ESTES EDUCATOR.com
launch learning fun

The Classic Collection

Model Rocketry: The Educational Space-Age Hobby

By Ann Grimm

EstesEducator.com

ESTES

educator@estesrockets.com

800.820.0202

Table of Contents

Dedication

To Vern and Gleda Estes who
made model rocketry both possible
and popular through their dedicated efforts.

Most of the technical reports and technical notes in this publication are reprinted as they first appeared. However, certain parts have been updated to present accurate current technical data.

These reports are published as a service to its customers by Estes Industries, Inc., Box 227, Penrose, Colorado.

One of the first principles any rocket designer must learn is that unless a rocket has a complex electro/mechanical guidance system, it will fly only if its center of gravity (also know as center of mass) is far enough ahead of the center of pressure to allow air currents to act against the rocket causing a stabilizing effect.

From your science class or other scientific studies you have probably learned that if a rotating force is applied to a free body in space it will cause it to rotate around its center of gravity. As an example of this, you could take a wooden dowel or uniform stick about two feet long and toss it into the air so that it will rotate end over end (see Fig. 1, example A). You will notice that regardless of how you throw the stick, vertically or horizontally, hard or easy, it will always rotate about its center. If a weight is attached to one end of the stick and it is again thrown into the air it will rotate about a new location (Fig. 1, example B). This time the point about which it rotates will be closer to the weighted end. If you take the weighted stick and balance it across a sharp edge you will find that the point at which it balances (its center of gravity) is the same point about which it rotated when tossed into the air (Fig. 1, example C).


Fig.1.
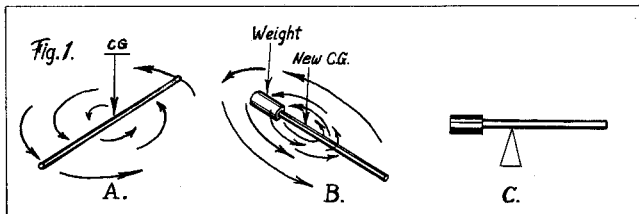
This simple explanation should aid you in understanding how a free body in space rotates around its center of gravity. A model rocket in flight is a free body in "space". If, for any reason, a force is applied to the flying rocket to cause it to rotate, it will always do so about its center of gravity.

Rotating forces applied to rockets in flight can result from lateral winds, air drag on nose cones, weights off-center, air drag on launch lugs, crooked fins, engine mounted off-center or at an angle, unbalanced drag on fins, unequal streamlining, etc. Obviously, some of these factors are going to be present in all rockets. Therefore, since rotating forces will be present, your rocket must be designed to overcome them. If your rocket is not so designed it will loop around and go "everywhere", but end up going nowhere. Nearly all model rockets are stabilized by air currents. By stabilized, we mean that all rotating forces are counteracted or overcome. This means that for each force trying to make the rocket rotate we must set up an equal and opposite force to counteract it.

How is this accomplished? Ask any rocket expert and he will simply say to design the rocket so the center of gravity is ahead of the center of pressure. From studying our first experiment it is easy to see how we could find the center of gravity by simply balancing the rocket on a knife edge as shown in example A of Fig. 3. But what and where is the center of pressure? The following experiment should aid you in understanding more about the center of pressure of a rocket.

Suppose we take the same 2 foot long piece of dowel used in our first experiment and place it on a low friction pivot as shown in example A of Fig. 2. (The low friction pivot consists of two needlepoints held rigidly in place on opposite sides of the object by a heavy wire or board framework. The needlepoints are placeed against the object just tightly enough to hold it, without interfering with

its rotating on the axis created between the two points). Suppose the dowel is held in a uniform air current (wind) of 10 to 15 miles per hour. If the pivot has been placed in the center of the dowel and if the dowel is uniform in size (area) the forces exerted by the air pressure will be equal on both sides of the pivot and the air current will produce no rotating effect. In this condition the center of gravity and the center of pressure will be at the same point.

Fig. 2
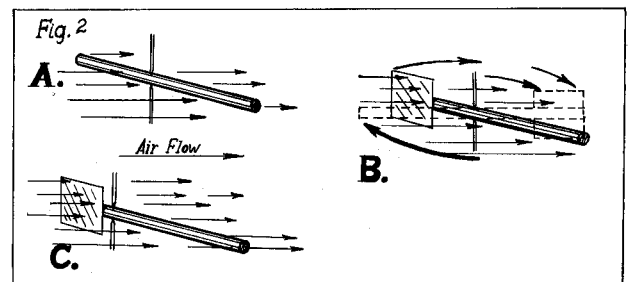
If a vane of 3" x 3" cardboard is glued to one end of the dowel and it is again put into the air stream with the pivot in the same position, the moving air current will exert the greatest force against the end of the dowel which has the vane attached to it as in example B of Fig. 2. This will cause the dowel to rotate until the end away from the vane points into the wind. If we now move the pivot closer to the vane end of the dowel we will be able to locate a point along the dowel where equal air pressure will be applied to both ends. The air current will no longer cause any part of the dowel to point into the wind. This point is called the lateral center of pressure. Remember, forces applied to the surface directly by air currents and the larger the surface, the greater the forces will be.

The ideal way to find the lateral center of pressure of a model rocket is to suspend the rocket between pivots as was done with the 2 foot dowel in Fig. 2, then hold the rocket in a uniform lateral air current. This can be accomplished to some degree of accuracy by holding the suspended rocket in a breeze of 10 to 15 m.p.h. The same affect can be accomplished very accurately by the use of a low velocity wind tunnel. However, since most model rocket builders and designers do not have wind tunnels and low friction pivots as described above, other methods must be provided for determining the center of pressure.

