Flying cluster rockets for fun and profit

(Well OK then, maybe just for fun)

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TRA# 1526, L2

When things go right: The author's second LOC/Precision King Viper III takes to the Mojave Desert skies on three I284 motors at the ROC-Stock VIII launch in November, 1998. The precise vertical liftoff angle indicates simultaneous ignition of all 3 motors. Igniters were Daveyfire electric matches with a single fold near the head, dipped in Firestar pyrogen.

You've seen us at your club launches: we're the guys who buy motors by the dozen and igniters by the box. When we look at a rocket, the first thing we do is turn it upside-down and count the motor tubes. We're cluster-maniacs, and for us, *it's gotta be multiple motors, if ya wanna dance with me.*

The challenge

Why do we fly clusters? The biggest reason for me is the challenge that clustering presents, since in addition to everything that must go right in a single motor flight, you also have to get multiple motors to ignite simultaneously. Although this can be tricky, with a bit of planning and careful preparation you can fly cluster rockets with the same success rate as single-motor rockets, but with a sense of satisfaction and accomplishment that simply can't be matched by flying single-motor rockets.

Another reason to cluster is that it offers new challenges without your having to advance to the next certification level. Particularly, moving from Level 2 into Level 3 requires a substantial commitment of time, energy and money. Once you reach Level 2, clustering gives you lots of opportunites to try new things without exceeding the Level 2 restrictions. Plus, you can fly more - you can make several Level 2 cluster flights for the price of a single Level 3 motor.

More variety

Motor combinations in cluster flights offer more variety than single-motor flights. In addition to making flights with multiples of a single motor type, some cluster configurations let you combine different motor types. With some cluster mounts you can even "air-start" some of the motors, giving you a 2-stage flight profile in a single-stage rocket. (Successful air-start flights always have a high "ooh-aah" factor with the crowd.)

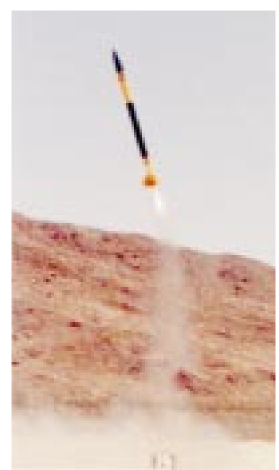
The villian: asymmetrical thrust

The possibility of asymmetrical thrust is what makes clustering more difficult than flying single-motor rockets. Asymmetrical thrust happens when one or more of the motors in a cluster fails to ignite, or ignites late. This produces thrust that is uneven around the rocket's central axis, and causes the rocket to fly other than a vertical trajectory. Sometimes, like when only 1 motor in a 3-motor triangle cluster ignites, the extreme asymmetrical thrust can result in a horizontal "cruise-missile" flight profile that is almost certain to end in a crash.

You can help ensure that all motors ignite properly by:

1) Selecting proper motors. They must produce a combined flight profile that is safe for the rocket, and they must have a propellant type and core geometry that promotes easy ignition.
2) Selecting the proper igniters. They must be capable of igniting the motors, they should draw as little electrical current as possible from the launch system, they should be extremely reliable, and they should be very consistent from igniter to igniter.

We will cover these issues in detail later in the article.



When things go wrong: The author's original King Viper III has just cleared the launch rod with only 1 of 3 J180 motors burning. Asymmetrical thrust has caused the rocket to rotate to the left. When the rocket was parallel to the ground the other 2 motors finally ignited, and it zoomed-off in "cruise-missle" attitude, hitting the ground under full power. Except for the LOC nose cone (which seem to be practically indestructable), the rocket was a total loss.

Cluster Motor Mount Configurations

Although there is an almost limitless variety of motor configurations you can use in cluster rocket design, over the years the following have proven to be the most popular. *(See chart on next page for illustrations of cluster configurations).* Each configuration has certain advantages and disadvantages.

There don't seem to be as many cluster kits available from manufacturers now as there were 10 or so years ago. I have mentioned the kits that I am aware of for each motor configuration, but those of you who are serious about clustering will no doubt want to scratch-build most of your fleet.

