TECHNICAL INFORMATION REPORT TIR-52

RELIABLE CLUSTER IGNITION

INTRODUCTION

The engineering state-of-the-art for obtaining simultaneous electrical ignition of two, three, or four model rocket engines has advanced considerably in the last year. No longer are cluster-powered model rockets purely a research experiment — today they are a commonplace, reliable method for increasing altitude performance and payload-carrying capability.

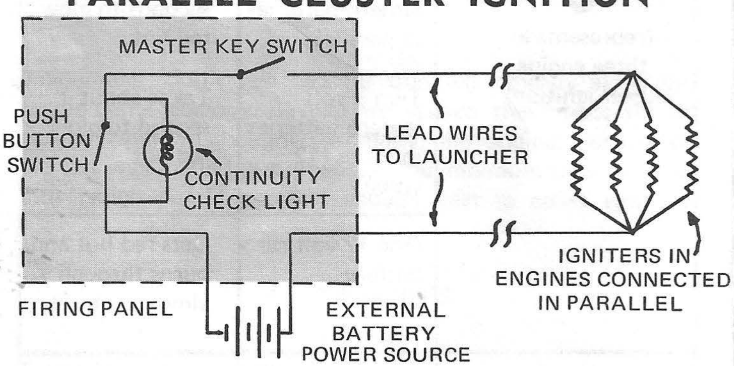
The purpose of this report is to provide rocketeers interested in trying cluster-powered model rockets with the basic information necessary to guarantee consistent success.

The question uppermost in your mind should be: "OK, what does a careful model rocketeer need in order to guarantee reliable ignition of his cluster-powered model rockets?" Basically, these two items make the big difference.

1. An AUTOMOBILE BATTERY for your electrical power source

2. SURE-SHOT igniters

PARALLEL CLUSTER IGNITION



The above is a complete circuit diagram for launching a four-engine cluster model rocket. It shows an igniter for each engine, the power source, and the internal components of the firing panel.

NICHROME WIRE

The igniters are made of very fine, high-electrical resistance nichrome wire. As you know from experience, the nichrome wire glows red hot shortly after you push the firing panel button. Electrical current flowing through the circuit causes this heat buildup in the wire and, as you can guess, the intensity of the glow is directly related to wire temperature.

PROPELLANT IGNITION

When the wire reaches the temperature at which the propellant burns (as indicated by the red glow), a successful ignition will occur. The object, then is to have each igniter in the cluster reach the propellant ignition temperature at the same exact instant in time, so that all four engines thrust evenly together just as if they were, in fact, a single engine.

IMPERFECT IGNITION

If one of the engines in the cluster fails to ignite, the rocket would have a tendency to pitch off-course to one side. Especially note that the farther the engines are located from the central axis of the rocket, the easier it is for a given amount of unbalanced thrust to cause a rotation from the desired vertical flight path. Since this report is stressing reliability, only those cluster configurations which keep the engines as near as possible to the central axis are discussed.

THE PARALLEL IGNITER CIRCUIT

In general, a parallel circuit allows each igniter wire to draw more individual current than possible in a series circuit. It has the added feature that if one of the igniters happens to burn-thru slightly before the others have reached propellant ignition temperature, the current flow still continues to the other engines.

Also, at the instant of burn-thru the amount of current to each of the remaining igniters automatically increases, thereby increasing the chance that they will all reach the propellant ignition temperature before the engines build up enough thrust to pull the rocket away from the micro-clips (which stops the current flow entirely).

Referring to the four-engine cluster circuit diagram, it is easy to see that if you mentally remove one igniter wire from the circuit there still remains three paths for the electricity to continue flowing through.

What is left, in essence, is an ideal three-engine parallel cluster ignition circuit. Removing a second igniter wire still allows current to flow through the circuit and again what remains is an ideal two-engine parallel cluster ignition circuit.

DIVISION OF CURRENT IN A PARALLEL CIRCUIT

If the individual resistance elements in a parallel circuit are all identical, the incoming current will divide itself evenly into each. This is exactly what is desired for obtaining perfect simultaneous cluster ignition. If the current in each nichrome is identical, then they all will heat up at identical rates. Thus, all will reach the propellant ignition temperature at exactly the same instant in time.

The resistance value of a given piece of nichrome depends strictly on its length. One of the important things to strive for in your parallel wiring hookups is to keep the nichrome wire lengths between micro-clip connections as near equal as possible.

THE EFFECT OF NICHROME LENGTH

You can perform a simple experiment to see just how sensitive the variation in wire length problem can be by just attaching a single 6 inch length of nichrome between two micro-clips. Depending on the voltage and power of your test battery, you will find that the 6" length probably won't even get hot enough to glow. Bring the clips to a 5" distance and see what happens when you push the firing button. As you keep decreasing the length of the nichrome wire between the micro-clip connections, the faster it will reach a red-hot glow. Eventually, as the length gets shorter and shorter the wire just gets red hot and melts almost instantly.

From this experiment we might conclude that for the above constant voltage condition that as we decrease resistance in the circuit, that current (or heating power) proportionally increases.

A long time ago, a fellow named Ohm wrote a simple equation which realistically describes this phenomena. If you can get some equipment and actually see what is physically happening yourself, you will understand the meaning of his abstract $E = IR$ math equation.