Keep in mind the fact that the air pressure applied to a surface is proportional to the area of the surface. It then becomes possible to approximate the rotating effect of the action of the air pressure by making a uniform area cutout of your rocket and locating the balancing point of this cutout. To make this cutout, simply lay your rocket over a piece of cardboard and mark around the edges. Next, cut around the lines and balance the cutout on a knife-edge as shown in example B of Fig. 3.
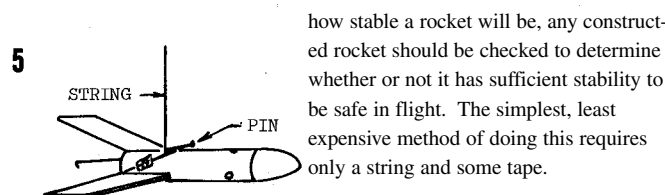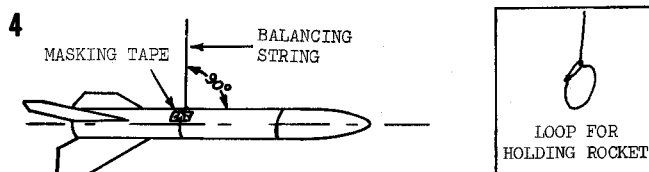

Fig. 3
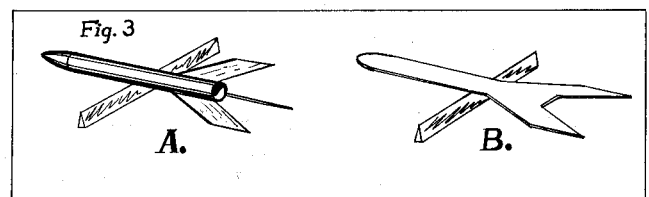
This method will determine the <u>lateral</u> center of pressure (the center of pressure with the air currents hitting the rocket broadside). If the rocket is designed so the lateral center of pressure is 1/2 the body diameter (1/2 caliber) <u>behind</u> the center of gravity it will have ample stability under all reasonable conditions. If, however, the rocket's fins are very crooked, set at opposing angles, or if the rocket uses a disc or cone for stabilizing, the lateral center of pressure should be set at least one diameter behind the center of gravity.

In flight, of course, the rocket will not be traveling sidewards, but with its nose pointed into the wind. With the model's nose pointed into wind, the location of the effective center of pressure will be affected by the shape of the fins, the thickness of the fins, the shape of the nose cone, location of the launching lug, etc. With most designs this shift is to the rear, adding to the stability of the rocket.
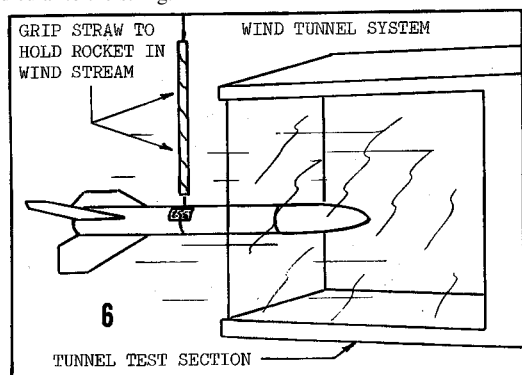
Suppose a model rocket starts to rotate in flight. It will rotate around its center of gravity. When it turns the air rushing past it will then hit the rocket at an angle. If the center of pressure is <u>behind</u> the center of gravity on the model, the air pressure will exert the greatest force against the fins. This will counteract the rotating forces and the model will continue to fly straight. If, on the other hand, the center of pressure is <u>ahead</u> of the center of gravity the air currents will exert a greater force against the nose end of the rocket. This will cause it to rotate even farther, and once it has begun rotating it will go head over heels in the air.

It is easy to see from this why it is best to build the rocket with its fins as far as possible to the rear. The farther behind the center of gravity the center of pressure is placed, the stronger and more precise will be the restoring forces on the model, and it will fly straighter with less wobbling and power-robbing side-to-side motion. Under no circumstances should fins be placed forward of the center of gravity on a model, as they will add to its unstability tendencies rather than help stabilize it.

When building high performance, lightweight rockets, quite often a more precise method of determining the stability margin of the rocket is desired. While the experienced rocketeer will develop an ability to tell by looking approximately

Apply a small piece of tape to hold the string in place. If the rockets center of gravity (balance point) falls in the fin area, it may be balanced by hooking the string diagonally around the fins and body tube as shown in Fig. 5. A common straight pin may be necessary at the forward edge of one of the fins to hold the string in place. This string mounting system provides a very effective low friction pivot about which the rocket can rotate freely.

For the first system, slide a soda straw along the string to a position just above the rocket. Then suspend the rocket in a low velocity air stream (wind tunnel or gentle breeze) with the nose of the rocket pointing into the wind. Then turn the rocket approximately 10" out of the wind to see if it recovers. If so, the rocket is stable enough for flight.

The second method involves swinging the suspended rocket overhead in a circular path around the individual, as shown in Fig. 7. If the rocket is stable, it will point forward into the wind created by its own motion. If the center of pressure is extremely close to the center of gravity, the rocket will not point itself into the wind unless it is pointing directly forward at the time the circular motion is started. This is accomplished by holding the rocket in one hand, with the arm extended, and then pivoting the entire body as the rocket is started in the circular path. Sometimes several attempts are required in order to achieve a perfect start. If it is necessary to hold the rocket to start it, additional checks should be made to determine if the rocket is flight-worthy.