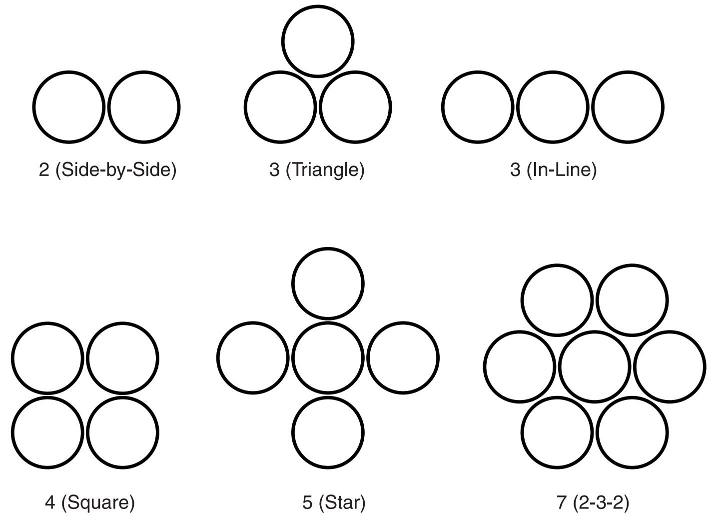
2 (Side-By-Side): This is the simplest cluster configuration, and requires that you always use 2 identical motors. One of its biggest benefits is economy; you can make a cluster flight with 2 single-use 29mm motors for less than you would spend on just one 38mm reload.

The LOC/Precision *Starburst* kit has a 2 x 24mm cluster mount, and is a good kit to get your feet wet in clustering. A more advanced 2-motor cluster kit is the Public Missiles LTD *Eclipse Type B*, which has 2 x 38mm motors.

3 (Triangle): You must always use 3 identical motors with this configuration, which can pack a lot of thrust into a relatively small diameter airframe. Another advantage is the simplicity of motor retention: Fill the void formed inbetween the 3 motors with epoxy (required to prevent ejection gasses from escaping), then drill a hole in the epoxy and thread a screw into the hole. To retain the motors, simply put an appropriate size washer on the screw and tighten it into the hole after the motors have been installed. The LOC/Precision *Viper III* uses 3 x 24mm motors in a triangle, and their *King Viper III* uses a triangle of 3 x 54mm motors.

3 (In-Line): The biggest advantage to the in-line configuration is that you can use 2 different motor types. Although the 2 outer mounts must always have identical motors, the central motor can be of a different type. However, you should always put the most powerful motor in the center. This ensures that a higher percentage of the total thrust will be located on the rocket's centerline, minimizing asymmetrical thrust should one of the outboard motors fail to ignite. If the central motor is powerful enough to provide a safe flight by itself, you can even fly this configuration with just one motor.

Typical Cluster Rocket Motor Configurations



These are the most popular cluster motor configurations. Not all of the motors must be of the same diameter. For example, the LOC/Precision Magnum kit uses a 3 In-Line mount with a central 54mm motor and two 29mm outboards.

One disadvantage of the in-line configuration is that it requires an increased diameter airframe over the triangle configuration. For example, an in-line 3 x 54mm mount requires a 7.62" diameter airframe, while a triangle of 3 x 54mm motors will fit in a 5.38" diameter airframe. The LOC *Magnum* kit uses an in-line configuration, with a 54mm central motor flanked by two 29mm motors, and their *Bruiser-Exp* kit has a 54mm central motor with 2 outboard 38mm motors.

4 (Square): This is an extremely flexible configuration, allowing you to make flights with either 2 or 4 motors. You can make 4-motor flights with 4 identical motors, or with 2 motors of one type and 2 of another. You could even launch the rocket on 2 motors and air-start the other 2 after the first 2 burn-out. Like the triangle mount, the square configuration packs a great deal of thrust into a relatively small airframe, and can use the simple single screw + washer motor retainer system. The LOC/Precision *Viper IV* kit uses a 4 x 24mm square motor mount, and their *4-29SS* kit uses a 4 x 29mm square motor mount. With all of the different 29mm single-use motors available, you can create an enormous variety of different flight profiles with the 4-29SS.

My scratchbuilt 329 was one of my favorite rockets to have fun with, having 3 x 29mm motor mounts in a 3" diameter airframe. I have flown it on all sorts of motors, ranging from F25s all the way up to G125s. This photo shows three G40 White Lightning motors powering it to an altitude of 3000 feet.