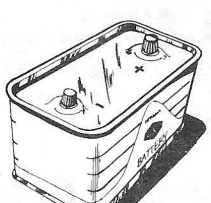
THE AUTOMOBILE BATTERY AS A POWER SOURCE

The best way to explain our reasons for stressing the importance of using a 12 volt automobile battery for your cluster ignition power source is to present you with more experimental test results and let you draw your own conclusions.

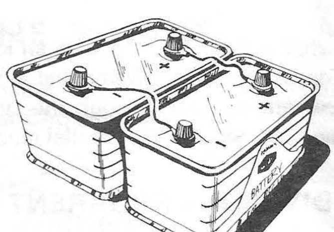
For comparison purposes, we made up three alternate power supplies based on the 6 volt lantern batteries which we recommend with all our firing panels. These batteries have excellent life, are quite portable, and are perfect for single engine ignition. As you will see, though, their available power leaves a lot to be desired when you are attempting to rapidly heat 3 or 4 nichrome igniters simultaneously.

The power sources used were:

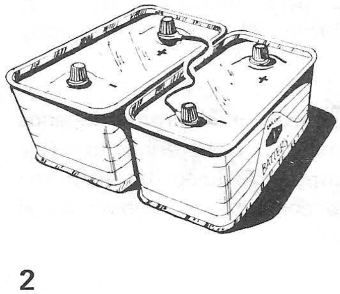
Single 6 Volt Lantern Battery



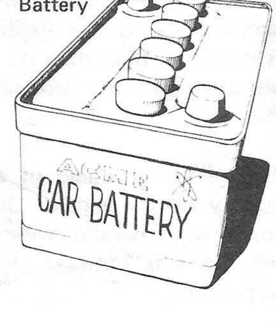
Two 6 Volt Lantern Batteries Combined in Parallel. This Still Produces 6 Volts.



Two 6 Volt Lantern Batteries Combined in Series. This now produces a total of 12 volts.



12 Volt Car Battery



Only brand new, fresh, 6 volt lantern batteries were used in the actual tests. An automobile battery in a car is recharged everytime it is driven so there isn't too much concern with how "fresh" it is. An automobile battery does not have to be removed from the car in order to be used for cluster launchings — neither was it removed for our tests.

In all tests, the nichrome wire lengths between micro-clip connections were kept to exactly one inch, since this length is quite close to what actually occurs in cluster engine wiring hookups. Centuri's Professional Firing Panel EP-612A was used throughout. Each test was subsequently repeated several times in order to insure accuracy of the experiment.

The results have been organized into the following table form for your convenience.

CLUSTER ELECTRICAL POWER COMPARISONS

Number of 1" Lengths of Nichrome Wire Connected in Parallel	Type of Electrical Power	Approximate Time It Takes Nichrome to Glow Red Hot
3 (represents a three engine cluster ignition)	One 6 volt lantern battery	Takes about 2 seconds to reach a weak glow
	Two 6 volt lantern batteries in parallel	Takes about 2 seconds to glow red hot
	Two 6 volt lantern batteries in series (12 volts)	Takes about 1 second to glow red hot
	One 12 volt car battery	Gets red hot and burns through almost instantly
4 (represents a four engine cluster ignition)	One 6 volt lantern battery	Does not glow
	Two 6 volt lantern batteries in parallel	Takes about 4 seconds to reach a weak glow
	Two 6 volt lantern batteries in series (12 volts)	Takes about 2 seconds to glow red hot
	One 12 volt car battery	Takes about 1/2 second to get red hot and burn through

The car battery, as expected, is the superior power source. You probably have a question though about the burn-thru. How good of an idea is it to reach the propellant ignition temperature, pass that mark on the way up to the nichrome wire melting point, and then burn-thru – all almost instantly. Do you think there is enough time for the heat to pass to the propellant in order to properly start it burning?

Perhaps you have used a car battery with a single engine rocket and experience an occasional misfire due to this apparent instant burn-thru. As soon as you pushed the button, the micro-clips fell away from the rocket due to igniter burn-thru and no ignition occurred. A very logical analogy to help you rationalize that this is what is happening can be taken from experience. If you wave your fingers rapidly through a candle flame, there just isn't enough time for the hot flame to have any effect whatsoever on your finger.

Then, why do we recommend the automobile battery when both the 3 engine cluster test wiring and the 4 engine cluster test wiring burn-thru? THE REASON IS THAT THE ABOVE CONCEPT IS SIMPLY NOT TRUE. IF AN IGNITER IS IN CONTACT WITH THE PROPELLANT, NO MATTER HOW FAST IT BURNS THRU IT WILL IGNITE THE PROPELLANT.

IMPORTANCE OF NICHROME TO PROPELLANT CONTACT

A discussion of another series of tests we performed should help prove successful ignition depends on contact and is not effected by burn-thru.

Incidentally, don't feel bad for thinking logically along the candle-flame analogy. When we started these tests this is exactly what we thought. Actually, the original purpose of the test was to find out what was the minimum time to burn-thru which would conduct enough heat to cause ignition.

