Technical Report TR-6

Cluster Techniques

ESTES

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INTRODUCTION

One of the most common and valuable techniques in the development of launch vehicles to boost large payloads is the use of several engines in a cluster to provide enough thrust for first stage lift-off and acceleration. Typical clustered launch vehicles include NASA's Little Joe, Saturn I and Saturn V.

In professional rocketry clustering makes it possible to combine several smaller, less expensive and more reliable rocket engines to boost the payload. If a single larger engine were to be used in a new launch vehicle design there could be a delay of several years before the engine can be developed, resulting in a vastly greater cost.

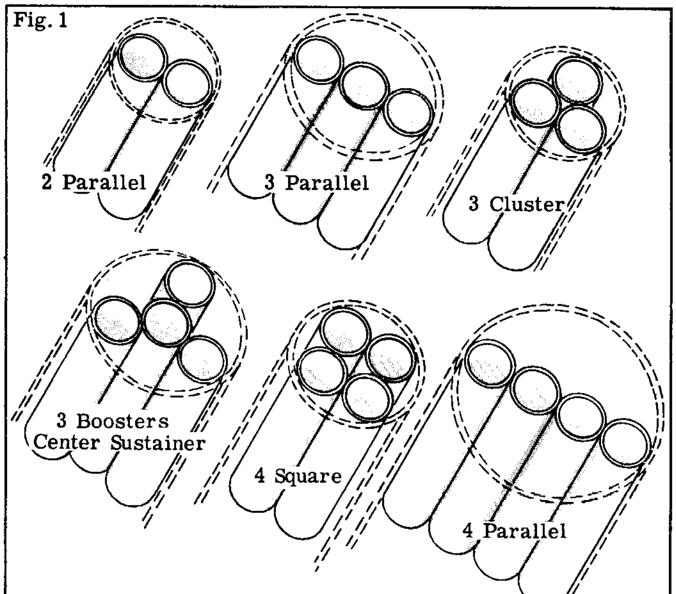
Model rocketeers can get many of these same advantages by using clusters in their vehicles. Many of the problems a model builder will encounter are similar to those met by professionals.

CLUSTER ROCKET DESIGN

ENGINE ARRANGEMENTS

It is common when clusters are mentioned to immediately think of three or four engines set in some arrangement that will allow them to all fit in a round body tube. Actually, any arrangement of two or more engines in the same stage of a model can be considered a cluster. Generally, four engines are the most that should be used in a model rocket, since more engines make ignition less reliable. Some typical arrangements are shown in Fig. 1.

Fig. 1



In designing a cluster rocket first make sure that thrust will be balanced around the center line of the rocket. An unbalanced arrangement will normally cause the rocket to veer off course. Similarly, all engines located away from the centerline of the rocket should develop the same amount of thrust. For example, the two outer engines in a parallel 3 engine cluster must be the same--although the center engine might be a B6-4, if one outer engine is a B14-5, the other one must be a B14-5.

All engines should be located fairly close together. Avoid wayout designs with the engines spaced several inches apart. The distance from the center of the nozzle of one engine in a cluster to the center of the nozzle of any other engine in the cluster should not be more than 10% of the rocket's length. It is better to keep the engines positioned so they almost touch each other. If this is done variations in thrust will not make the rocket veer off course.

Unusual engine arrangements should be developed carefully. Check to be sure the thrust from all engines will balance. A <u>slight</u> amount of imbalance or misalignment can be offset by using extra large fins or a small amount of spin angle on the fins. If thrust is very far out of balance, however, the rocket will not fly straight enough to be safe.

ENGINE MOUNTING

Once the basic engine arrangement for a cluster model has been chosen, the next step is to design an engine mounting system. The engine mounting system serves three purposes: First it should hold the engines securely in place throughout the flight. Second, it should align the engines so they work together as a unit and give a straight flight in the desired direction. Finally, the engine mounting system must seal the rear of the rocket so that the recovery system ejection gases cannot leak out through cracks and holes in the back of the model.

