BASIC SKYROCKET CONSTRUCTION

by M. F. Vander Horck

Rockets are among the oldest pyrotechnic devices known, probably antedating even the rudimentary firecracker. There is little doubt that the first rockets resulted from four successive discoveries:

1) that a mixture of saltpeter and charcoal when ignited would burn without access to atmospheric oxygen;

2) that this mixture would burn more fiercely when confined in a bamboo stalk or other container than in the open;

3) that the jet of flame and gases issuing from the container would be longer and more forceful if the opening were "choked" or restricted in size; and finally

4) that by ramming the mixture solidly in a tube, with the addition of a little sulfur, and <u>forming a hollow central cavity through most of the charge</u>, the impulse of the exhaust gases could be made to propel the case for some distance.

Of these discoveries, the first three might well have been stumbled upon accidentally, but the last must have required a definite effort of some early pyrotechnist's imagination. The principle involved is, that the more surface area of powder exposed to the first flame, the greater will be the initial thrust. A little calculation will show that a cavity about 1/3 the diameter of the charge and extending about 7 times its diameter into the powder (a typical figure) will increase this surface area by at least 7 times over that of an "end-burning" solid charge. This principle was described in John Bates' "The Mysteries of Nature and Art", second book, written in 1634 but was certainly discovered long before.

The applications which have been made of the rocket principle for missile propulsion, signalling and illuminating devices, jet-assisted-take-off for aircraft, life-saving line carriers for ship-to-shore and ship-to-ship use, high-altitude telemetry and sounding, weather modification (as in cloud-seeding to combat hailstorms) and even as boosters in connection with today's huge liquid-propellant space vehicles, are too well known to require elaboration. We are concerned in this article only with solid-propellant rockets and specifically with those used for pyrotechnic display, generally called skyrockets.

(It should be noted that this category does not include so-called amateur or model rocketry, from which it differs in several important respects. Amateur rocketry generally makes use of solid end-burning charges of comparatively slow-burning propellants such as a sulfur and zinc dust mixture, either poured into the casing in a molten state and allowed to solidify or moulded or machined to fit. The case itself may be of metal (never used in skyrockets) and reusable after recovery, and the exhaust nozzle must be carefully formed to take maximum advantage of the available thrust, which does not reach a peak until the rocket is well on its way. This nozzle is closed by a brittle plastic or metal disc incorporating an electrical ignitor, which ruptures when enough heat and pressure have built up to sustain burning. A skyrocket, on the other hand, develops maximum thrust within about the first second after ignition and thereafter travels mostly on momentum, with the remaining powder contributing mainly to the brilliant "tail", which is noticeably lacking in amateur rockets.)

Solid-propellant rockets of all types have the disadvantage that they are "one-shot" devices and can not be turned on and off at will like those with liquid propellants, but this lack is compensated for by the fact that they can be stored indefinitely, ready for instant use. Moreover, they bypass the failure-prone valves and other sophisticated mechanics that have plagued space technicians in the building of missiles and space vehicles. (In the unlikely event that the reader does not know it, rockets are even more efficient in the vacuum of outer space than at sea level, since they do not depend on the pressure exerted by the exhaust gases on the atmosphere nor on atmospheric oxygen for combustion.)

For the pyrotechnist, two big advantages of the rocket over the aerial shell are that it does not require a mortar for firing, only a suitable above-ground launcher, and that there is not the abrupt set-back or shock like that delivered by the lift charge below a shell. Again, there is a disadvantage, that of the falling case and stick which today precludes the firing of rockets in public exhibitions except over large clear areas or bodies of water. Where the latter conditions prevail, however, it should be remembered that the comparatively mild acceleration of a rocket permits the use of chlorate stars which would be too sensitive for the conventional aerial shell. (Note that the name "stickless rocket" is sometimes applied to comet shells which leave a brilliant trail as they ascend, but these require a mortar and lift-charge for firing.)

