITY, WA 99320 (City / State / ZIP) NAR No: 77452

Email Address: cpchri1@attglobal.net Membership Expires: 4/2003

I, CRAIG CHRISTENSON certify that I am a Level 2 certified member in good standing of the National Association of Rocketry.

Signature: ______ Date: 8/24/02

Motor designation: M1315W Motor Manufacturer: Aerotech

CONSTRUCTION PACKAGE AFFIDAVIT (Completed by certification team).

I, the undersigned, am a senior member of the NAR, distinct from the applicant, and a member of the NAR Level 3 Certificatio Committee. I have reviewed the airframe construction data presented to me and I confirm that the applicant has followed an complied with accepted construction practice in this Level 3 project. My assessment is based on:

- __ Inspection during construction
- __ Documented Level 2 test flight
- X Review and approval of construction package documentation
- __ Other: ______

Name (printed): Scott A Binder Signature: ______

NAR No: 77669 Membership expires: 5/ /03 Certification Level: L3 cc

RECOVERY PACKAGE AFFIDAVIT (Completed by certification team).

I, the undersigned, am a senior member of the NAR, distinct from the applicant, and a member of the NAR Level 3 Certificatic Committee. I have reviewed the recovery system design data presented to me and I confirm that the applicant has followe accepted guidelines in the design and implementation of a recovery system for this Level 3 project.
My assessment is based on:

- __ Recovery certification package review and a test flight demonstrating recovery systems
- X Recovery certification package review and documentation of the recovery system ground testing

Name (printed): Scott A. Binder Signature: ______

NAR No: 77669 Membership expires: 6/ /03 Certification Level: L3 cc

LEVEL 3 PRE-FLIGHT INSPECTION CHECKLIST (completed by certification team)

- YES Are all pyrotechnics and electronic deployment devices "safed" when presented for inspection? (The rocket must have this capability to pass the safety inspection).
- YES Does the rocket airframe conform to the Construction Package?
- YES Does the rocket recovery system conform to the Recovery System Package?
- YES Has the Certification Package stability analysis been reviewed? Is the CG forward of the aftmost allowable location?
- YES Have the Certification Package performance predictions been evaluated to determine that the motor and launch pad are adequate for a safe, stable flight?

The answer to all of the above questions must be "YES" to proceed.

LEVEL 3 PRE-FLIGHT INSPECTION CHECKLIST CONTINUED (completed by certification team)

- YES Does the motor have a minimum total impulse of 5120.01 Newton-seconds and a "M", "N", or "O" designation?
- YES Is the motor NAR or Tripoli certified?
- YES Is the rocket's predicted altitude no greater than 90% of the FAA waiver restriction?
- YES Has the pre-launch checklist been accomplished to verify the flight readiness of the model?
- N/A Has radio frequency usage, if applicable, been coordinated with the other fliers?
- YES Is a launch device sufficient to launch a rocket in this impulse class available?
- YES Is a launch system sufficient to safely ignite a rocket motor of this impulse class available?

The answer to all of the above questions must be "YES" to proceed.

The signatures below certify that the model has been inspected and is believed to be safe for flight. The signatures below certify that the certification package has been reviewed, found complete, and accurately describes the model about to be flown. The individuals below are the only ones who may certify this flight attempt. One of the following individuals must be a member of the Level 3 Certification committee.

Name (printed): Scott A. Binder Signature: ______ NAR No: 77669

Birth Date: 5/29/66 Membership expires: 6/ /2003 Certification Level: 3 L3CC: yes

Name (printed): KENT M. NEWMAN Signature: ______ NAR No: 74607

Birth Date: 07/21/51 Membership expires: 02/ /03 Certification Level: L3 L3CC: ____

LEVEL 3 POST-FLIGHT CHECKLIST (completed by certification team)

- yes Did the rocket make a stable flight? The certification attempt is a failure if the answer is "NO".
- yes Did the recovery system operate adequately to safely recover the model? The certification attempt is a failure if the answer is "NO".
- yes Did the rocket remain intact during recovery deployment, with no separation of parts without recovery devices? The certification attempt is a failure if the answer is "NO".
- yes Have all pyrotechnic devices and electronic controls been "safed" for Post-Flight inspection?
- no Is there any damage that would prevent an immediate reflight of the model? The certification attempt is a failure if the answer is "YES".
- No Did the model exceed the FAA waiver authorized altitude? The certification attempt is a failure if the answer is "YES".