Small wind gusts or engine misalignment can cause a rocket that checks out stable when started by hand as described above to be unstable in flight. To be sure that the rocket's stability is sufficient to overcome these problems, the rocket is swung overhead in a state of slight imbalance. Experiments indicate that a single engined rocket will have adequate stability for a safe flight if it remains stable when the above test is made with the rocket rebalanced so the nose drops <u>below</u> the tail with the rocket body at an angle of 10 degrees from the horizontal (see Fig. 8). With cluster powered rockets a greater degree of stability is needed since the engines are mounted off center. The cluster-powered rocket should be stable when imbalanced to hang at 15 degrees from the horizontal. Heavier rockets which accelerate at a lower rate require a similar margin of stability.

4 MASKING TAPE — BALANCING STRING

LOOP FOR HOLDING ROCKET

5 STRING — PIN

how stable a rocket will be, any constructed rocket should be checked to determine whether or not it has sufficient stability to be safe in flight. The simplest, least expensive method of doing this requires only a string and some tape.

7

8 MARK CHART IN 5° INCREMENTS

The rocket to be tested (with an engine in flight position: the center of gravity is always determined with an engine in place) is suspended from a string as illustrated in Fig. 4. The string is attached around the rocket body using a loop as shown. Slide the loop to the proper position so the rocket is balanced, hanging perpendicular to the string.
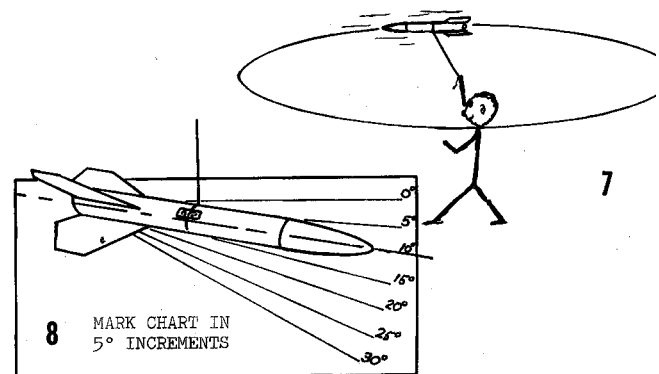
GRIP STRAW TO HOLD ROCKET IN WIND STREAM   WIND TUNNEL SYSTEM

6

TUNNEL TEST SECTION

Caution should be exercised when swinging rockets overhead to avoid collision with objects or persons nearby. Velocities in excess of 100 miles per hour are possible. This is sufficient to cause injury.

Suppose you construct a rocket and find that it will not be stable. **Do not try to fly it.** Corrections must be made. Tests have been made where the stability of the rocket was in question. If it was completely unstable it would loop around and around in the air, seldom reaching over 30 feet in height and never reaching a velocity in excess of 20 or 30 miles per hour. However, occasionally one of these rockets would make a couple of loops, suddenly become stable due to the lessening of the fuel load, and make a bee line straight into the ground. Had anyone been standing in the wrong place a serious injury could have resulted.

If a rocket does not show the degree of stability required for safety it can be easily altered to conform either by moving the center of gravity forward or by moving the center of pressure rearward. To move the center of gravity forward, a heavier nose cone is used or a weight is added to the nose of the rocket. To move the center of pressure rearward, the fins may be made larger or moved farther back on the body tube. With many designs, a greater stability is obtained by constructing the rocket so that a large portion of the fins project beyond the rear of the rocket body.

ESTES

Multi-staging is one of the most prominent characteristics of modern rocketry. The technique is used with solid propellant rockets and liquid propellant rockets, in rockets less than a foot tall and in rockets which tower to over one hundred feet. Multi-stage rockets are used to send up payloads from ants to humans to 500 feet, into orbit, and on to other planets.

The performance necessary for high orbits, moon shots and interplanetary probes is provided by multi-stage rockets. The principle advantage of multi-staging is the elimination of unnecessary weight in the later portions of the rocket's flight. For example, compare two rockets weighing 1500 pounds at takeoff, one a single stage missile and the other a two-stage rocket. The single stage rocket holds 1000 pounds of fuel inside a 500 pound body while the two stage rocket consists of two 250 pound bodies, each carrying 500 pounds of fuel. When half the fuel in the single stage rocket is used there is still another 1000 pounds for the remaining half of the fuel to carry. On the other hand, when half the total fuel load of the two stage rocket is used, the stages separate leaving 250 pounds of dead weight behind with only 750 pounds for the remaining half of the fuel to move. This weight saving is even greater at burnout when the single stage rocket weighs 500 pounds and the multi-stage rocket only 250.

The principles of model rocketry and professional rocketry are identical although the model rocketeer uses somewhat different operating methods than the professional. The young rocketeer who masters the principles of multi-staging is gaining knowledge which he will find useful in his future career.

IGNITION

The lower or first stage of a multi-stage rocket is always ignited by standard electrical means. For further details, refer to the instruction sheet which is included with all rocket engines. The second stage ignition is accomplished automatically upon burnout of the first stage. As you will notice in figure 1A, the first state engine has no delay or ejection charge. This is to assure instant ignition of the following stage upon burnout.

In figure 1B the propellant has been partially burned leaving a relatively large combustion chamber. As the propellant continues to burn, the remaining wall of propellant becomes thinner and thinner until it is too thin to withstand the high pressure inside the combustion chamber. At this point the remaining propellant wall ruptures, allowing the high pressure inside the combustion chamber to exhaust forward toward the nozzle of the next stage, carrying hot gases and small pieces of burning propellant into the nozzle of the second stage engine. This action is illustrated in figure 1C.