The first item to consider in designing the engine mounting system for a new model is a method for retaining the engines. They can be held in place either with masking tape or engine holders (#EH-2 or #EH-3). Masking tape (which is wrapped around the engine to make it fit tightly in the mounting tube) has the advantages of lighter weight and lower initial cost. On the other hand, engine holders do not weigh much more, allow quick and easy replacement of engines, and are positive -- once the engine is in place it is held securely and won't come out until it is intentionally removed.

Fig. 2

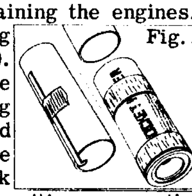
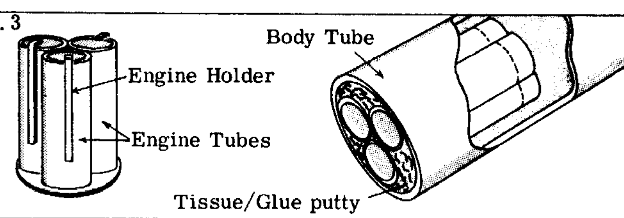


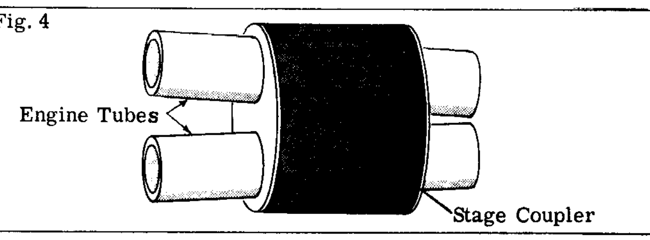
Figure 3 shows typical engine mounting systems for a three engine model. Note that when engine holders are used, the spaces between tubes are sealed at the front of the engine mounting tubes, while when masking tape is to be used to secure the engine in place the spaces can be sealed at the extreme rear of the rocket. The same considerations apply to any other cluster model, regardless of the number of engines it uses.

Fig. 3



If a body tube is large enough to hold three engines, it can also hold two engines. Figure 4 illustrates techniques which

Fig. 4



can be used to position and align engine mounting tubes which would otherwise fit too loosely in the rocket body tube. When it is necessary to make special rings to position and support the tubes, the rings should be cut from fairly heavy cardboard such as is used in shoe boxes. An Estes #KNS-1 knife, wrapped with three or four layers of masking tape and mounted in an ordinary school compass, makes an excellent tool for cutting the rings.

Occasionally it is desirable to mount several engines in a body that would normally be too small. A good example of this would be the use of two engines in a model with a BT-55 body tube. In this case slots should be cut in the body. Each slot should be the same length as an engine mounting tube and just wide enough to let the mounting tubes stick out the same amount on each side of the body. Figure 5 shows a typical rocket built in this way. The cut-out pieces of body tube can be trimmed to make fairings for a smooth transition from the body to the projecting engine mounting tubes. A fairing can also be made by cutting a nose cone in half and carefully carving and sanding the halves until they fit smoothly in place.

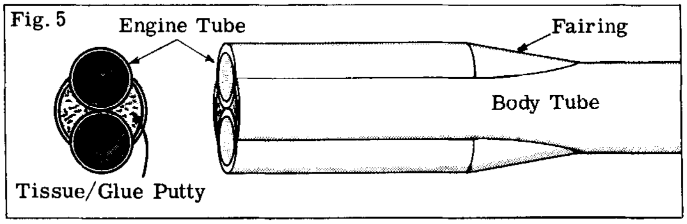


Fig. 5

From these examples it can be seen that there are countless ways of mounting engines. As long as the engines are held in alignment, the rear of the model is sealed to prevent ejection gas leakage and a path is provided for the ejection gas to blow forward, just about any system will work. In any case, the engine mounts must be strong enough to stand up to the engines' maximum thrust. The best way to make sure the engine mounting system will be strong enough is to use plenty of glue when building it.

STABILITY

Because the weight of several engines is concentrated in the rear of a cluster rocket, extra attention should be given to designing the rocket so it is stable. Since the engines will not always all be producing exactly the same amount of thrust at the same time, an extra margin of stability is needed. A good cluster model will have extra-large fins. These fins should be located well to the rear on the body--fins ahead of the model's center of gravity (balance point) should be avoided since they make the model less stable.