LEVEL 3 FLIGHT CERTIFICATION AFFIDAVIT (Completed by certification team).

We, the undersigned, being members of The National Association of Rocketry, distinct from the applicant, have witnessed a demonstration by (Name) Craig Christenson, (NAR #) 77452 of skills relative to the building and safe operation of high power rockets. We attest that the applicant is 18 years of age or older and a member in good standing of the NAR. We believe this member is qualified to build and operate high power models with a total installed impulse up to 40,960 Newton-seconds.

X Post-flight inspection of rocket completed (See inspection list above).

Name (printed): ______ Signature: ______ NAR No: 77669

Name (printed): KENT M. NEWMAN Signature: ______ NAR No: 74607

NAR HIGH POWER LEVEL 3 CERTIFICATION APPLICATION (supplement)

LEVEL 3 TEMPORARY CERTIFICATION CARD (completed by certification team).

Send completed forms to:

National Association of Rocketry
P.O. Box 177
Altoona, WI 54720

Use temporary L3 certification until new
Membership card arrives from NAR HQ.

NAR LEVEL 3 CERTIFICATION
NAR # 77452 Expiration date: 4/ 03
Name: CRAIG CHRISTENSON
Certification date: 08/24/02
Witnessed by: [signature] 77664 L3CC
Authorizing Signature
Witnessed by: [signature] 74607
Authorizing Signature
Void 1 year after certification date or on expiration date, whichever comes first.

LEVEL 3 CERTIFICATION FAILURE FORM (completed by certification team).

In event of a certification failure send this form and the entire L3 Certification Form to Stephen Lubliner at 9968 E. Domenic Lane, Tucson, AZ 85730. The purpose of this form is not to document the modeler's failures. It is designed as a research tool to study and refine the Level 3 certification program. The modeler's contact information is optional. Please explain reasons for failure and possible remedies thoroughly. Please use additional paper if required.

LEVEL 3 CERTIFICATION FAILURE FORM (completed and mailed to above address by a certification team member).

During which flight phase did the failure occur?

__ Launch __ Powered flight (boost) __ Coast to apogee __ Initial recovery system deployment event

__ Subsequent recovery system deployment event __ Descent to ground __ Ground impact __ Other

Which system/component failed?

__ Airframe structure __ Electronics/pyrotechnics __ Recovery __ Propulsion/motor __ Other

Explain (use the back of this page if required): ____________

Certification Team Witness:

Name: ____________ Eve. Phone: ____________ Email: ____________

Modeler's Contact Information (optional)

Name: ____________ NAR#: ____________ Date: ___/___/___

Evening Phone: ____________ Email: ____________

Address: ____________ City: ____________ State: ___ ZIP: ________

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Craig Christenson (background) and friend making sure the electronics are armed and ready on Craig's Level Three flight. Photo courtesy of Craig Christenson.

Appendix 5

Tripoli Sample Level Three Form(s)

Level 3 Data Capture Form

Tripoli Advisor Panel PRE-FLIGHT DATA CAPTURE

NAME: Rich Pitzeruse	ADDRESS: [redacted]	PHONE #: [redacted]
TRA #: 4513	LAUNCH LOCATION: Geneseo, NY	DATE: July 4th, 2002
ROCKET SOURCE: KIT SCRATCH Scratch built upscale of old Estes kit.	ROCKET NAME: The Bionic Citation Patriot	COLORS: Red, white, blue, black, gold
ROCKET DIAMETER: 7.6"	ROCKET LENGTH: 10'	ROCKET WEIGHT LOADED: Approximately 50 lbs
AVIONICS DESCRIPTION: R-DAS Missile Works RRC2X	MOTOR TYPE: Aerotech M1315	THRUST TO WEIGHT RATIO:
LAUNCHER REQUIREMENTS: 1" Unistrut Rail	LENGTH: 12'	
CENTER OF PRESSURE:	HOW CALCULATED: Rock Sim	
CENTER OF GRAVITY:	HOW CALCULATED: Rock Sim	
MAXIMUM VELOCITY: 700 ft/sec (Mach .64)	HOW CALCULATED: WinRasp	
MAXIMUM ALTITUDE: 6000'	HOW CALCULATED: WinRasp	
WAS FLIGHT SUCCESSFUL:	YES:	NO:
TAP NAME: Ray Halm		
TAP NAME: Jim Livingston		
TAP NAME:		