Skyrockets today come in many sizes. While Brock, in his "History of Fireworks", has mentioned eight-foot-long monsters with sticks of 20-foot length or so, the largest that are likely to be encountered, even in exhibition work, would not exceed about two feet in length or three inches in diameter. The great majority are under the "one-pound" maximum (8" long) and range from the very small "bottle rockets", so called because they are essentially nothing but open-ended $1\frac{1}{2}$" black powder firecrackers and can be launched from the neck of a pop-bottle, to those about six inches long, complete with a nose-cone filled with stars which bursts at the top of its trajectory. Some of the smaller rockets have no such "garniture" and are called "honorary" rockets, deriving their whole effect from the glowing tail and the "whoosh" as they go up. The propellant is always a mixture of saltpeter, charcoal and sulfur in varying proportions, with more charcoal used in the larger sizes as noted below. Usually, bigger grains of charcoal are included than actually neccessary for combustion, to enhance the effect of the glowing tail. Metallic inclusions like steel or iron filings, titanium, etc., can also be used to increase brilliance but should be kept to a minimum since they add to the weight of the rocket without contributing to thrust. (Iron or steel particles should of course be treated to prevent rusting by the saltpeter.)

For dimensional and construction details in this article, we have chosen a typical "one-pound" rocket, but note that the proportions given for length, diameter, etc. can be equally well applied to larger or smaller rockets. For example, the $\frac{1}{4}$" nozzle for a 3/4" bore can be reduced to 1/8" for a 3/8" bore, with other measurements reduced accordingly, as noted in the instructions for a "sub-ouncer" rocket described at the end of the article. The only proportion which varies from small to large rockets is that of the charcoal to the other ingredients.

ONE-POUND SKYROCKET AND RAMMING TOOLS

(shown slightly more than half actual size)

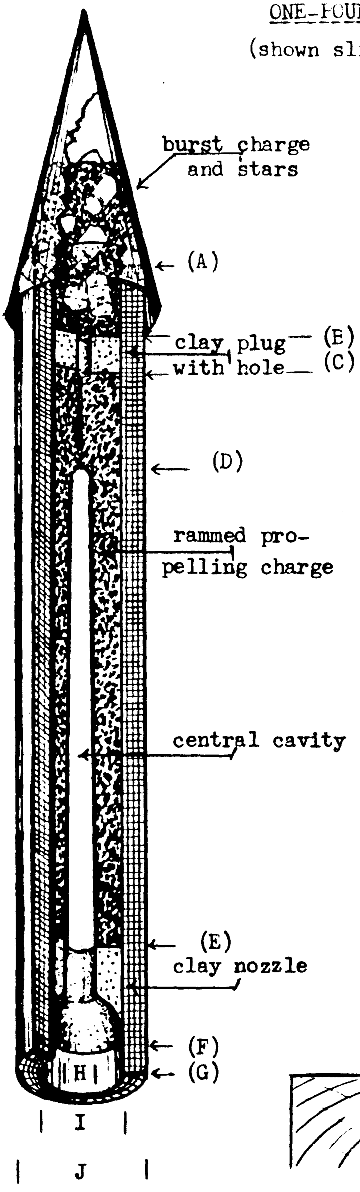

FIG. 1

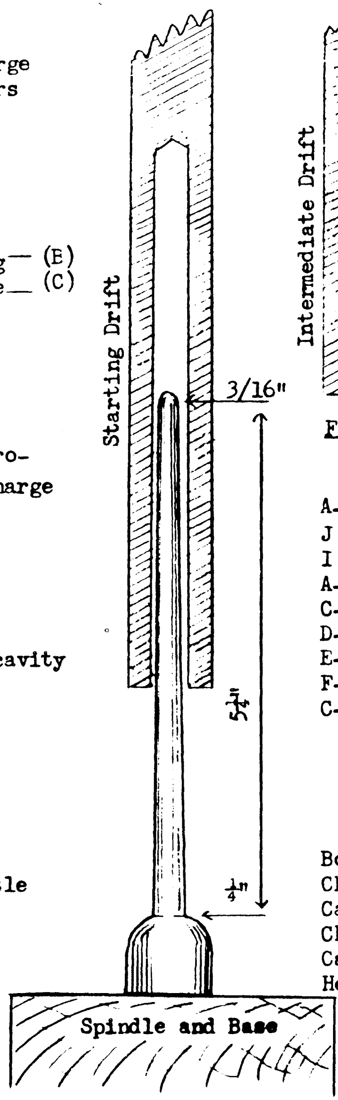

FIG. 2

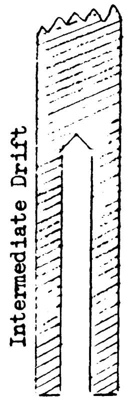

FIG. 3

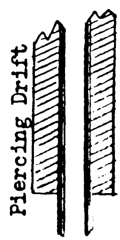

FIG. 4

DIMENSIONS:

A–G (case length) 8"
J (case O.D.) 1¼"
I (case I.D., bore) 3/4"
A–B 3/4"; B–C 5/16"
C–D (heading) 1"
D–E (core length) 5"
E–F (choke length) ½"
F–G 5/8"
C–E (total charge length) 5 3/4"

PROPORTIONS:
(approximate)

Bore - 1
Choke opening - 1/3
Case length — 11
Charge length — 8
Cavity length — 7
Heading length - 1

(Note that all proportions are in comparison with diameter of bore.)

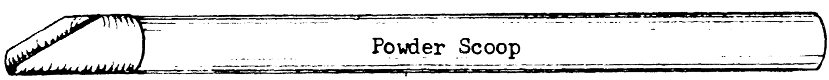

FIG. 5

TOOLS: Fig. 1 is a cutaway view of a typical "one-pound" skyrocket, with the hollow core left unshaded for clarity. As with certain other fireworks nomenclature, the term "one-pound" is deceptive, since it is derived from the weight of a lead ball of the same diameter as the outside of the casing; the rocket actually weighs less than a half-pound when completed. The casing is rolled around a 3/4" metal or wooden former, beginning with an 8" by 17" strip of hardware paper and finishing with an 8" by 20" piece of 120# chipboard inserted into the last turn of hardware paper, both pieces well pasted. When dried, this results in a very sturdy tube with a smooth bore. But case rolling is an art in itself, too elaborate to cover here and modern mass-production has made it almost unneccesary for the pyrotechnist to "roll his own" except as a pastime on rainy days!

The same does not apply to rocket loading tools, however, and the pyrotechnist with some machining ability and access to a lathe can profit by making his own tools. These are illustrated in figures 2 through 5. It is essential that the spindle and drifts be made from non-sparking materials such as brass or aluminum, since the greatest danger in ramming black powder is from accidentally striking a spark. In factory work, the spindle itself is often of steel or gunmetal for durability and long wear, but this demands that the drifts be made of non-ferrous materials. This writer prefers brass for both spindle and drifts, although aluminum is cheaper, easier to machine and quite satisfactory unless large-scale manufacture is planned. The spindle in particular should be highly polished to facilitate ease of removal after the charge is rammed.

The starting drift is the most difficult to make (Fig. 2) because the central hole which fits over the spindle is comparatively long and must be bored exactly parallel to the outside for its entire length. This fact almost demands the use of a lathe, or at the least a drill-press. The hole must be just large enough to fit over the spindle at the base (in our example, ¼"). We have shown only one intermediate drift, but two or more are generally used, with progressively shorter holes to match the rising charge of composition and fractionally smaller diameters to correspond with the taper of the spindle. These drifts can be made of hardwood dowel material if desired, of the same diameter as the former on which the case is rolled, but the top should be wound with wire or have a tight-fitting metal sleeve to prevent spreading and cracking from repeated mallet blows. If of larger diameter than the drift itself, such a sleeve will present a better surface for the mallet to strike and facilitate removal from the case. A finishing drift (not illustrated) with no central hole is used to ram the "heading" above the top of the spindle and the top clay plug, if the latter is to be solid. Some operators prefer to do this and afterward drill a small hole to communicate fire to the "pot" to ignite the burst charge. A quicker method is to use a "piercing drift" to ram the clay and form the hole in the same operation (Fig. 4). This can either have a projecting pin about 3/16" in diameter or a tube of thin brass or aluminum running through the drift as shown. We prefer the latter because it actually removes the clay and does not press it down into the powder, and it easy to clean out if it becomes plugged. Moreover, the operator can judge by examining the removed clay whether the hole extends just through the plug and into the composition (as it should) or is too short or long and adjust the length of the little tube accordingly. Starting with a tube press-fit into the drift and flush with the top, extending about 5/8" out the bottom, the operator can cut or file it to the correct length. Just a little black powder showing in the end of the tube after ramming the clay indicates that a hole of the right length has been made.