TEST SAMPLES

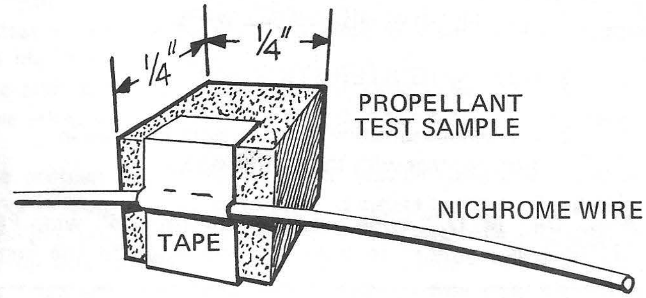
To perform this experiment, we prepared several dozen special propellant test samples at our engine plant. These were small 1/4" cubes of the same propellant mixture used in model rocket engines and they were compressed to shape under the exact same pressures used in the manufacture of model rocket engines.

These propellant test samples were prepared under the same rigid safety controls used in manufacturing model rocket engines. Also, the following experiments were conducted by college trained engineers with graduate degrees. If you attempt to repeat these experiments yourself, you will be in strict violation of the Model Rocket Safety Code.

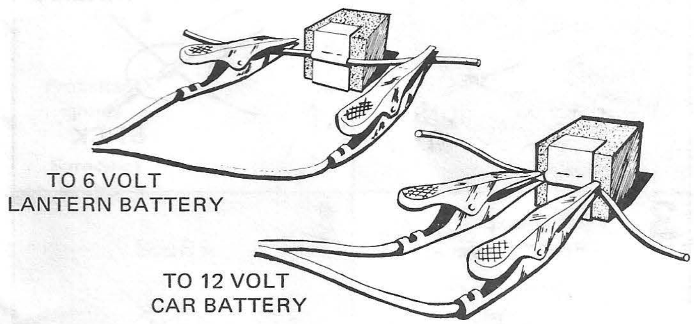
Keep in mind that even though you do not manufacture model rocket engines yourself, that you can learn a lot by using them. Similarly, you can learn something useful from the results of these professionally performed experiments without actually having to try them yourself.

IGNITION EXPERIMENT

In order to insure a good contact, the nichrome wire was taped to each cube as shown.



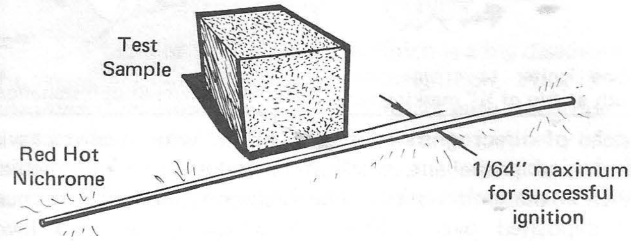
Starting out with a single 6 volt lantern battery and a micro-clip spacing of about 3/4" we progressed from test sample to test sample to the point where we ended up using a car battery and a minimum wire length of 1/8". Every single one of these tests resulted in the ignition of a propellant cube.



We began wondering if using the tape to hold the wire in good contact affected the validity of the experiment. We found from another dozen tests that if the wire was just laying against its test cube, it would also cause ignition every single time.

Next, we decided to find out how far away the igniter wire could be from the test sample and still cause an ignition. We started out at 1/32" and couldn't get an ignition at that distance – even when we increased the nichrome wire length to the point where it wouldn't burn-thru, but rather would produce a steady, red-hot glow.

It turns out that the nichrome wire can be no farther away from the propellant than about 1/64" to obtain an ignition (either under the burn-thru or steady glow conditions).



After performing the above experiments, some of the advantages of Centuri's Sure-Shot igniters became apparent and several additional simple experiments could now easily be performed to verify if some new conclusions were indeed true.

Just in case you have never used a Sure-Shot, we will first explain what they are and how to assemble and install them in the engines.

CENTURI SURE-SHOT IGNITERS

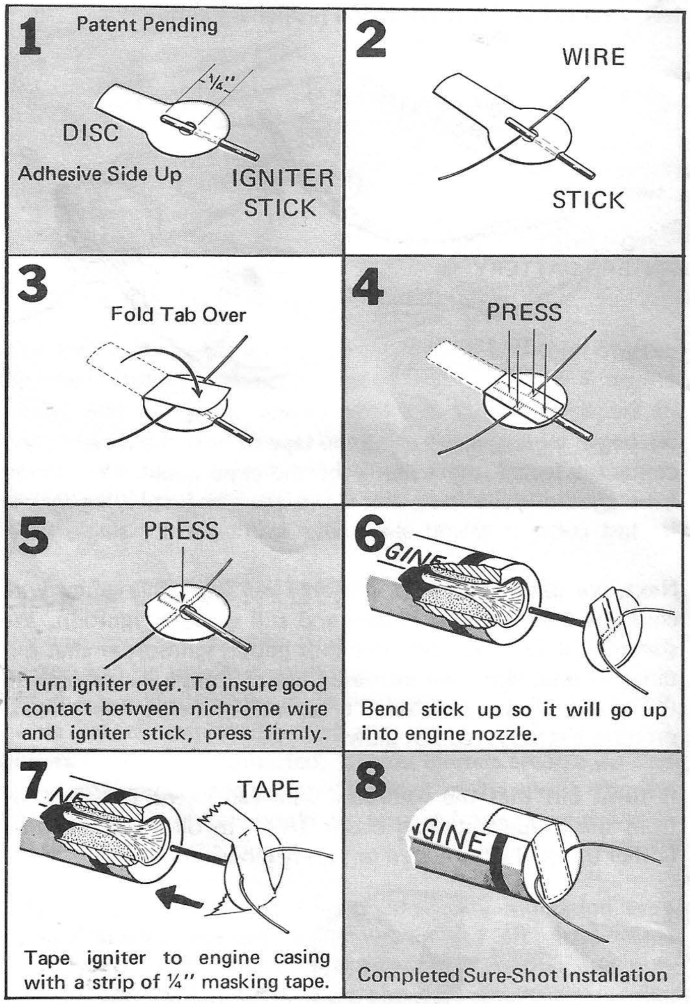
Sure-Shot igniters are made up of three parts:

1. A 2" length of NICHROME WIRE
2. A special IGNITER STICK, and
3. A pressure-sensitive DISK to hold the wire in firm contact with the igniter stick.

Also, 1/4" or 1/2" wide masking tape (or 1/4" wide PRO/STRIPE) is required to hold the Sure-Shot to the engine.

Sure-Shot igniters are available in kit form in a package of 12 for 50¢ (Catalog No. IG-12). A twelve foot roll of 1/4" wide masking tape is available for 20¢ (Catalog No. MT-25).

They are assembled and installed as shown below:



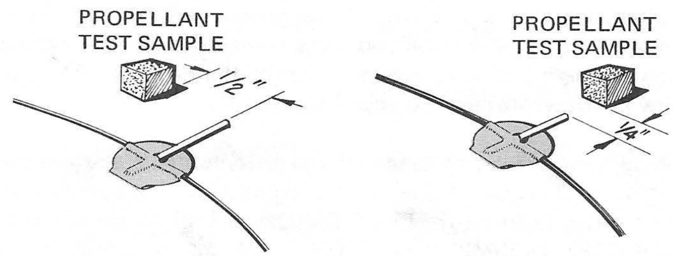
Instead of direct ignition using nichrome wire in contact with the engine propellant, we have introduced an intermediate device — the igniter stick. The stick contains a brown chemical deposited over a fine wire which ignites at a lower temperature than the propellant ignition temperature.

Actual observation of igniter stick tests show that they entirely consume themself instantly in one big "poof". Even though the nichrome is attached at the very end of the stick, there is no significant time increment for the flame to reach the other end. For this reason the igniter stick can be thought of as a heat amplifier for the nichrome rather than as a fuse.

IGNITER STICK EFFECTIVENESS

Exactly how effective is this heat amplifier? You'll remember that we previously established that direct nichrome wire ignition required the wire to be 1/64" or closer to the propellant test samples.

In a new series of tests using the igniter stick, we found that the propellant, at a distance of 1/2" from the side of the stick as shown, would ignite every single time. Even at a distance of 1" we obtained ignition in about half of the tests. When placed at the end of the stick, ignition of the propellant test sample was 100% reliable at a distance of 1/4" as shown.

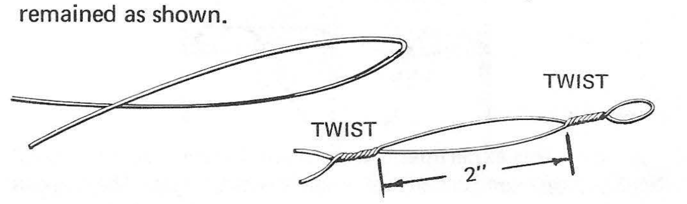


Keep in mind that the above tests were performed in the open without the additional funneling effect of the engine nozzle. We feel that confining the combustion of the stick in an insulated tube (the nozzle) would extend the above propellant ignition distances even further.

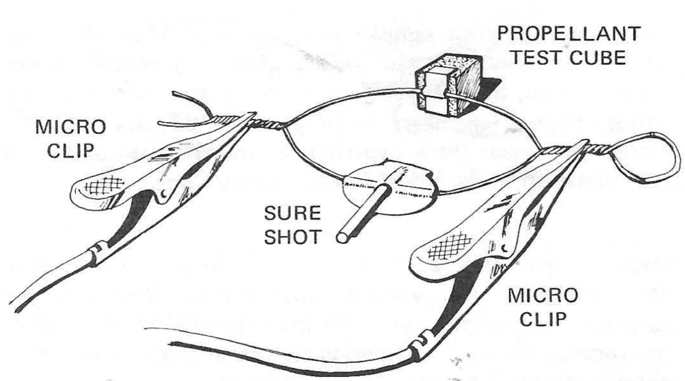
IGNITION TEMPERATURE

We mentioned earlier that the brown chemical of the igniter stick ignites at a lower temperature than the propellant. This has the advantage that less total battery current capacity is required for a successful cluster ignition.

To prove that the igniter stick indeed had a lower ignition temperature than the propellant, we performed a few more experiments. The basis of the experimental proof is that equal lengths of nichrome wire, connected in parallel, heat up at exactly the same rate. A 6" length of the nichrome was made into a loop and then both ends twisted together until 2" remained as shown.



Then the two straight sections were spread apart and a Sure-Shot attached to the middle of one and a propellant test sample was taped to the middle of the other as shown.