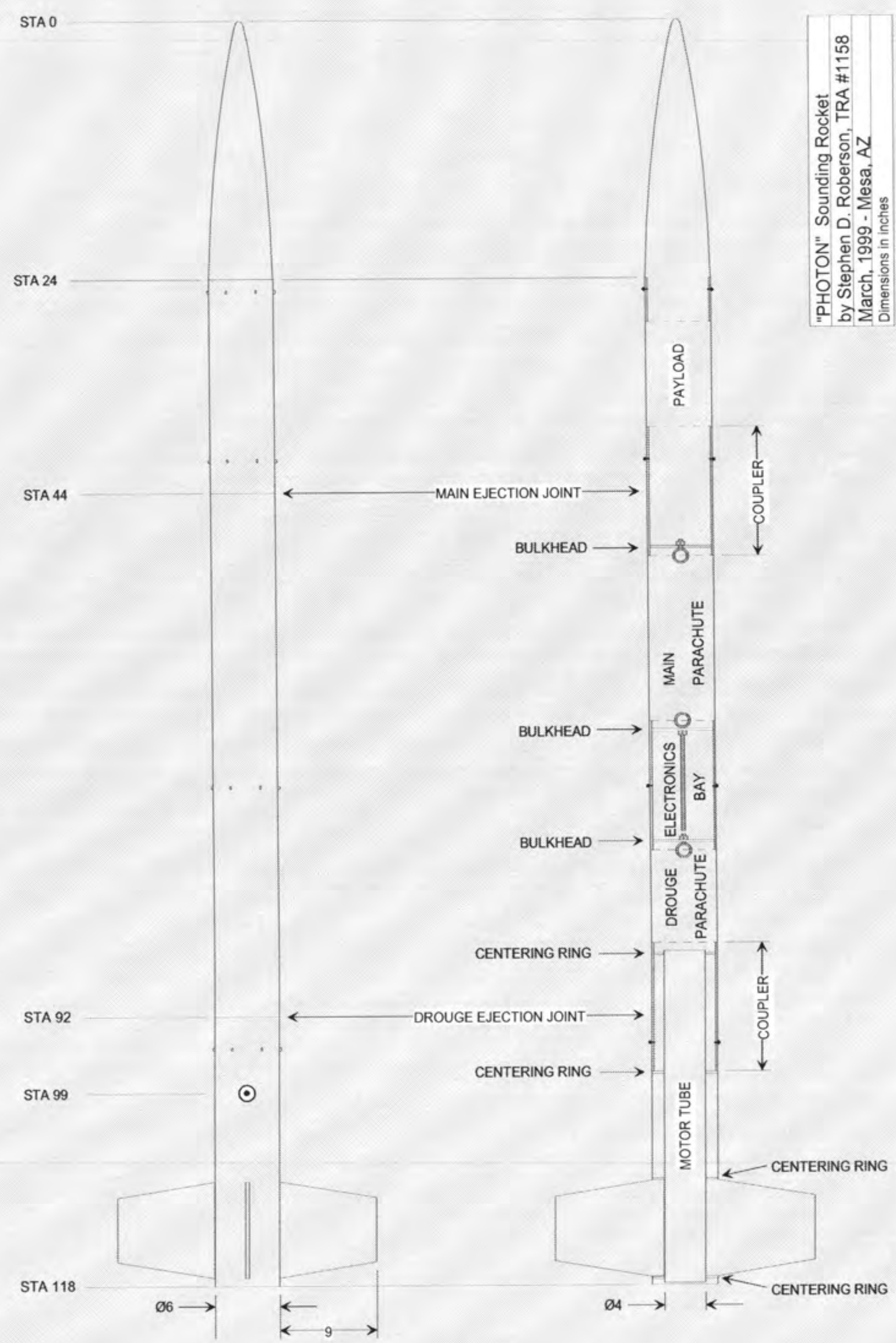
Level 3 Data Capture Form