Fig. 5 shows a simple powder scoop that this author has found very convenient to introduce the composition into the casing with minimum spillage. It is made of a length of dowel about the same diameter as the bore or slightly smaller, with a piece of tubing fitting tightly on the end and shaped about as shown. By inserting it into the case and tapping it lightly, all the powder will fall into the tube.

A fairly heavy rawhide mallet is used to ram the composition, mainly because a solid metal hammer would soon deform the top of the drifts. (Note: a rubber mallet is completely unsatisfactory; it does not deliver enough impact to consolidate the clay or powder properly.) The spindle itself should of course be installed on a substantial base, such as a block of hardwood; this can be done by drilling and tapping the underside of the metal shoulder and running a 5/16" or 3/8" bolt up through the wooden base, after recessing the bottom to accept the head of the bolt.

The only other tool needed (optional) is a conical form around which to shape the paper nose. It should be tapered about as shown in Fig. 1. A disc of about 6" diameter is slit radially out from the center, wrapped around the former with the bottom edges even, and pasted where it overlaps.

CLAY: Either fireclay or what is known in the ceramic industry as "grog" or "grout" can be used (the former obtainable at brickyards and the latter at ceramic shops). This is used in its powdered form, which usually has enough residual moisture to compact firmly when rammed, though it feels dry to the touch. Its suitability can be tested by removing the case from the spindle after forming the choke and examining it. The rammed clay should be smooth and hard to the touch, though grooves can be scratched in the surface by a sharp instrument. If it has a tendency to crumble, it may be slightly dampened, preferably with oil. Water, especially in excess, may cause shrinkage as it evaporates.

PROPELLANT: For a one-pound rocket, Weingart has recommended a mixture of 16 parts saltpeter, 12 charcoal, and 3 sulfur (by weight), while Brock has specified 13, 7¼ and 2 respectively. It can be seen that the two writers differ mainly in the proportion of charcoal to be used, but that in both cases this is much larger than that of strong black powder (15, 3, 2). Lancaster, in the formula he has supplied for Ellern's "Military and Civilian Pyrotechnics", recommends proportions that work out to 15½, 8, 1½, which is pretty close to Brock's, no doubt indicating British preference, but he does not specify which caliber rocket this applies to.

Since every pyrotechnist seems to have his own pet formula, this writer might as well recommend his own too, which is 14 saltpeter, 8 charcoal and 2 sulfur, and refer the reader to Weingart's sage if simplistic advice: "If rockets burst before ascending add more coal; if they ascend too slowly add more saltpeter." In general, however, the larger the rocket, the more charcoal should be used, and for a spectacular tail, it should be about a half-and-half mixture of fine and coarse. For smaller than one-pound rockets, the saltpeter should be powdered; for larger ones, the granulated grade may be used.

RAMMING: The case is slipped over the shoulder of the spindle, where it should fit snugly, and a scoop of clay is dumped in and the starting drift pushed down over it and given eight to ten hard blows with the mallet to form the choke. The drift is then removed and a scoop of powder added, which is consolidated by replacing the drift and giving it about half-a-dozen somewhat lighter blows. However, do not be too gentle, as the proper performance of the rocket will depend on firm packing of the composition. This process is repeated till the case is full to about an inch from the top, changing to the shorter intermediate drift(s) at the proper time, and using the solid finishing drift for all powder above the spindle top. (Two marks on each drift to show its lower and upper limit are helpful; if the second drift is used too early, it may scratch or deform the spindle.)

Finally, another scoop of clay is put in and consolidated with either the finishing or piercing drift, as desired. As an added touch, the fire-hole can receive a daub of priming-paste to insure ignition of the burst-charge (black powder with 2% dextrin or starch and moistened with water).

FINISHING: The nose-cone is inverted and about half-filled with stars and a burst-charge of about FFFg or FFFFg grain or strong meal powder; adhesive is applied around the rim of the rocket, which is pressed down into the cone and again turned right-side-up to dry. Be sure the cone is properly aligned. (If fancy paper is to be wrapped around the case, it should be pasted on before attaching the cone, with about two inches extending beyond the choke end.) About six inches of black match or (preferably) 1/8" safety fuse is inserted into the nozzle, with a good four inches extending, and attached with another daub of priming paste, which should completely fill the hole in the choke. When this sets, the extending paper can be twisted around the fuse and tucked in. The stick is then smeared with glue on one side for about six inches and securely bound to the case with twisted wire about an inch-and-a-half from each end. A stick for this size rocket should be roughly ¼" thick and three feet long. Be sure it is parallel with the case before the glue dries.