For this system to work, the rocket must be designed and built to make the best use of the operation of the engines. If the upper stage engine is simply placed ahead of the booster engine so that the two can separate easily, ignition reliability may fall as low as 40 percent, depending on the type of booster used. This unreliability in ignition is the result of several causes. First, when the forward propellant wall of the booster burns through,

Fig. 1A

Solid Propellant

Fig. 1B

Ceramic Nozzle

Fig. 1C

Cellophane Tape
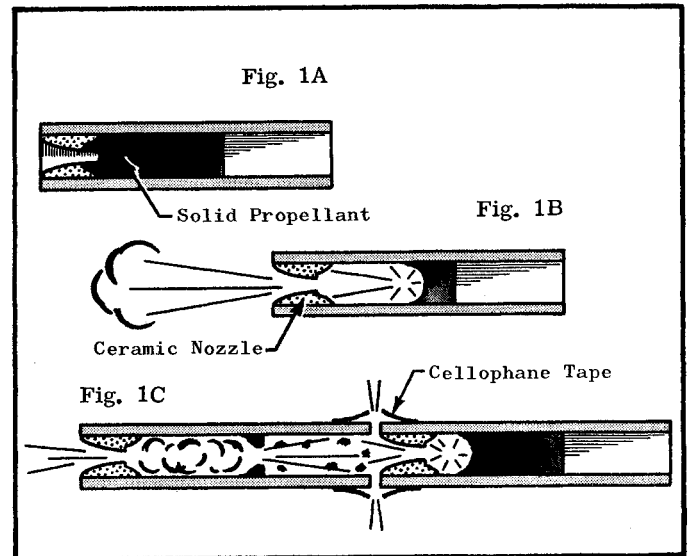
high pressure is built up in the area between engines. This pressure will force the stages apart. Second, the nozzle of the upper stage engine is quite small making a difficult target for the hot gases and burning particles. Also, the nozzle of the upper stage will cool gases slightly as they enter it.

These problems in multi-stage ignition led to an extensive research program at Estes Industries. Revisions in engine design, gimmicks such as pressure relief vents, etc., were tried, but none proved satisfactory. What was needed was a method of controlling stage separation so that the hot ignition gases would have a proper chance to act on the upper stage engine before the upper and lower stages parted company,

After data on several hundred-test firings had been collected, the problem was reanalyzed to find the factors which contributed most to reliability. There were two: An extremely tight joint between stages and a coupling which forced the two stages to move apart in a completely straight line.

The simplest, most reliable method of joining stages tightly was immediately considered - tape. By wrapping one layer of cellophane tape around the joint between engines and then recessing this joint 1/2" rearward in the booster body tube, as in Fig. 2, reliability suddenly jumped to almost 100%. Thus it was discovered that the coupling system played the most important part in multi-stage ignition reliability.

Fig. 2

Cellophane Tape
$\frac{1}{2}$"
UPPER STAGE
BOOSTER
Engine joint
Body tube joint
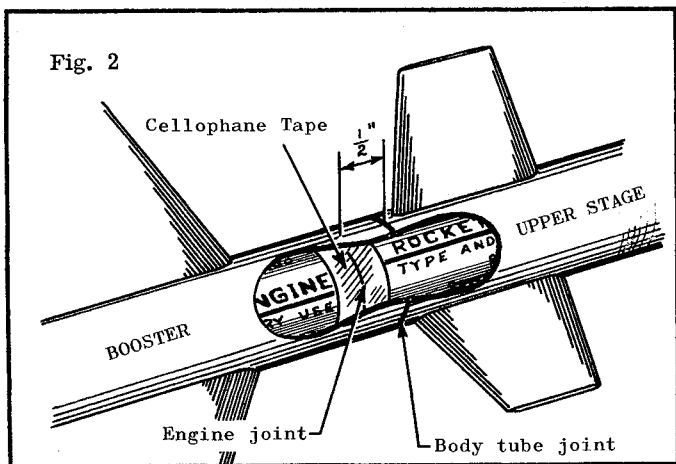
STAGE COUPLING

We have already seen that the stage coupling must be tight and must allow the stages to move apart only in a straight line directl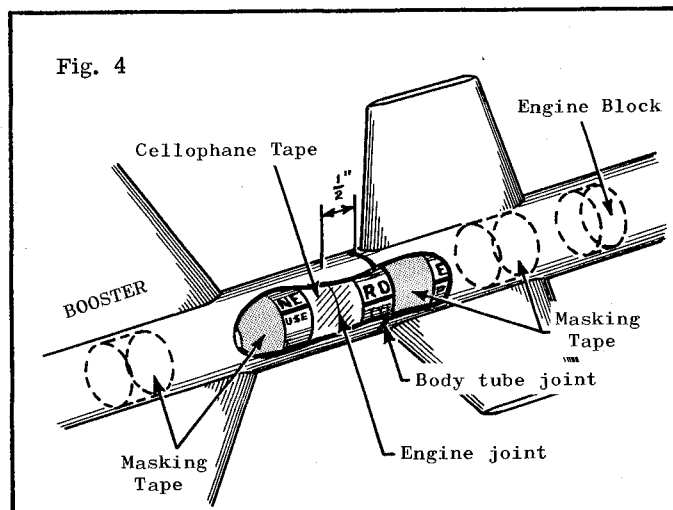y away from each other. This is to gain control over stage separation, preventing premature separation and incomplete separation. To understand just how tight this joint must be, wrap a single layer of 1/2" wide cellophane tape <u>tightly</u> around the joint between two engines as in Fig. 3A. Then, grasping each engine firmly as in Fig. 3B, pull them apart. If you repeat this a few times you will develop a "feel" for stage coupling which will prove very valuable when you build and fly multi-stage rockets.