5 (Star): The 5-motor configuration lets you make flights with 1, 2, 3, 4, or 5 motors. However, 2- and 4-motor flights leave the rocket's center mount empty, so the effect of asymmetrical thrust should one or more motors fail to ignite would be more severe than if the center mount was powered. Two-motor flights must use identical motors, while 3-, 4-, and 5-motor flights can be done with dissimilar motors. (Be sure to follow the rules explained in the previous paragraphs.)

The Public Missles LTD *Ultimate Endeavor* kit has a central 54mm mount surrounded by four 38mm mounts, and the LOC Custom Engineering *Esoteric* kit has 5 x 54mm mounts. When I flew my *Esoteric* at Springfest 1993, I used a central K550 with 2 outboard J275s. The flight was perfect, and was featured on the cover of the May 1993 issue of *HPR* *(see pg. 6 for photos).*

The most powerful 5-motor star cluster rocket in the world was the first stage of NASA's Saturn V moon rocket. It used a star configuration of 5 Rocketdyne F1 engines that produced a total thrust of about 8,000,000 lbs. They burned for more than 3 minutes, producing a total of more than 6.3 *billion* Newton-Seconds of thrust.

7 (2/3/2): The 7-motor configuration has been popular for a long time. It packs big-time thrust into the airframe and offers extreme flexibility of motor selection, while the increased number of motors reduces the affect of asymmetrical thrust if some fail to ignite. It can be flown on 1-, 2-, 3-, 4-, 5-, 6-, and 7-motors. If you're planning on scratchbuilding a 7-motor rocket, be careful of it's center of gravity and make the rocket long enough to counteract the weight of 7 motors at the aft end. (A "Fat Boy" type of rocket with a 7-motor mount will probably need lots of nose weight to be stable.)

The LOC Custom Engineering *Ultimate Max* kit has 7 x 38mm motors in a 5.38" diameter airframe, while their *Top Gunn* kit puts 7 x 54mm motors into a 7.6" diameter airframe.The Thoy *Nighthawk* is one of the most popular cluster kits of all-time, and has a 7 x 29mm mount. I've flown a Nighthawk with many different motor combinations, my 2 favorite flights being one with 7 x F25 motors and another with 7 x F14 motors.

Using fewer than the maximum number of motors

No matter what motor configuration you use, if you fly the rocket with fewer than the maximum number of motors you must fill the empty motor tubes so that ejection gasses don't escape, and so the empty tubes don't get burned by the exhaust flame. The easiest way to do this is to install spent expendable motor casings into the empty mounts.

Cluster Motor Selection

Just as in any rocket flight, your first priority in motor selection for a cluster flight must be *ensuring that the motor combination you choose will produce a safe flight profile in the rocket*. The process for determining whether a particular motor/rocket combination is safe is the same for a cluster rocket as it is for a single-motor rocket, so you can use flight simulation computer software to run simulations with clusters as well as single motors. If you don't use a computer to simulate flights you have to combine the thrusts of all the motors in your cluster to determine the total thrust, and then treat them as if they were a single motor, using this figure in your calculations. If you are using dissimilar motors in a cluster things get more complicated - you must consider the motors' different thrust profiles (see below) as well as the amount of thrust that each produces when determining whether or not the flight will be safe.

Your next most important consideration when selecting motors for a cluster flight is to choose motors that ignite easily. Ignition of a rocket motor occurs when the proper amount of pressure has formed in its core. The 2 characteristics of a motor that determine how quickly it pressurizes are its propellant type and its core geometry. Since its been many years since I've flown anything but an Aerotech motor, I must restrict the following information to only that brand of motors. For information about other brands of motors you should contact the manufacturer.

Not all crashes of cluster rockets are caused by problems with motor selection or ignition. When I flew my 329 with 3 x G125 motors, I simply mis-judged the power of the motors and selected a too-short delay time. The rocket was travelling so fast at (the much too early) ejection that the airstream slammed the bottom of the payload coupler into the airframe between two of the fins. (Once again, the LOC nosecone survived unscathed.) The damage was too severe to repair, so I built a new 329.