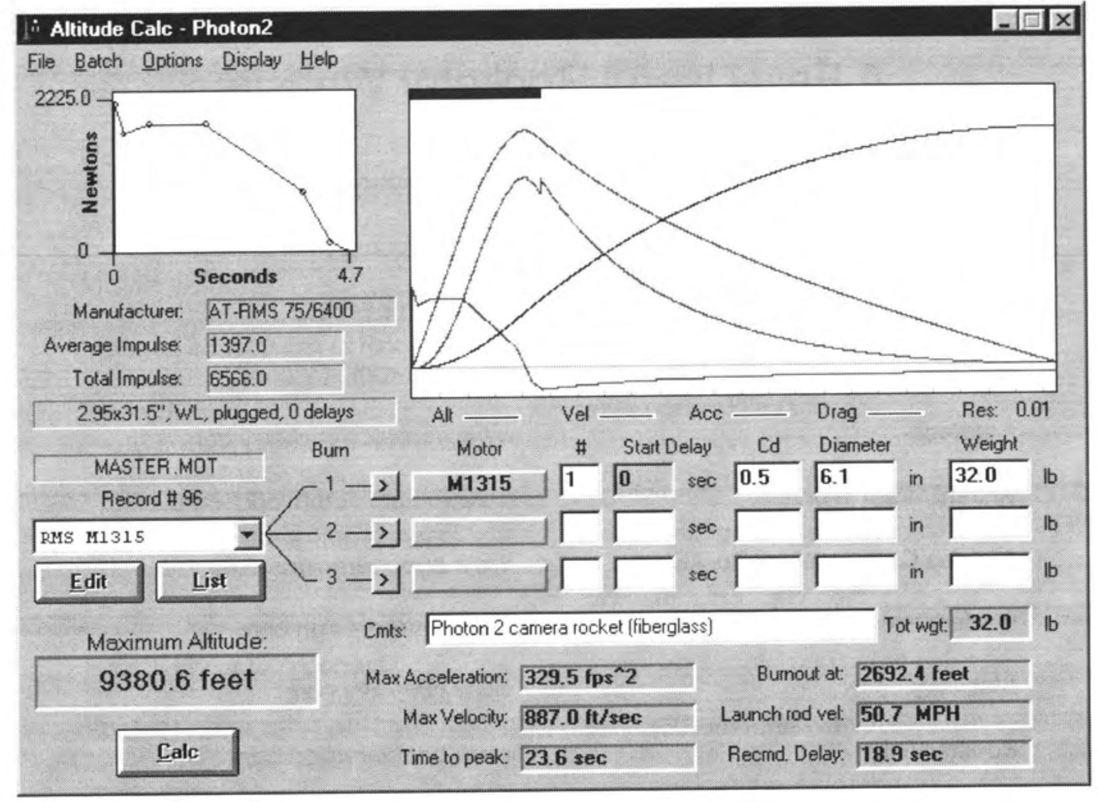
Tripoli Advisor Panel PRE-FLIGHT DATA CAPTURE