Fig. 3A
Cellophane Tape
Engine joint

PULL APART IN
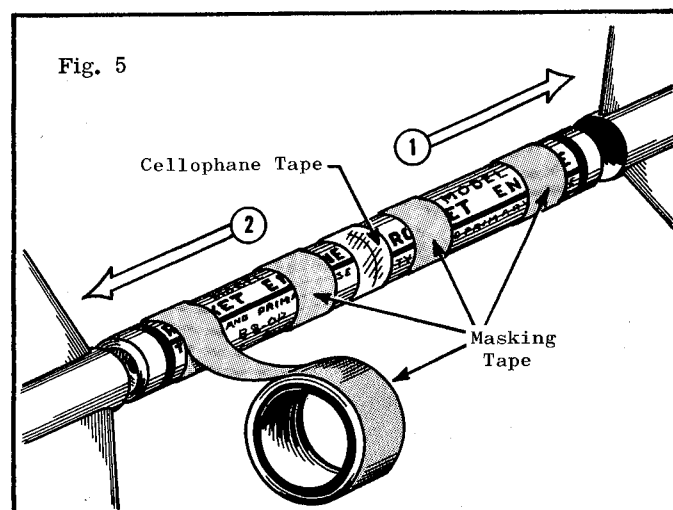STRAIGHT LINE
MOTION

Fig. 3B
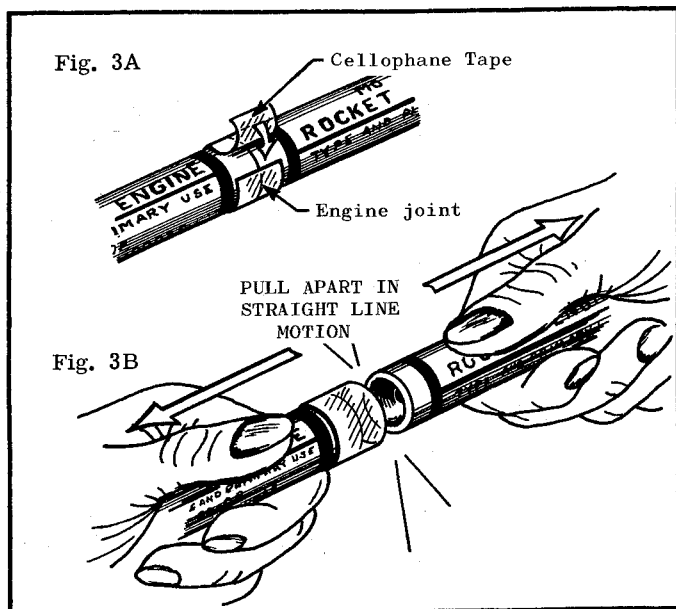
The proper coupling system to use in a rocket will depend on the size of the body tube. The coupling system for rockets using tubes of approximately 3/4" diameter (BT-20) is shown in Fig. 4. With this system the upper stage engine must project at least 1/2" rearward into the booster body tube to provide straight-line separation. The engines are taped together before being inserted into the rocket. Check carefully before and after taping to be sure the engines are in their proper positions (nozzle of upper stage engine against top end of booster engine). Failure to check carefully can be highly embarrassing as well as damaging to the rocket.

When the engines are taped together they can be inserted into the rocket. Wrap masking tape around the upper stage engine at the front and near the rear as in Fig. 5 to give it a <u>tight</u> fit in the body and push it into place. Then wrap the booster engine and push the booster into position. Failure to get the upper stage engine in place tightly enough will result in the recovery system malfunctioning, while failure to get the booster on tightly enough can result in its dropping off under acceleration, leaving the entire engine unit dangling from the upper stage while the rocket loops around in the air.

Fig. 4

Cellophane Tape
$\frac{1}{2}$"
Engine Block
BOOSTER
Masking Tape
Body tube joint
Engine joint
Masking Tape

The procedures used for two stage rockets should also be used on rockets with more stages. It is important, however, to get considerable experience with

Fig. 5

Cellophane Tape
Masking Tape

two stage rockets before attempting to design a 3 or 4 stage model.

Rockets using large diameter tubes (BT-50 and BT-60) require somewhat different methods, but the same principles of tight coupling and straight-line separation must be followed. The recommended coupling method for larger diameter tubes is illustrated in Fig. 6. The stage coupler is glued to the booster body tube, with the adapter for the upper stage engine mounting positioned forward to allow the stage coupler to fit into the upper stage, while the tube adapter in the booster is positioned to the rear.

Fig. 6
Engine Block
Adapter is forward in body tube
Stage Coupler
(glued to booster tube)
$\frac{1}{4}$"
Note : no engine block in booster adapter

4
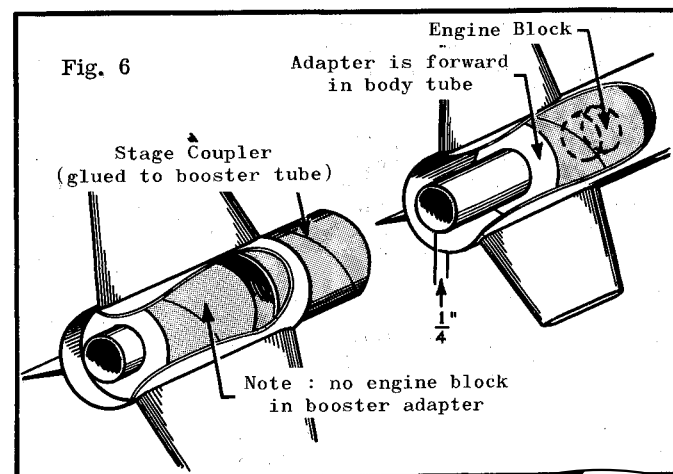
The most satisfactory method of mounting engines in rockets with large diameter tubes involves positioning the upper stage engine holder tube to project 1/4" rearward from the end of the main body and positioning the engine block so the engine projects 1/4" rearward from the end of the engine holder tube (see Fig 7). This allows the engine to be held in place in its mounting by wrapping a layer of masking tape <u>tightly</u> around the end of the tube and the engine as in Fig. 7B. The engine mounting in the booster must be built to leave space for this engine mounting (see Fig. 7C).