Aerotech propellant type ignition characteristics:

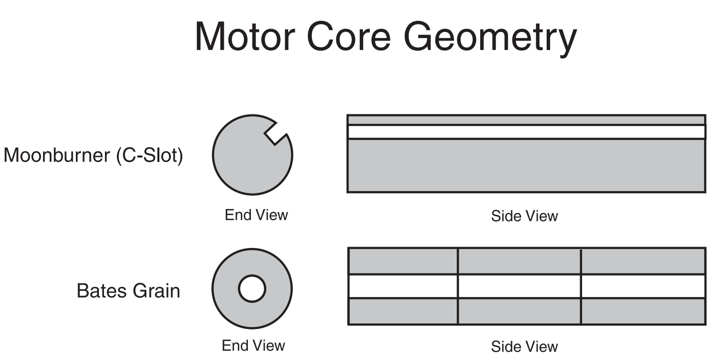
Blue Thunder: Blue Thunder propellant ignites so quickly that it's by far the best type of propellant to use if you're just starting in clustering. Providing that the igniters and launch system are up to the task, using Blue Thunder motors in a cluster is almost a guarantee of a successful flight. One of my favorite Blue Thunder motors to cluster with is the I300. It packs a serious take-off wallop, and 2 of them can be used to lift a large rocket without draining your bank account.

White Lightning: Once you have a few successful flights under your belt, successfully clustering with White Lightning motors should be pretty easy. Although they don't ignite as quickly as motors with Blue Thunder propellant, White Lightning motors ignite readily enough to make them quite reliable for clustering. However, your choice of igniter becomes more important with White Lightning motors, since you must deliver more heat to the propellant to achieve ignition due to the non-burning elements that produce the smoke and flame. Additionally, when clustering with 54mm White Lightning motors you should pay careful attention to their core type (see below). One of the most impressive things about a large cluster of White Lightning motors is that it produces a huge white flame and cloud of white smoke that is reminiscent of the Space Shuttle's SRB boosters.

Black Jack: Due to the amount of non-burning elements in the propellant that create the black smoke, Black Jack propellant is the most difficult Aerotech propellant to ignite, taking the longest time to come-up to pressure. Although I have had successful cluster flights with 29mm Black Jack motors, igniting a cluster of large-core Black Jack motors is extremely difficult. The last time I attempted this (with 3 H112 motors in a scratchbuilt rocket), despite my best efforts and the use of the "hottest" igniters available, 2 of the motors ignited so late that the rocket flew over a mile downrange. Although the recovery system deployed successfully and the rocket was not damaged, I doubt that I'll be attempting another cluster of 38mm Black Jack motors any time soon.

Core type ignition characteristics:

Besides its propellant type, other motor characteristics that you must consider for clustering are its core geometry and core size. A motor's core gemoetry is the physical shape of its burning surface. With the exception of four 54mm motors, all Aerotech reloadable motors regardless of propellant type have a Bates Grain core geometry (a cylindrical central "tunnel" through all of the propellant grains). Because the propellant surrounds the core equally on all sides in a Bates Grain, they are relatively easy to ignite.



Aerotech reloadable motor core geometries: The J90, J180, J135, and K185 are Moonburners, while all other Aerotech reloadable motors are Bates Grains. Because they expose more propellant to the igniter's flame front, as a rule Bates Grains are easier to ignite than Moonburners. However, since the J180 Moonburner uses Blue Thunder propellant, it ignites more readily than the other Moonburners.

The J90, J180, J135 and K185 long-burning 54mm motors have a Moonburning (also known as a "C-slot") grain geometry, named because the single propellant grain has a small cut-out running along one edge that gives it a cross-section resembling a crescent moon, or the letter "C". Because there is propellant only on one side of the slot in a Moonburning motor, they tend to build up pressure more slowly than Bates Grains. While they are not impossible to successfully cluster, Moonburning motors require that you use igniters that can deliver a very large and hot flame front to the propellant.

The J180 is a special case. Although it is a Moonburner, the J180 uses Blue Thunder propellant, so it is much easier to ignite than the other 3 Moonburner motors which use White Lightning propellant.

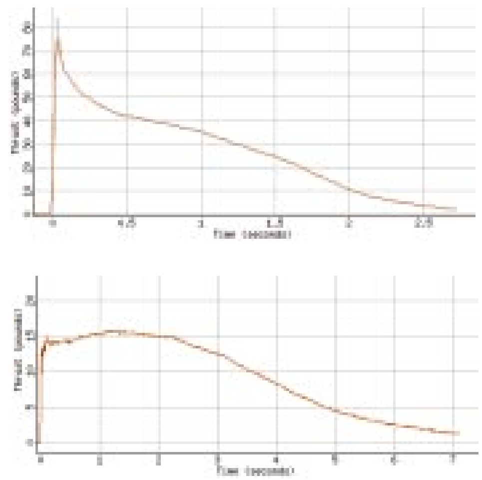
As for core size, all other things being equal, the larger the core a motor has the more slowly it will ignite, since a larger core takes longer to pressurize. Therefore, the larger the motor, the more attention you have to pay to the igniter's thermal characteristics (see below), and the more difficult it is to achieve simultaneous ignition.