It's easier to stabilize a tall rocket than a short one. Since body tubes are relatively light, there's no real reason to use too short a tube. In general, a two or three engine model should use a body between 15" and 24" long. If the model carries a payload it should be located near the very front of the rocket. This forward payload weight, combined with a long body, brings the center of gravity forward and increases the model's stability. *

Since a cluster rocket will usually be heavier than a single engine model, it is apt to land harder. In addition, the forces acting on a cluster model's fins in flight are greater. The result is that the cluster model will need extra strong fins. Big fins should be made stronger than small fins. Because of this one-eighth inch thick balsa sheet is the most popular fin material for cluster birds.

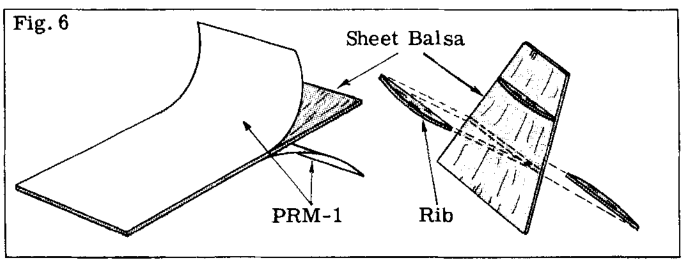


Fig. 6

Fin stock thinner than 1/8" can be used, but it should be reinforced for best results. Two reinforcing methods are commonly used: Self-adhesive paper (#PRM-1) can be applied to both sides of the fin or strengthening ribs can be glued to the fin, parallel to the root edge and spaced evenly along the fin as shown in figure 6.

A small amount of spin can be useful with cluster rockets. Slightly off-center thrust can be evened out if the rocket spins slowly. However, too much spin will waste thrust since drag on the rocket increases as the rocket spins faster. One way to give the rocket the right amount of spin is to glue the fins to the body at a slight angle. A non-symmetrical airfoil on fins that are straight on the body will also produce enough spin. Finally, a small angled "spin tab" can be added near the tip of each fin. In any case, make sure all fins or tabs are made to spin the rocket in the same direction.

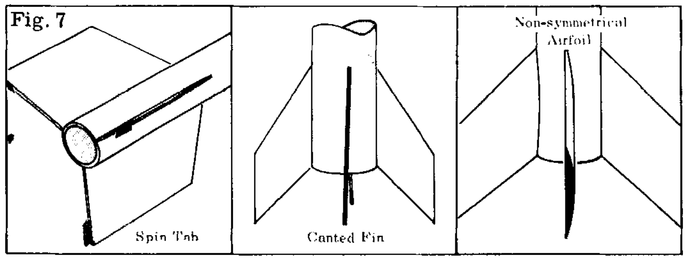


Fig. 7

It can be mighty embarrassing to lead all your friends in a grand procession out to the launch pad for the maiden voyage of your "super" bird if that bird decides to go up 50 feet and then loop around in the air. To avoid this embarrassment (and to insure safety) TEST IT BEFORE YOU FLY IT. Use either a wind tunnel or the string method described in Technical Report TR-1 to make sure the model will be stable. If the model is tested by the string method it should have at least a 15° to 20° "margin" of stability. If the rocket is not stable you can either make it longer, add nose cone weights or install larger fins.

RECOVERY

Since a cluster rocket is usually larger and heavier than a conventional rocket, its recovery system must be designed to handle a greater load. Parachute recovery is the only system which has actually proven practical for cluster rockets. Generally, two parachutes are used on models with large payload sections; rockets with small payload sections often need only one parachute. Some designs, however, may require three or even four 'chutes. A good rule to follow is to provide at least 40 square inches of parachute area for each ounce of rocket weight.

There is a reason for using at least two 'chutes on a model with a large or delicate payload section. This eliminates the possibility of the payload section snapping back on the shock cord after ejection and damaging the rocket or payload. The parachute on the payload section can be attached directly to a lightweight payload section. For heavy or delicate payloads, however, a short length of shock cord should be used to connect the 'chute to the payload section. The booster section's 'chute should be attached with a 1/4" wide shock cord at least 18" long (part #SC-2).