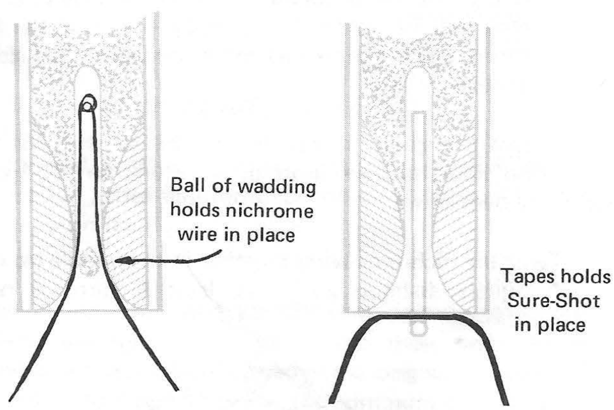


The reason a 2" length was used was to avoid instantaneous heating. Instead, heat would build up slower and it would be easier to visually detect if the Sure-Shot actually ignited before the propellant sample. A piece of asbestos sheet was placed between the two in order to prevent the one which ignited first from immediately igniting the other. The results of the tests showed that yes, the Sure-Shot was igniting first (after about a 1/2 second buildup using two 6 volt lantern batteries in series).

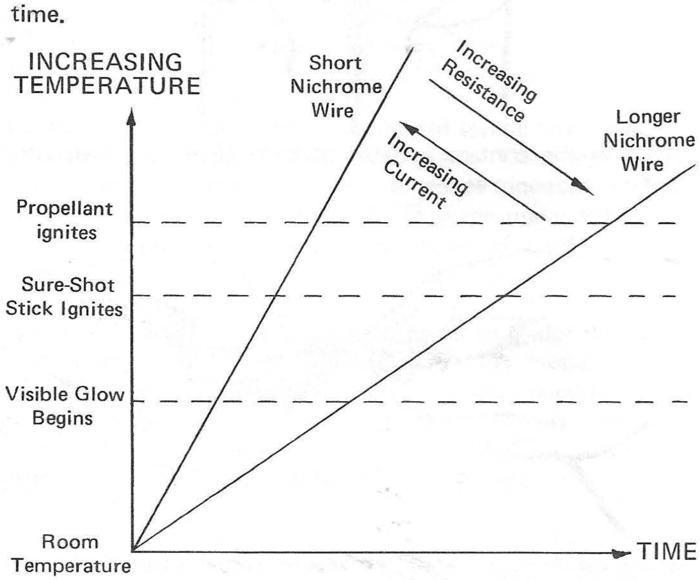
All tests showed that an obvious time increment existed before the wire reached the higher temperature required to ignite the propellant. In fact, with practice, we developed fast-enough reactions that we could release the firing panel button after the Sure-Shots ignited, but before the propellant could ignite.

MINIMUM NICHROME WIRE LENGTH

One more advantage of Sure-Shots should be mentioned which most readers probably noticed immediately. The Sure-Shot method uses less than half as much nichrome wire as the direct nichrome ignition method. This is because the wire need only be in contact with the igniter stick and it does not have to go up through the nozzle to touch the propellant directly and then back down again as shown.



This means for a given battery current capacity the igniter wire will reach a given temperature in a shorter amount of time.



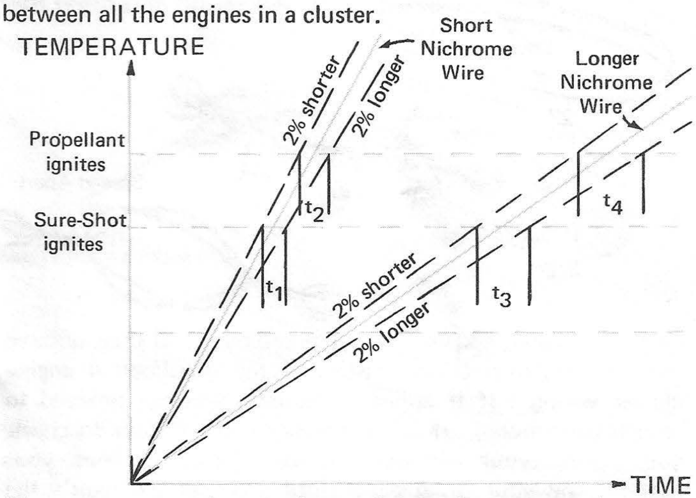
The above graph summarizes most of the important points we have learned with our experiments. Study it for awhile and see what it is telling you.

IMPORTANCE OF MINIMIZING TIME

As you surely noticed, we have been stressing over and over the importance of lots of current for cluster ignition in order to insure that the wire heats up to ignition temperature just as fast as possible. If your nichrome wire leads to each engine are identical in length, they all heat up exactly at the same rate and reach the ignition at the same time — so you may have asked what's the difference if it takes a little extra time?

The problem lies in assuming that you can grip the nichrome wires in your cluster at exactly identical lengths. Practically speaking, you can't and you will end up with one wire slightly shorter and another slightly longer. This means less resistance, more current, and faster heating in the first case and more resistance, less current, and slower heating in the case of the longer wire.

Resistance varies linearly with wire length so we can plot the effect of say a 2% tolerance variation in nichrome wire length between all the engines in a cluster.



The t_1, t_2, t_3, and t_4 marks on the graph represent the time span between ignition of various engines in the cluster. This time span must be kept to a minimum and ideally should be zero. As you can see, time t_4 is larger than time t_1.