Combining different motor types in a cluster

As mentioned previously, different motor types have different ignition times. This can have a dramatic impact on the performance of a cluster in which you use dissimilar motors. The safest approach when using dissimilar motors is to make sure that the centrally-located motor is the most powerful one, and is the easiest to ignite. With Aerotech motors that usually means using a Blue Thunder motor in the central position.

Motor thrust profiles

Another factor to consider when using dissimilar motors in a cluster is their differing thrust profiles (how they deliver thrust over the total time they burn). Using dissimilar motors in a cluster will produce a complex overall thrust profile that is a combination of the individual motor profiles. To do this successfully you must have very reliable data on the actual thrust profiles of each motor you are using. Since the data supplied by the motor manufacturer is often over-simplified, or shall we say, *market-ized* to show the motor in the most favorable way, I suggest that you use thrust profile information supplied by independent testing organizations like Tripoli or the NAR when planning any cluster flight, *especially* one with dissimilar motors.



Examples of different motor thrust profiles. Although both the H125 (top) and H45 (bottom) are both full 320ns H motors, each one delivers that total thrust very differently over time. The H125 has a total burn time of about 3 seconds, with a peak thrust of nearly 80 lb at ignition, which decreases to less than 40 lb after 1 second, and to 10 lb after 2 seconds. The H45 burns for 7 seconds, producing only 15 lb of thrust at ignition, and maintaining this level for almost 3 seconds before gradually decreasing over the next 4 seconds. (Note that the vertical and horizontal scales of the 2 graphs do not match.)

When flying a dissimilar cluster, I recommend that you place the motor with the highest initial thrust spike into the rocket's central mount. This will help minimize any asymmetrical thrust should any of the outboard motors fail to ignite or ignite late.

Because of the number of variables involved with using dissimilar motors, I advise that you not cluster with dissimilar motors until you have considerable experience under your belt clustering with identical motors.

Igniter Requirements for Clustering

For a variety of reasons, many if not most commercially-available igniters are not suitable for use in clustered rockets. Igniters that work well in clusters must have all of the following qualities:

The ability to ignite the motor

Although this seems obvious, every time I do RSO duty at club launches rocketeers bring rockets to the rangehead with igniters that cannot reliably ignite the motor they're using. Failing to ignite the motor on a single motor flight is merely an embarassment, but on a cluster flight failing to ignite one or more motors can lead to a crash.

For cluster flights it is crucial that the igniters be able to deliver a large, hot and long-lasting flame front to the propellant. The larger the motor (with its correspondingly larger core), the larger and hotter a flame the igniter must supply. Plain electric matches only produce heat for a fraction of a second before they blow themselves apart. Although they get hot, they don't stay hot for a long enough time to reliably ignite motors larger than a G or a small-core H. For clusters you must use igniters that have some sort of pyrogen on the head in order to achieve reliable ignition.

Low current draw

Igniters for clusters must require a relatively small amount of electrical current to fire. The current required by a single igniter must be multiplied by the total number of igniters to determine how much total current is required to ignite the cluster. For example, a Firestar igniter requires 8 amperes of current to reliably fire. Although most launch systems can supply this, a cluster of 5 motors with Firestar igniters would require 40 ampers of current, which is beyond the capability of many (if not most) launch systems. I recommend that you use igniters that have a current rating of no more than 5 amperes. This will assure compatibility with most launch systems even on a cluster of 5 motors (25 ampere requirement).

High reliability and consistency

Igniter reliability and consistency are much more critical for cluster flights than they are for single-motor flights. It is particularly important that all of the igniters in a cluster consistently draw the same amount of current from the launch system. That way no single igniter will "hog" more current and fire early.