Additional steps can be taken to improve a cluster rocket's recovery system. A "stuffer" tube can be used in a long booster body to control the ejection gases and to keep the parachute from moving too far rearward in the body. The stuffer tube can be a section of either BT-20 or BT-50, centered and held in place in the body with two rings as shown in figure 8.

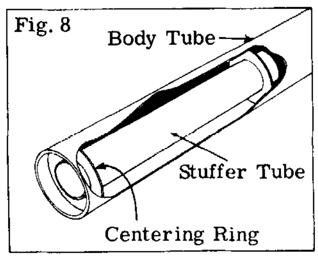


Fig. 8

To reduce fin breakage the recovery system can be attached to the outside rear of the body instead of the front. This is done by gluing one end of a string in a hole in the body about one inch from the rear. The other end of the string is tied to the shock cord. The string should be long enough to reach up the side of the body tube and back two or three inches into the inside of the body tube.

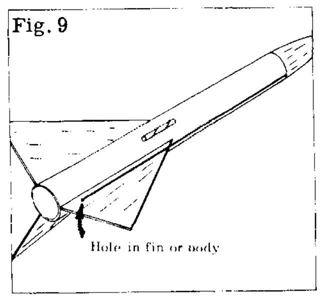


Fig. 9

*For more information on stability, see Technical Report #TR-1 and Technical Report #TR-9. These reports may be ordered at $ .25 each.

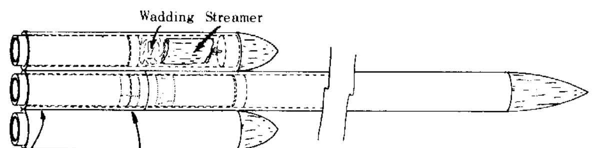
The best way to protect parachutes from the heat of ejection gases is to use an adequate amount of flameproof wadding. Use enough loosely packed wadding to fill the body for at least twice the diameter of the tube. Stuff the wadding into the tube just far enough to allow space for the parachutes, shroud lines and nose cone. Don't push the wadding all the way to the rear of the tube.

MULTI-STAGING

Clustering can be combined with multi-staging only under special circumstances. Certain rules must be followed if the rocket is to be either safe or successful. The first rule is that only the first stage can be clustered. To understand the reason behind this, remember that each engine in a multi-stage model rocket must be coupled directly to the engine ahead of it. However, if three engines in one cluster stage are each coupled to engines in another cluster stage, one booster engine will burn through a tiny fraction of a second before the others. This variation in time is enough to force the stages apart before the other two engines can ignite.

As a result, the only successfully proven staged and clustered system uses a bottom stage which has one engine in the center and two or three engines alongside it. This center engine is coupled directly to the single engine of the next stage. The outside engines can be placed in pods with a streamer or parachute recovery system to return the booster gently. In this case the outside engines should have short delays (B4-2).

Fig. 10 (See TR-2 for more information on staging methods.)



Glue pods to booster section only. Use extra-large fins on booster, smaller fins on upper stage.

IGNITION

Ignition is the most important part of successful clustering. All engines must ignite at once or within a tiny fraction of a second of each other. Many techniques have been tried to obtain successful ignition. Some methods proved unreliable, others were also unsafe. The only system which has proven safe and reliable through extensive testing is direct electrical ignition using standard igniters.

Five things are necessary for successful electrical ignition: The correct engines must be used; the igniters must be installed in the engines correctly; the igniters must be connected together correctly; the electrical launching system must be in good condition with good connections throughout and the launcher battery must have enough power. If there is a flaw in any of these five areas, ignition will not be completely successful. If everything is done correctly, all engines will ignite at the same instant and the rocket will roar skyward.

TYPES OF ENGINES

Since the usual purpose of clustering is to boost a payload to a greater altitude than would be possible with a single engine, it is usually necessary to use B or C class engines. A single engine rocket using a B14-5 engine will normally lift a payload higher than a cluster rocket with four 1/2A6-2 engines. However, A or smaller engines can be useful for the first test flights of a lightweight cluster model.