In the case of the nichrome wire in contact with propellant condition (the t_4 condition), it is possible that the rocket could have started moving up and disrupted the micro-clip connections before the last engine ignited! The advantages of Sure-Shots with their inherently shorter nichrome wire length and lower ignition temperature (the t_1 time increment condition) should now be plain to see.

NICHROME CONTACT

One more thought to keep in mind which is a big disadvantage of using direct nichrome to propellant ignition. How do you guarantee that the wire really is in contact with the propellant or at least within 1/64" of it? You cannot visually inspect inside the nozzle once the wadding is in place and surely the very act of inserting the wadding moves the wire around a little.

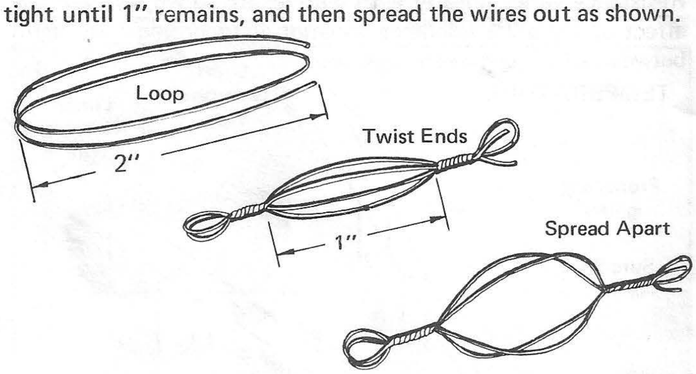
If you are using plain nichrome wire in your single engine rockets and you have a misfire, it is irrelevant because the rocket simply remains on the launch pad. Many rocketeers, however, find misfires to be frustrating and time consuming and choose to use Sure-Shots even in their single engine rockets to assure perfect ignition every time. With cluster powered rockets, however, misfires have to be one of your major concerns if you wish to avoid damaging your model.

PRE-LAUNCH ELECTRICAL SYSTEM CHECK

After making your battery and launcher connections, you should connect a single 1" long piece of nichrome to your micro-clips. Pushing the firing button melts the nichrome and verifies that the circuit is complete.

Next, you want to verify that your system has enough current to ignite the cluster. To do this we recommend that you simulate a four engine cluster ignition with four 1" pieces of nichrome in parallel. Plain nichrome wire comes with your model rocket engines or can be purchased in 2 foot lengths for 15¢ (Cat. No. EW-32) or 12 foot lengths for 50¢ (Cat. No. EW-32A).

The fastest way to make this simulation test wiring is to start with an 8" length and loop it twice. Next, twist the ends tight until 1" remains, and then spread the wires out as shown.



Grip the twisted ends with your micro-clips and then observe the heat buildup characteristics of the simulated 4 engine cluster wiring. If it appears adequate, you can proceed to launch your model. If it looks weak, you will have to check your wiring, your micro and battery clip connections, your battery, and your firing panel until you find and rectify the system fault.

CONTINUITY CHECK

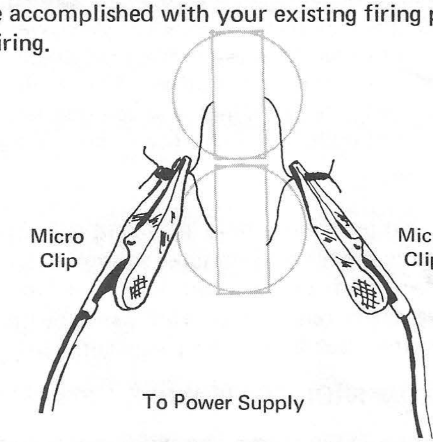
The value of the continuity check as it applies to cluster ignition can be summed up in one word – "useless". The fact that the continuity check bulb lights when you turn on your master switch only means that at least one of the Sure-Shot igniters is properly connected. Cluster igniters are in a parallel circuit and you can see by referring back to the wiring diagram that any three igniters could be removed and current would still flow through the circuit.

It is also possible to get a good continuity indication even though none of the igniters are connected properly. This could happen if the micro-clips touch one another and produce a "short" circuit. A short circuit is simply an undesirable complete circuit in that none of the electricity flows to the igniters. This, of course, is a problem not strictly confined to clusters. One must learn to avoid micro-clip shorts even with single engine launches.

The continuity check, as it applies to cluster ignition, only tells you that your master switch is on, that your battery power supply is connected, and that the circuit is complete. It says nothing, however, about whether or not your cluster wiring circuit is correct and ready to go. This is why a pre-launch visual inspection of all wiring is absolutely necessary with cluster rockets.

TWO ENGINE WIRING

A 2 engine cluster is the easiest wiring hookup to make and it can be accomplished with your existing firing panel equipment and wiring.



Assuming the parachute, wadding, and electrical system have all been prepared, then:

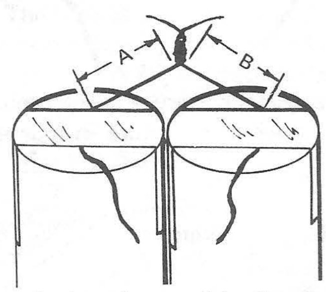
1. Prepare Engines

   a. Install Sure-Shots in each engine.