Fig. 7A

Fig. 7B

Fig. 7C

Fig. 8
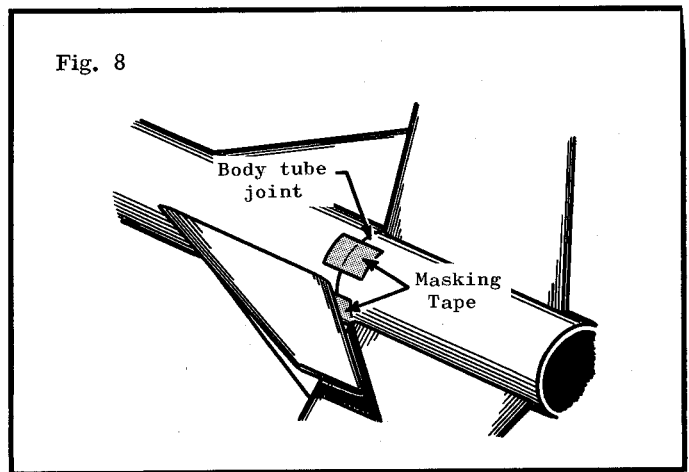
With any coupling system, certain rules must be carefully followed. Engines must be held in their respective stages securely. Engine blocks must be strongly glued. Engines may be secured in their body tubes by (1) wrapping tape around the middle of the engine until it makes a very tight friction fit in the body as in Fig. 9A, (2) taping the end of the engine to the engine holder tube as in Fig. 9B, or (3) by a combination of wrapping the engine with tape and properly positioning engine blocks as in Fig. 9C.