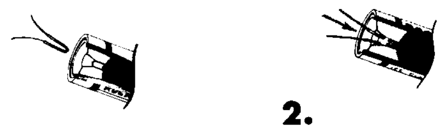
To decide which engines are best for a rocket, divide its total weight (including payload and engines) by the number of engines it uses. Compare the result with the "maximum rocket weight" listed in the engine selection chart in your catalog to find which engines can be used. For a more accurate choice of engines, read Technical Report #TR-10 (50¢ per copy). The method described on page four of the report gives good results. Careful selection of engines can prevent damage to the rocket which might occur from too early or late ejection.

NOTE: Before installing the engines in your cluster rocket, pack the front of the engine above the ejection end cap with flame-proof wadding. This eliminates any possibility of one engine's ejection charge igniting the ejection charge of another engine and damaging the rocket. This is extremely important when one engine in a cluster fails to ignite at lift-off.

INSTALLING THE IGNITERS

For direct electrical ignition the igniters in the individual engines must be installed correctly. Before starting, read the instructions which come with your Estes engines. Several points should be remembered when installing igniters; First, the igniter must be inserted so its coating touches the black propellant grain. The bent end of the igniter should reach at least 9/16" into the end of the engine. The heat generated by the igniter is not great enough to cross a gap between the igniter and the propellant and still start the engine. There must be direct contact.

Fig. 11



1. Bend and insert...

2. Tamp in wadding

The second point to remember is that the igniter must not "short" or touch itself. The one lead should follow one side of the nozzle; the other lead should follow the opposite side of the nozzle. If these leads cross and short circuit, the current cannot reach the part of the igniter which is against the propellant and the engine will not ignite.

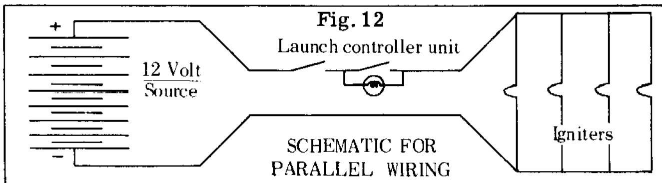
Finally, the wadding must be tamped in carefully and firmly. A small square (3/4" x 3/4") of flameproof wadding (Cat. #RP-1A) is rolled into a ball, dropped into the nozzle between the leads, and forced down further into the nozzle with a ball point pen or pencil point. When the wadding is installed correctly it is possible to pick up the engine by one igniter lead and shake lightly without the igniter coming loose.

It's best to test your igniter installation techniques by flying single engine rockets many times. When you know that you can install igniters and get successful single engine ignition every time, you're ready for a cluster.

CONNECTING THE IGNITERS

For positive ignition all igniters must be connected in parallel. There is a reason for this. If the igniters are connected in series, one igniter will burn through first and stop the flow of electricity to the others. When the igniters are connected in parallel the burn-through of one igniter lets more electricity flow to the others, making them heat faster. A series connection often results in the ignition of only one engine; a good parallel connection almost always results in the ignition of all engines.

Fig. 12



There are several good ways to connect the launcher leads to the igniter leads. In a parallel cluster the simplest method is to use two straight pieces of stiff wire (a straightened paper clip will do) for buss bars as shown. A pair of tweezers can be used to wrap the igniter leads around the wires--one lead from each engine to one wire, the other lead to the other wire. One micro-clip from the launcher is connected to each buss bar.