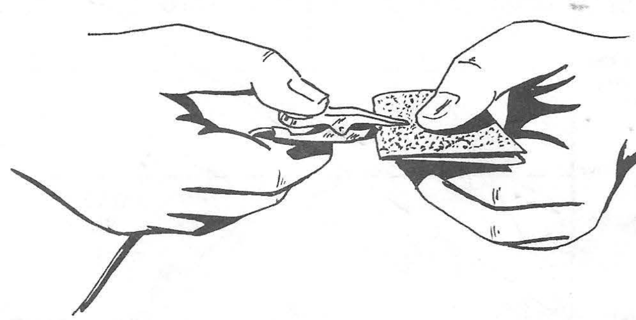
   b. Apply tape by wrapping it around the engines so that they will fit tightly in the body – so that the parachute, not the expended engine casing, will be ejected at peak altitude.

   c. Insert engines in the body tube so that the tape holding the Sure-Shots in place will be lined up as shown above.

2. Twist the nichrome wires together in the middle (so distance A equals distance B) – at least 5 turns is required.



3. Clean the contact surfaces of both micro-clip leads with fine sandpaper as shown.



4. Mount Rocket. Slide the rocket over the launch rod and grip each pair of twisted nichrome wires with a micro-clip. You will note that the micro-clips seem to have a much firmer grip on two wires twisted together than they would have on just one wire.

5. Important Checks. Now comes two of the real important points that cannot be overlooked if you want to guarantee reliability.

   a. Tug Test. With the rocket in place, give each micro-clip lead a gentle tug or pull. If it slides easily – you do not have an adequate contact. Keep shifting the clip until you do! (Note: This problem occurs very often when trying to grip a single strand of nichrome. The reason for this is obvious – the wire is very fine and unless the micro-clip jaws are perfectly flat, you will have to be selective as to what point on the clip is used for the actual gripping).

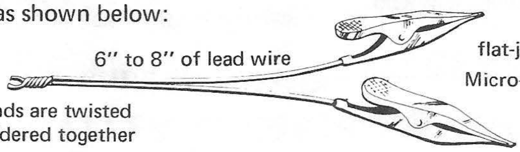
   b. Visually inspect all connections. No micro-clip should be touching any metal (launch rod or blast deflector) or any other micro-clip.

6. Once you have established that everything is in order, do not jar or otherwise move the rocket or the wire leads as it may move some of the clips and break contact or induce a short circuit.

7. Clear to launch.

THREE ENGINE WIRING

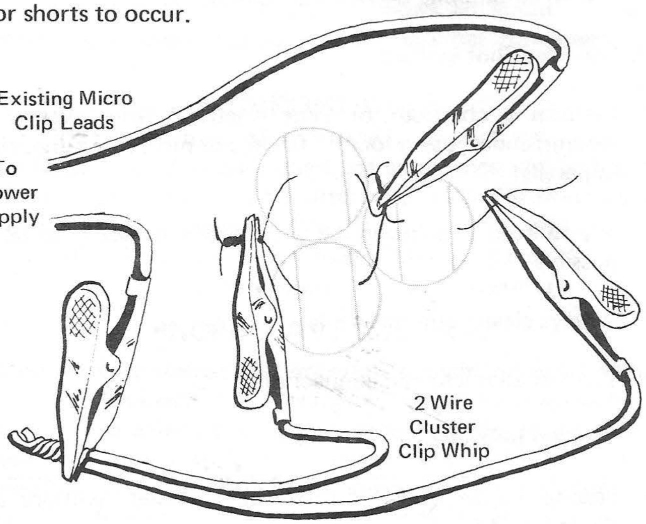
The next step up is to prepare a 3 engine cluster. In order to do this you will have to add one item to your firing panel and launching equipment. This item is a two-lead Cluster Clip Whip as shown below:



This same Clip Whip also enables you to fire 4 engine clusters. Its purpose is to merely enable you to grip all the nichrome wire leads in the cluster and thus distribute current evenly to each.

> For your convenience, Centuri is offering the above Cluster Clip Whip in completely assembled form for 95¢ (Catalog No. ECW-1).

Centuri's recommended technique for wiring a three engine cluster is as shown. Other ways, using additional micro-clip leads exist but we feel keeping the number of leads to a minimum increases reliability directly, by reducing the possibility for shorts to occur.



Note that the single wire on the right is not gripped as close in as possible, but rather at a point which will give approximately the same nichrome wire length as found between the center attachment and where the left hand micro-clip grips the twisted pair.

PROCEDURE

Again we assume that the parachute, wadding, and electrical system have all been prepared.

1. Prepare Engines

   a. Install Sure-Shots in each engine.

   b. Apply tape around each engine casing.

   c. Insert engines so that the tapes holding the Sure-Shots are aligned as shown.

2. Twist all 3 middle leads together.

3. Twist the 2 leads on the left together.

4. Clean the contact surface of all micro-clips with fine sandpaper.

5. For convenience, attach the Cluster Clip Whip as shown before sliding the rocket in place on the launch rod.

6. Mount the rocket in place on the launch rod.

   a. Grip the center three wires using one of your existing micro-clip leads.

   b. Grip the soldered end of the Cluster Clip Whip with the other existing micro-clip as was shown in the illustration.

7. Important Checks.

   a. Tug test all micro-clip connections.

   b. Visually inspect to see that no clips are touching each other or any launcher metal.