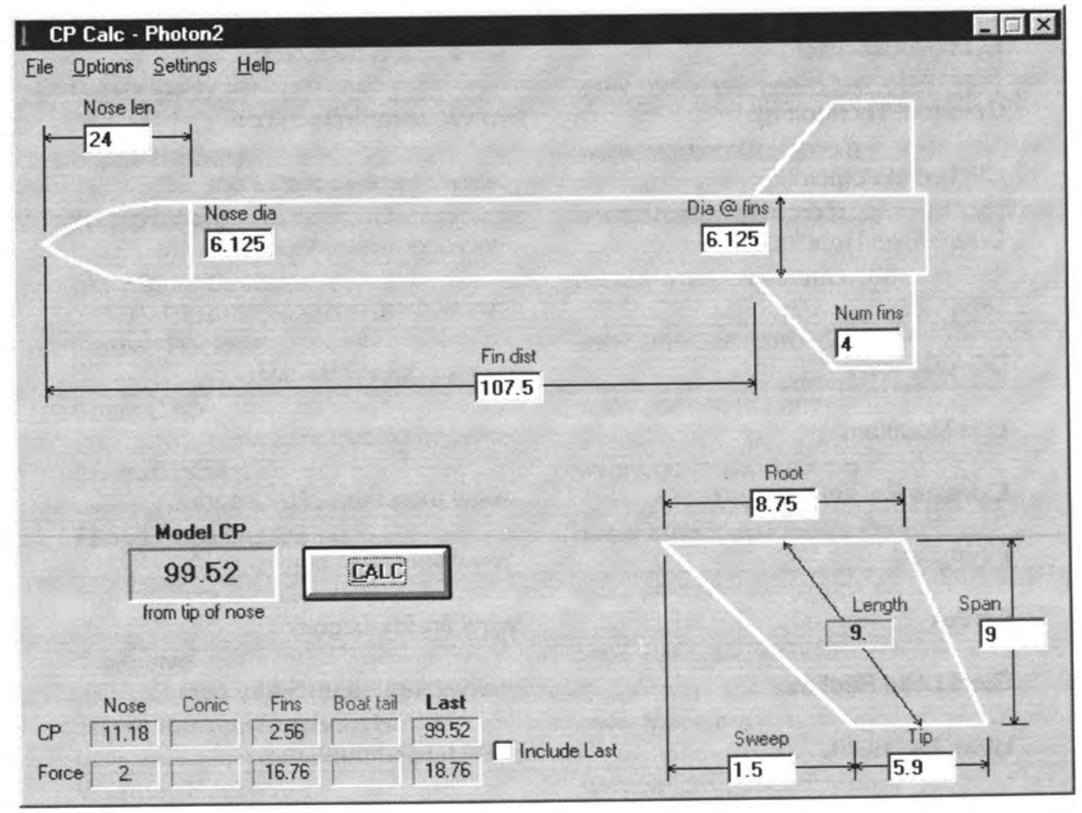
NAME: Mark Canepa	**ADDRESS:** 7605 N. Highland, Clovis, CA 93611	**PHONE #:** (559) 322-2199
TRA #: 5918	**LAUNCH LOCATION:** Riverdale, CA	**DATE:** pending
ROCKET SOURCE: KIT: SCRATCH: xxx	**ROCKET NAME:** unnamed	**COLORS:** primer gray
ROCKET DIAMETER: 7.67"	**ROCKET LENGTH:** 118"	**ROCKET WEIGHT LOADED:** 39 lbs.
AVIONICS DESCRIPTION: Black sky and Olsen	**MOTOR TYPE:** Aerotech M1419	**TRUST TO WEIGHT RATIO:** 8 to 1
LAUNCHER REQUIREMENTS: Rail	**LENGTH:** standard	
CENTER OF PRESSURE: 83.46"	**HOW CALCULATED:** Winroc	
CENTER OF GRAVITY: 75"	**HOW CALCULATED:** manual	
MAXIMUM VELOCITY: 808fps	**HOW CALCULATED:** Winroc	
MAXIMUM ALTITUDE: 7,000'	**HOW CALCULATED:** Winroc	
WAS FLIGHT SUCCESSFUL:	**YES:**	**NO:**
TAP NAME:	Pius Morizumi	
TAP NAME:	Karl Baumann	