Fig. 13

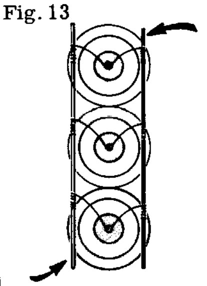


Fig. 14

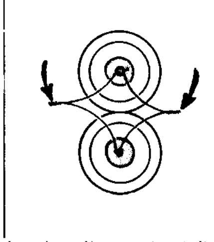
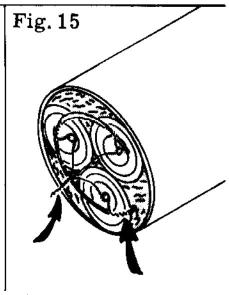


Fig. 15

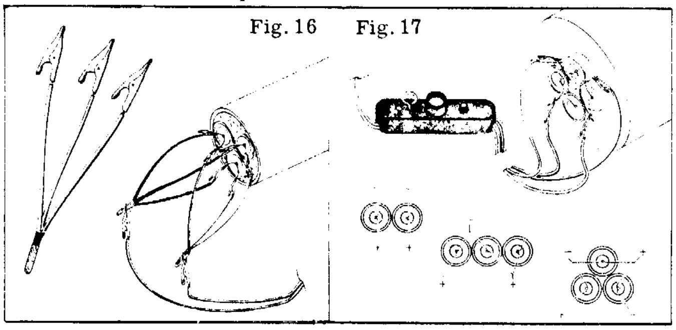


Connect launcher micro-clips at points indicated by arrows.

A combination of these two methods can be used for three engine circular clusters. First the engines are placed in the rocket so one igniter lead is toward the inside, the other toward the outside. The inner leads are twisted together. A wire loop (a large paper clip makes good raw material) is then formed and the outer igniter leads are twisted tightly around the wire of the loop. One micro-clip is attached to the twisted leads at the center, the other clip is attached to the loop.

When two engines mounted close together are used the best method is to simply connect the igniters to each other. If the engines are inserted in the rocket so the leads match as in fig. 14, the ends of the igniter leads can be twisted together quite easily. The launcher's micro-clips are then clipped onto the twisted leads for launching. When twisting or wrapping igniter leads, be careful not to pull the igniters out of the engines or away from the propellant.

Still another method is to use several clips on each launcher lead. The most common way of doing this is to make two "clip-whips" as shown in fig. 16. These clips attach to the igniters, one clip from one whip to one lead of an igniter, a clip from the other whip to the other lead of the igniter. With the clips in place, pieces of masking tape are applied at all points where there is a chance of the clips touching each other. The leads from the electrical launching system are then connected to the twisted ends of the whips.



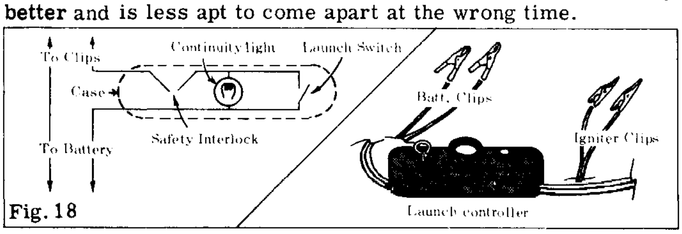
A variation of the clip whip system uses four micro-clips, permanently attached so two fork off from each launcher lead. The leads should be marked so the pairs of clips which are connected to the same lead can be easily identified. This system was developed for use with the four engine cluster in the Uprated Saturn I model, but also works well with two and three engine models. Fig. 17 illustrates a good four-clip electrical system along with several suggested connection methods.

Many other methods can be used to connect igniters on cluster models. The important points to remember are that the igniters must be in parallel, they should be connected as close in to the nozzle as practical and the micro-clips must have clean contact surfaces. Sand or file the jaws of the clips before each launching. After the rocket is on the pad and hooked up make a careful inspection to be sure there are no places where bare leads or micro-clips touch each other and create a short circuit.

THE POWER SYSTEM

Most rocketeers have access to a good, proven power supply for cluster launching--the battery in the family car. A car battery has more than enough power for igniting a reasonable number of engines and need not be removed from the car to be used. A fully charged six volt car battery which has clean terminals can be used to ignite up to 3 engines. However, a 12 volt car battery is far better, and will handle up to four engines easily.