Igniter Recommendations For Cluster Rockets

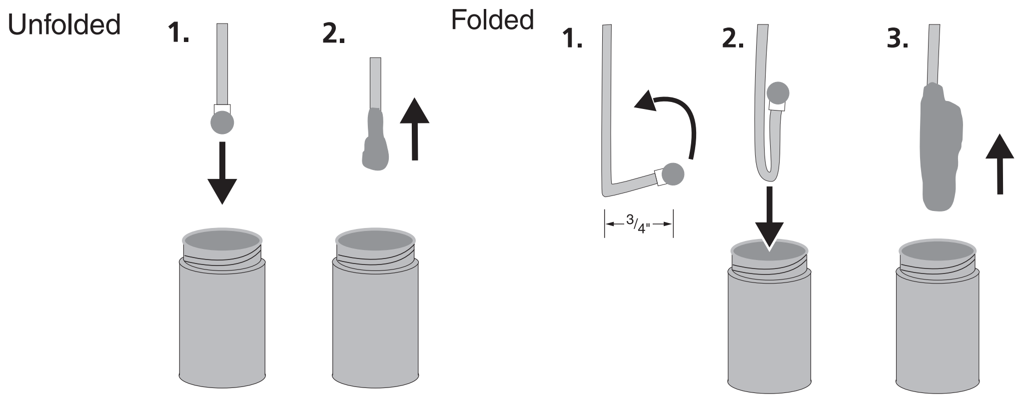
"Home-made" igniters:

My preferred igniter for clusters is Daveyfire (or equivalent) electric matches that have been dipped in Firestar pyrogen. The matches require less than 1 ampere of current to fire (so they can be used with virtually any launch system), are extremely consistent and reliable, and with the Firestar pyrogen, produce a flame that is large enough, hot enough and long-lasting enough to reliably ignite K motors.

I make "Dipped Daveyfires" in 2 sizes: non-folded, for use in H and I motors, and folded, for use in J and K motors. Folding the match 3/4" below the head allows it to pick-up more pyrogen, which is required for larger motor cores. Remember that the size of the motor's nozzle limits the diameter of the igniter. (Since it is *highly unsafe* to assemble a reloadable motor with the igniter installed in it, your chosen igniter must be small enough to be inserted through the nozzle after you bring the rocket to the launch pad.)

Firestar pyrogen comes in a kit that you mix at home. The procedure is simple, and the company supplies an instructional video along with your first order. You can contact Firestar at www.ddave.com/firestar/

To create your own Dipped Daveyfires follow the diagrams to the right, below.



Making "Dipped Daveyfire" electric match igniters.

For unfolded matches (H and I motors), dip the electric match into Firestar pyrogen 1/2" - 3/4" past the match head, and withdraw slowly, letting the excess pyrogen drip back into the bottle.

For folded matches (J and K motors), fold the wire against itself about 3/4" from the match head then dip the folded end into the pyrogen so that it completely covers the match head. Withdraw it slowly, letting excess pyrogen drip back into the bottle.

Thermalite

Thermalite is a demolition fuse that was used extensively in high power rocket motor igniters for many years.The Federal government has imposed strict regulations on the transportation and possession of thermalite, making it very difficult to obtain.

Although thermalite can be used for igniters, pyrogen formulas like Firestar and Magnalite create more heat and therefore, make more reliable igniters for clustering than thermalite.

Commercially-available igniters

Recommended for clustering:

Trailing Edge Technologies' tungsten "Fire-In-The-Hole" (http://members.aol.com/jturner/): These igniters have a pyrogen head that produces a white-hot flame for over one second, and only draw around 2 amperes of current each. Jim can custom-make igniters in sizes that fit motors as small as an E all the way up to an M. I use these igniters exclusively for G and smaller motors, and have not had a single failure, even with clusters as difficult as 7 x F14 (Black Jack propellant) motors.

Magnalite (www.rocketflite.com): These igniters have a pyrogen similar to Firestar, but with a lower current draw of around 5 amperes each. Make sure that the launch system can reliably deliver enough current to the pad if you are using a cluster of more than 3 of these igniters.