COMMENTS: As stated, the foregoing description applies to a basic "one-pound" commercial skyrocket, made by hand. In practice, they are often, if not usually, made by the use of hydraulic gang-rammers, on the same machines used for roman candles. The writer has seen such a machine capable of ramming 144 cases at the same time, but the same steps described are followed for each operation, only with more than one casing. "Shifting boards" are used in place of powder scoops to dump exactly equal amounts of clay and composition into all tubes at once, and all rammers (drifts) go down to the same depth and at the same pressure, achieving great uniformity of compaction, which says something for mechanization in fireworks manufacture!

One writer has asked us why, if rocket casings are loaded with black powder, they don't explode like a firecracker. The answer is, that by virtue of being tightly packed, the powder burns only on its surface. To "explode", black powder must have a little "breathing space"; if about half the powder in a rocket were placed loosely in the casing, it would undoubtedly blow up, if the quality of the powder were good. When this happens, it is a sure sign that the ramming has not been done correctly, leaving air pockets within the charge or around it, or that the powder is too strong.

Another frequently-recurring question is, why doesn't the powder crumble and fall away from the sides of the case after it is removed from the spindle, if no binder is used? The simple fact is, that it doesn't if firmly compacted. There is enough adhesion between the particles so that the rammed charge remains solid, even under comparatively rough handling, as experience will demonstrate.

"SUB-OUNCER" ROCKETS: Newcomers to the pyrotechnic field may wish to learn first-hand the principles of rocket construction without investing in tools for the one-pound size or mixing large batches of powder. In the January 1967 issue of "PYRONEWS" (the second issue of the now defunct publication which preceded AMERICAN PYROTECHNIST), this editor presented an article on making three-inch rockets with very cheap tools and materials, based on suggestions by W.R. Withrow. Though these little rockets weigh only about a third of an ounce, they perform remarkably, reaching heights of 500 feet or so, and can even carry a few small stars.

The materials required are only a couple of feet of 3/8" dowel, a roll of 3" gummed paper tape, a nail about 1/8" in diameter and 2½" long, a piece of board for the base of the spindle and a suitable stick such as 1/8" dowel about two feet long. Construction of the spindle and drifts will be obvious from Fig. 6 below:

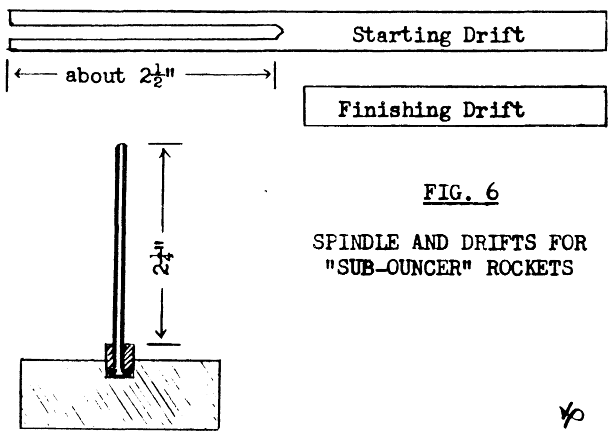

FIG. 6

SPINDLE AND DRIFTS FOR "SUB-OUNCER" ROCKETS

Cut off a ½" length of dowel and drill a hole lengthwise for a press-fit over the nail; then bore a 3/8" hole ¼" into the board to be used as a base, and, pushing the nail into the piece of dowel up to the head, glue the piece into the base as shown. File off the point of the nail into a rounded end and be sure the length of it is perfectly smooth. The two drifts are cut from the dowel to any convenient length that will extend above the 3" case when inserted, and a 1/8" hole bored in one of them as shown. This illustrates the fact that a rocket spindle need not neccesarily be tapered, and, if it is perfectly cylindrical, only one drift is needed until the charge reaches above the top of it. The main reason for the taper in larger spindles is to facilitate removal of the charged case after ramming.

The case is made from a 10" length of the 3" gummed tape rolled around another length of dowel. This is best done by first rolling up the entire length, keeping the ends even, then unrolling all but