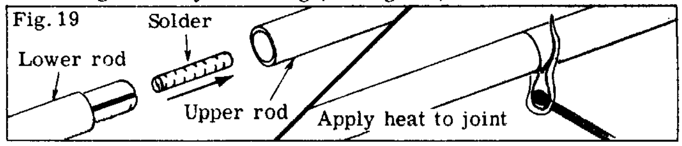
To connect the battery to the rocket and control the electrical current, a heavy duty launch system should be used. The Estes "Launch Control System" (Cat. No. 651-FS-5) or a similar unit is ideal. A suitable unit uses about 18 feet of #18 two conductor wire. Make all connections in the system carefully. If possible solder all permanent joints; a soldered joint conducts electricity better and is less apt to come apart at the wrong time.



The illustration shows a typical launcher circuit. If heavier wire (#16, for example) is used, the distance from battery to rocket may be increased. If the length of the wires is kept to a reasonable minimum, however, more current will reach the rocket, giving faster and more reliable ignition. Any system must be capable of delivering at least 5 amperes to each igniter. If the current is less than this the engines will not ignite at the same time; some may fail to ignite at all.

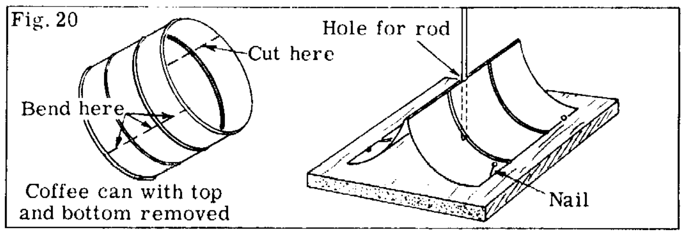
LAUNCHERS

In addition to a heavy duty power supply, a cluster rocket needs a heavy duty launcher. A unit such as the Tilt-A-Pad is designed to handle a cluster model of reasonable size. Even so, special care should be taken. First, the legs should be spread as wide as possible, locked tightly in position, and held down with rocks or bricks. A two-piece rod should be fitted tightly. If the joint between the rod sections is even slightly loose, it can be tightened by soldering (see fig. 19).



The launch rod for a cluster rocket should be at least 36" long. However, unless something is drastically wrong with the model, there is little reason to use a rod more than 54" long. Normally a 1/8" diameter rod is adequate. For extra large models it may be desirable to obtain a four to six foot long rod of either 3/16" or 1/4" diameter from a local hardware store or machine shop. (If a larger diameter rod is used, a special launch lug will be necessary. A large soda straw will work.)

When a launcher is designed especially for use with cluster rockets it should have an extra large blast deflector and a large, heavy base. A two foot square piece of 3/4" thick plywood makes a good base. The round (Cat. No. 651-BD-2) blast deflector works well with most rockets. A good deflector can also be made from a coffee can as shown.



USE A CHECKLIST

To avoid skipping a vital step when preparing a cluster model for flight it is often worthwhile to make up a countdown checklist for your rocket. The list below covers the general requirements of most cluster rockets. For rockets with special characteristics a more detailed checklist should be prepared.

☐ 18 Install enough loosely packed flameproof wadding to fill the body for a distance equal to at least twice its diameter. Pack the 'chutes, shroud lines and shock cord in over the wadding and slide the payload section into place.

☐ 17 Select engines of the correct size and pack flameproof wadding into them ahead of their ejection end caps.

☐ 16 Install igniters in the engines, making sure they touch the propellant grain and do not short circuit.

☐ 15 Insert the engines into the engine mounting tubes so the igniter leads are positioned correctly. Make sure the engines are held securely in place.

☐ 14 Connect the igniters together, to a loop, clip whips or buss bar as necessary to form a parallel connection.

☐ 13 Remove the safety key from the electrical system.

☐ 12 Place the rocket on the launcher. Support it off the blast deflector if necessary for access to the igniter wiring.

☐ 11 Clean the micro-clips with a file or sandpaper.

☐ 10 Connect the micro-clips to the igniters.

☐ 9 Double-check all connections to make sure the igniters are hooked-up in parallel and there are no short circuits.

☐ 8 Clear the launch area. Alert the recovery crew and trackers.

☐ 7 Check for low flying aircraft in the vicinity and for unauthorized persons in the recovery area.

☐ 6 Arm the launch panel and begin the final countdown.

☐ 5 ☐ 4 ☐ 3 ☐ 2 ☐ 1 LAUNCH!