Not recommended for clustering:

Aerotech Copperhead (high current draw, difficult to properly connect)

Firestar (high current draw)

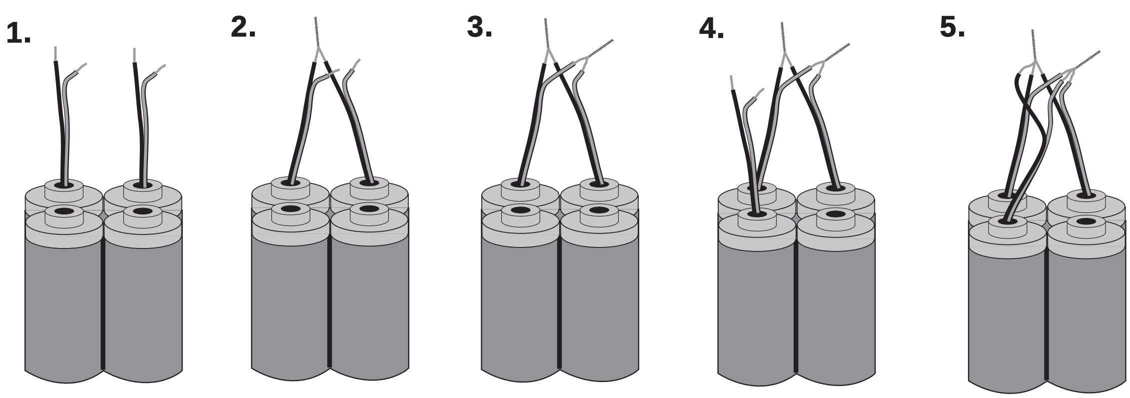
Plain electric matches (won't reliably ignite H and larger motors)

Installing Igniters In Motors

Put a sharp bend in each igniter wire right below its pyrogen head. This will ensure that the pyrogen is in contact with the motor's propellant. Insert each igniter as far into the motor as it will go, and tape it to the motor's nozzle to secure it. Do not completely block the nozzle opening with tape.

Wiring igniters together

Use parallel wiring ONLY. Avoid series wiring (see sidebar). Follow the diagrams below.



1) Insert igniters into two motors. Use masking tape to secure them in position (not shown), then separate the leads.

2) Twist two of the leads together

3) Twist the other two leads together.

4) Insert another igniter into the third motor and separate its leads.

5) Twist one lead into the first bunch you connected and twist the other lead into the second bunch.

6) Repeat steps 4 and 5 for each motor in the cluster, inserting one igniter at a time and twisting it into the others before inserting the next igniter.

Sidebar: Igniter Wiring

NEVER use series wiring with igniters. Series wiring sends the electrical current through the igniters in a "daisy-chain", one after another in a line. If the first igniter in the line burns, electrical current stops flowing to the other igniters further down the line, and they can't fire. Series wiring also raises the electrical impedance of the igniter load, reducing the amount of electrical current that the launch system can supply to the cluster, which further increases the likliehood that the igniters won't all fire in unison.

Connecting Igniters To The Launch System

Before connecting the igniters to the launch system, strike the system's launch clips together and look for a spark. If there is a spark the pad is live - NEVER CONNECT IGNITERS TO A LIVE LAUNCH PAD. Notify the LCO to safe the pad. Once the pad has been safed, strike the clips together again to confirm that there is no spark.

Bring a piece of 80 - 100 grit sandpaper with you to the launch pad and sand the launch clips to remove motor exhaust residue and corrosion. This will improve electrical current flow to the igniters, allowing them to receive the maximum amount of electrical current the launch system can supply.

Connect one of the bunches of igniter wires to one of the launch system clips and the other bunch to the other launch system clip. Bend each bunch of wires around its clip so that as much of the exposed wire is in contact with the clip as possible. Make sure that all of the igniters stay in the motors- it's easy to inadvertantly pull them out when you're connecting the leads.

Make sure that the two clips don't touch each other and that they don't touch the launch pad or any other piece of metal when you set them down - this will create a short-circuit and prevent ignition.

Use the launch system's continuity check to confirm that you have the igniters properly connected to the launch system. Note that with a cluster rocket, even if only one igniter has continuity the continuity check will still confirm continuity - the check does not confirm that all of the igniters have continuity.

If you've followed all of the advice in this article, the odds are high thay you'll have a successful cluster launch that you can be proud of, so you can make that long walk back to the rangehead without butterflies in your stomach. (However, it never hurts to give the rocket a little peck on its cheek or perform your own personal good luck ritual just to help appease the rocket gods.)

Left: The author poses with his Esoteric before its first flight in 1993. (Note the hammer being used as a launchpad standoff.)

Right: The Esoteric has a perfect liftoff on 1 x K550 and 2 x J275s. Magnalite igniters were used for all 3 motors.