Fig. 9A

Fig. 9B

Fig. 9C
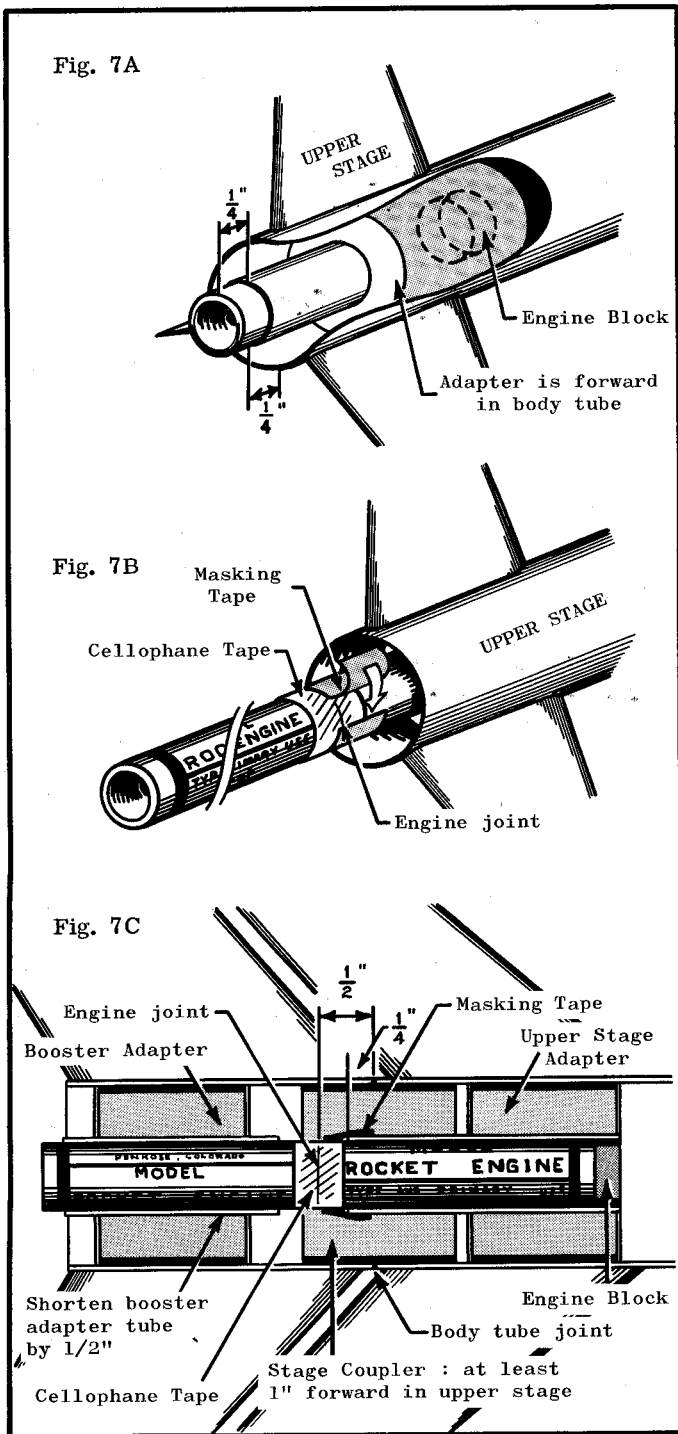
Normal procedures call for taping the engines together with cellophane tape before mounting in the rocket. By doing this a better coupling is achieved. Figure 8 illustrates a slightly different method, recommended for use with Series I and Series III boosters only. Applying tape to the outside of the rocket is easier than taping the engines, but is also poor aerodynamic practice.
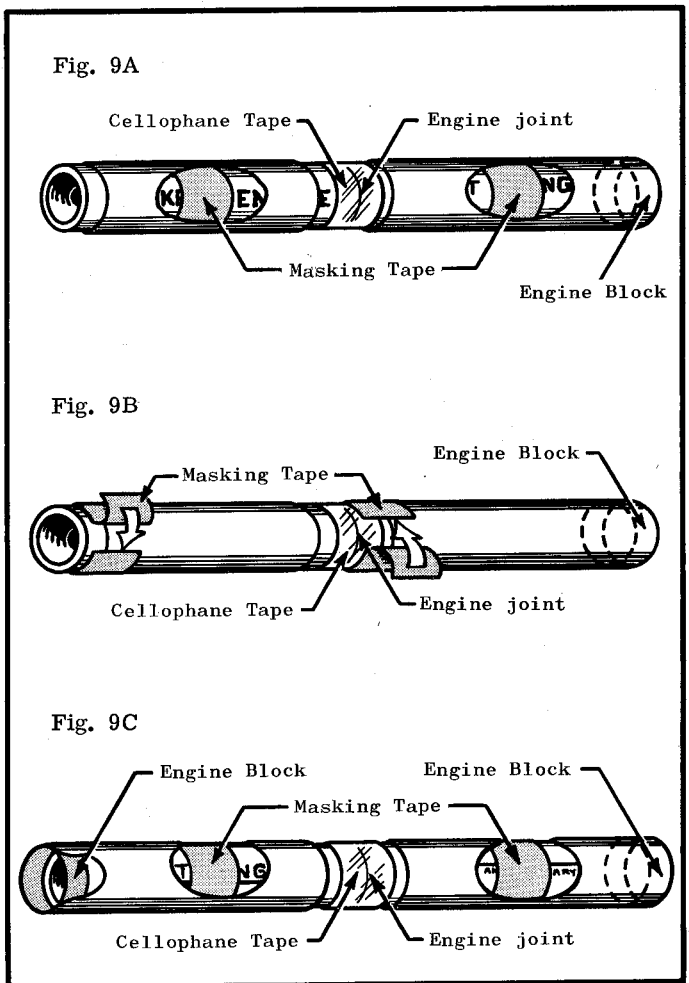
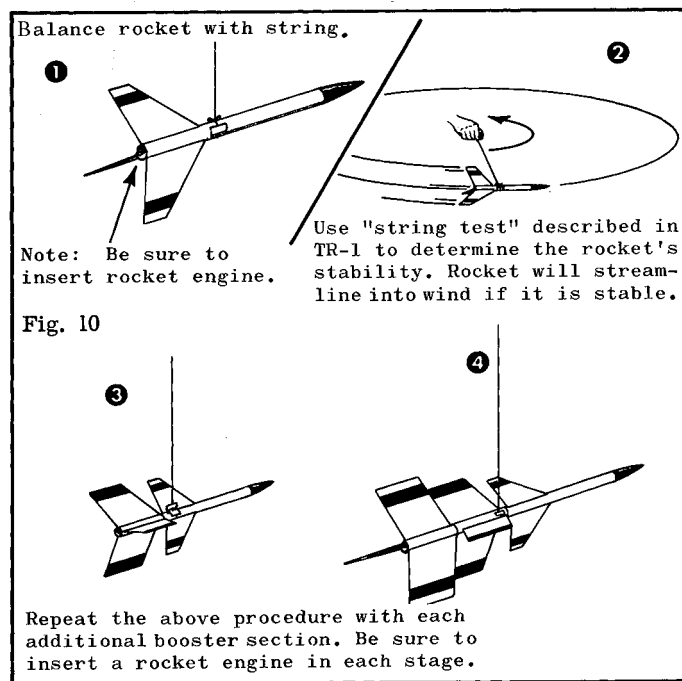When the forward wall of propellant in the booster ruptures and hot gases blow forward, the joint between the engines is pressurized. If the rocket has been constructed with proper care and the engines mounted carefully, the tape that holds the stages together will break, allowing the stages to separate, but not until the upper stage has ignited. If proper care is not exercised, almost anything can happen.

STABILITY

Multi-stage rockets, like single stage rockets, are stabilized by air currents acting against the fins (see technical report TR-1). Since two or more engines are mounted near the rear of the rocket, it has a tendency to become tail-heavy. To compensate for this rearward movement of the center of gravity, extra large fins must be used on the booster or lower stages. As a general rule, the lower set of fins on a two-stage rocket should have two to three times the area of the upper set. Each additional stage then requires even greater fin area.
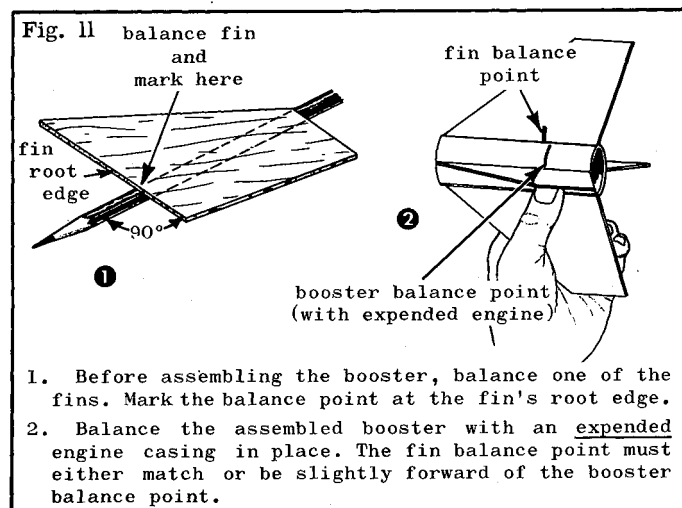
When checking a multi-stage design for stability, test first the upper stage alone, then add the next lower stage and test, and so on. In this manner the builder can be sure that his rocket will be stable in each step of its flight, and he will also be able to locate any stage which does not have sufficient fin area. Always check for stability with engine in place.