Appendix 6

Roberson Sample Level Three Information







Appendix 7

A Few Useful Rocketry Websites

Adept	www.adeptrocketry.com
Aerocon Systems	www.aeroconsystems.com
Aeropack	www.aeropack.net
Aerospace Specialty Products	www.asp-rocketry.com
Aerotech	www.aerotech-rocketry.com
Animal Motor Works	www.animalmotorworks.com
Apogee Components (RockSim)	www.apogeerockets.com
Binder Design	www.binderdesign.com
Blacksky	www.blacksky.com
BoosterVision	www.boostervision.com
BSD Rocketry	www.bsdrocketry.com
B2 Rocketry	www.b2rocketry.com
CD3 (Rouse-Tech)	www.rouse-tech.com
Cesaroni Technology	www.cesaronitech.com
CP Technologies	www.space-rockets.com
Countdown Hobbies	www.countdownhobbies.com
Deep Sky	www.deepskyrocketshop.co.uk
DGA Rockets	www.dgarockets.com
Ellis Mountain	www.ellismountain.com
Extreme Rocketry magazine	www.extremerocketry.com
Fiberglast	www.fiberglast.com
Firefox	www.firefox-fx.com
Giant Leap Rocketry	www.giantleaprocketry.com
Hawk Mountain	www.hawkmountain.ws
Hypertek	www.hypertekhybrids.com

LOC/Precision	www.locprecision.com
Loki Research	www.lokiresearch.com
Magnum Rockets	www.magnumrockets.com
Maximum Thrust	www.maximumthrust.net
Missile Works	www.missileworks.com
National Association of Rocketry	www.nar.org
Perfectflite	www.perfectflite.com
Public Missiles Systems	www.publicmissiles.com
RCS Rocket Motor Components	www.rocketmotorparts.com
Rebel Rocketry	www.rebelrocketry.com
Rocket Motor Components	www.rocketmotorparts.com
Rocket Hunter	www.rockethunter.com
Rocketman	www.the-rocketman.com
Rocketmotion	www.rocketmotion.com
Rocketry Online	www.rocketryonline.com
Rouse Tech	www.rouse-tech.com
Sigma Rockets	www.sigmarockets.com
Shadow Aero	www.shadowaero.com
Sky Ripper Systems	www.skyrippersystems.com
Smokin Rockets	www.smokinrockets.com
SpaceCAD	www.spacecad.com
Squirrel Works	www.squirrelworks.com
Tango Papa Decals	www.tangopapadecals.com
Top Flight Recovery	www.topflightrecoveryllc.com
Transolve	www.transolve.com
Tripoli Rocketry Association	www.tripoli.org
Wildman Rocketry	www.wildmanrocketry.com
Wrasp	www.wrasp.com

Appendix 8

Sample Checklist for High-Power Rocket Launch

Is a flight card prepared and properly filled out? ______

Is the rocket stable (CP v CG)? ______

Is the thrust-to-weight ratio sufficient (i.e. 5:1)? ______

Is the motor properly assembled? ______

Is the motor properly secured (motor retention)? ______

Are all points of attachment secured? ______

Is the parachute protected from ejection charges? ______

Are the ejection charges sufficient and secure? ______

Is the nose cone firmly attached (drag separation)? ______

Is there a vent hole for the payload bay? ______

Is there a static porthole for the altimeter bay? ______

Is the battery for any electronic device brand new? ______

Is the battery for any on-board device secure? ______

Are all electronic wires secure and connected? ______

At the pad:

Are all altimeters/timers/transmitters turned on? ______

Are all safety switches/shunts properly armed or removed? ______

Is the igniter properly installed? ______

Additional Checklist for Level Three Certification Launch

Have you submitted all of your paperwork? ______

Will your TAP/L3CC member be present? ______

Is a motor vendor coming with your L3 motor? ______

Does the local club have a compatible launch pad? ______

Do you have backup altimeters/timers on board? ______

Have you used your electronics before? ______

Have you read the directions for your electronics? ______

Are you using ALL of the altimeter/timer ports? ______

Is a Level Three igniter ready? ______

Will the igniter need a dowel attachment? ______

Do you have friends/crew to help with setup at the pad? ______

Do you have friends/crew to help with recovery? ______

Did your TAP/L3CC member sign off your paperwork? ______

Note re electronics: As discussed in Chapter 14, all Level Three certification flights must have electronics-activated ejection charges. This usually means altimeters. Always use every port available on your altimeters for a Level Three flight. Do this even if you plan on deploying your main parachute at apogee. This will help prevent you from mistakenly using only the main ports, which will lead to a lawn dart or core sample.