8. Do not move or otherwise jar the rocket.

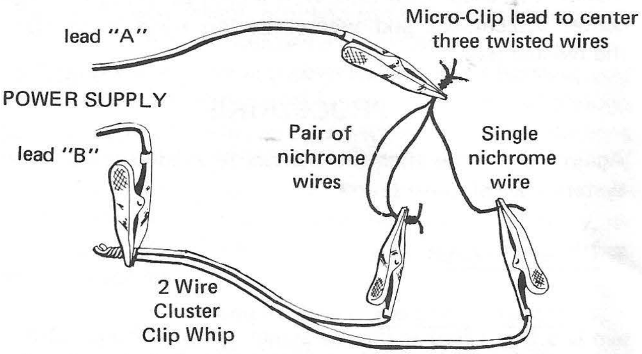
9. Clear to launch.

A MISCONCEPTION

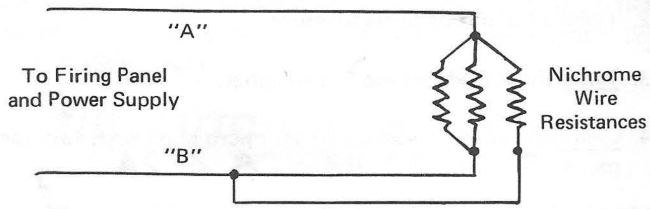
A note needs to be added at this point to clarify most people's intuitive feeling that the pair of wires to the left of center on the illustration will be receiving only half the current that the single wire to the right of center receives. This would indeed be bad from the standpoint of our desire to obtain reliable simultaneous cluster ignition because if the above condition were true, then the engine to the right of the center would surely ignite first.

The current in each igniter wire, however, is identical and we'll try to show you why without resorting to any mathematical circuit equations.

The following illustration is the same exact three-engine wiring hookup after some mental rearrangement.

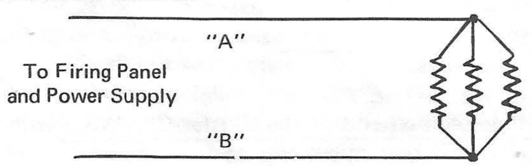


Keeping in mind that the electrical resistance of the micro-clip lead wires is negligible in comparison to the large resistance of the nichrome wire, the above can now be rearranged into its representative schematic circuit (where —WW— means an electrical resistance).



Thus, we can see that one end of each nichrome wire is connected directly to point "A" via zero resistance, and the other end directly to point "B" via zero resistance.

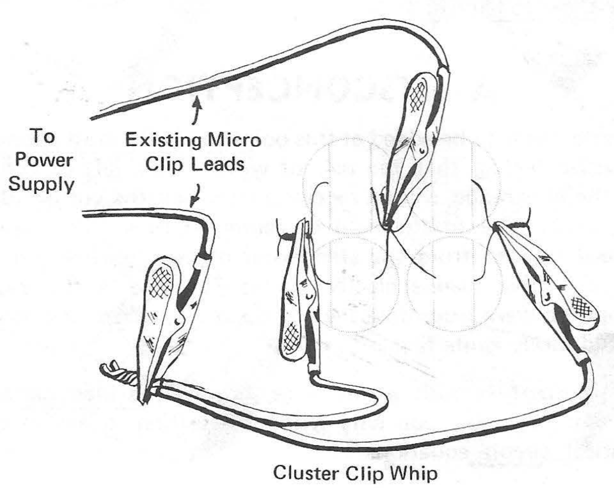
This is the same as:



which is a parallel circuit. If all of the nichrome wires (the resistance part of the circuit) are equal in length (each has the same resistance value) then the current is evenly distributed to each. Knowing this should also help you understand why you should try to make all nichrome wire connections equal in length.

FOUR ENGINE WIRING

Centuri's recommended technique for wiring a four engine cluster uses the two wire Cluster Clip Whip as shown.



Again, assume that the parachute, wadding and electrical system have been prepared.

1. Prepare Engines
   a. Install Sure-Shots in each engine.
   b. Apply tape around each engine casing.
   c. Insert engines so that the tapes holding the Sure-Shots are aligned as shown.
2. Twist the nichrome wire leads together as shown (4 in the middle, 2 at each end).
3. Clean the contact surface of all micro-clips with fine sandpaper.
4. For convenience, attach the Cluster Clip Whip to the two twisted end wires before sliding the rocket in place on the rod.
5. Mount the rocket in place.
   a. Grip the center 4 wires using one of your existing micro-clip leads.
   b. Grip the Cluster Clip Whip with the other existing micro-clip lead.
6. Important Checks.
   a. Tug test all micro-clip connections.
   b. Visually inspect to see that no micro-clips are touching each other or any launcher metal.
7. Do not move or otherwise jar the rocket.
8. Clear to launch.

REVIEW

The main points to remember concerning Reliable Cluster Ignition are:

1. Use an automobile battery for electrical power.
2. Use Sure-Shot igniters.
3. Perform a checkout of your electrical firing system as recommended, using four 1" lengths of nichrome connected in parallel.
4. Try to keep your nichrome wire lengths as nearly equal as possible.
5. Always clean your micro-clips.
6. Tug test all micro-clip connections.
7. Visually inspect all connections.

Additional copies of TIR-52 (Reliable Cluster Ignition) are available for 25¢.