Balance rocket with string.

❶

❷

Note: Be sure to insert rocket engine.

Use "string test" described in TR-1 to determine the rocket's stability. Rocket will streamline into wind if it is stable.

Fig. 10

❸

❹

Repeat the above procedure with each additional booster section. Be sure to insert a rocket engine in each stage.

To obtain the maximum stability from the fin area, care should be taken in construction to create an aerodynamically "clean" shape. The transitions between stages should be as smooth as possible to prevent interrupting the airflow and causing turbulence.

BOOSTER RECOVERY

Most lower stages are designed so that they are unstable after separation.

Fig. 11

balance fin and mark here

fin balance point

fin root edge

90°

❶

❷

booster balance point (with expended engine)

1. Before assembling the booster, balance one of the fins. Mark the balance point at the fin's root edge.
2. Balance the assembled booster with an _expended_ engine casing in place. The fin balance point must either match or be slightly forward of the booster balance point.

This is because the booster alone is "nose-light", since its center of gravity is fairly close to the stage's rear. The booster should be built so that the center of the area of the fin (its balance point) matches or is up to 1/4" ahead of the booster's balance point with an expended engine casing in place. Thus boosters will require no parachute or streamer, but will normally tumble, flutter or glide back to the ground. If the booster is to be used again, it should be painted an especially bright color, as it does not have a parachute or streamer to aid in spotting it once it is on the ground.

TYPES OF ENGINES

Lower and intermediate stages always use engines that have no delay and tracking charge and no parachute ejection charge. There is no delay so that the next stage will receive the maximum velocity from its booster. The engines which are suitable are those which have designations ending in zero, such as the C6-0 and D12-0.

The selection of booster engines will depend on several factors, including the rocket's stability and weight, launch rod length, and weather conditions. Generally heavy rockets and rockets with large fin area should use B6-0 or C6-0 booster engines unless there is no wind blowing. Experience has shown that even a gentle breeze is enough to make these models weathercock severely, resulting in a loss of altitude and a long chase after the rocket. This is especially so when engines other than those mentioned are used.

In the upper stage an engine with a delay and tracking charge and parachute ejection charge is used. As a general rule the longest possible delay should be used as multi-staging imparts considerably more velocity to the final stage, and the rocket must have an opportunity to lose this velocity before the parachute is ejected. Greater altitude will be obtained and damage to the recovery system avoided in this manner. Engines suitable for upper stage use are those with long delays such as the B6-6 or C6-7.

MULTI-STAGE - BUILDING AND FLYING

Before attempting to build a multi-stage rocket, the rocketeer should build and fly several single stage rockets to familiarize himself with the principles involved. The reliability of a two stage rocket is always less than a single stage rocket, and as more stages are added the reliability drops even farther. Hence, more building and flying skill is required as the rockets become more complex.

Fins must be securely glued on multi-stage models and especially on booster stages since considerable pressure is applied to the fins at stage separation. It is usually a good idea to put launch lugs on both the upper and lower stages of a multi-stage vehicle. Special attention to other details of rocket construction, including attachment of shock cords, nose cone fit, and alignment of fins is also quite important.

When flying multi-stage rockets, extra caution should be taken to select a field that is free of dried weeds, grass, or other highly combustible materials. The field should be at least as wide and as long as the maximum altitude the rocket is expected to reach. There should be no persons in the area who are not observing the rocket flight.

Multi-stage rockets should be flown only in reasonably calm weather, as they have an extreme tendency to weathercock. When the rocket is placed on the launcher, care should be taken to assure that the alignment of the stages is not disturbed. Observers should be assigned to follow each individual stage to prevent the loss of part of the rocket.

General safety precautions such as adequate recovery systems, not launching when planes are overhead, and others which are normally taken with single stage rockets should also be taken with multi-stage rockets. Attention to safety rules makes rocketry activities considerably more enjoyable and educational.

ESTES

These reports are published as a service to its customers by Estes Industries, Inc., Box 227, Penrose, Colorado 81240

Single Station Tracking

Every rocketeer asks the question: "How high did it go?" However, previously, few model rocketeers had the facilities to determine altitudes with any reasonable degree of accuracy. Some have attempted to find the altitude achieved by their rockets by the use of a stop watch, but this method is so highly inaccurate that the computed altitude may fall anywhere within 200% of the actual altitude. Several years of experience among model rocketeers have proven that optical systems are the only practical means for finding altitudes with any reasonable degree of accuracy.

The use of an optical tracking system requires the use of mathematics. The particular field of mathematics which is used the most in altitude computation is trigonometry. While this field is normally considered an advanced high school subject, any rocketeer can master its basics and apply them to his rocketry activities. If the rocketeer masters a few simple processes, he is ready to solve almost any problem in altitude computation.

One of the first principles of trigonometry is that all of the angles and sides of any triangle can be found if any three of its parts, including one side are known. Every triangle has six parts: Three angles and three sides. If we know two angles and one side, we can find the other angle and the other two sides.

In determining the height of a rocket we collect two types of data: distances and angles. This data is used to create a triangle which is a model of the lines which would join the tracker and the rocket, the rocket and a point directly below it on the ground, and the point on the ground and the tracker.


Fig. 1
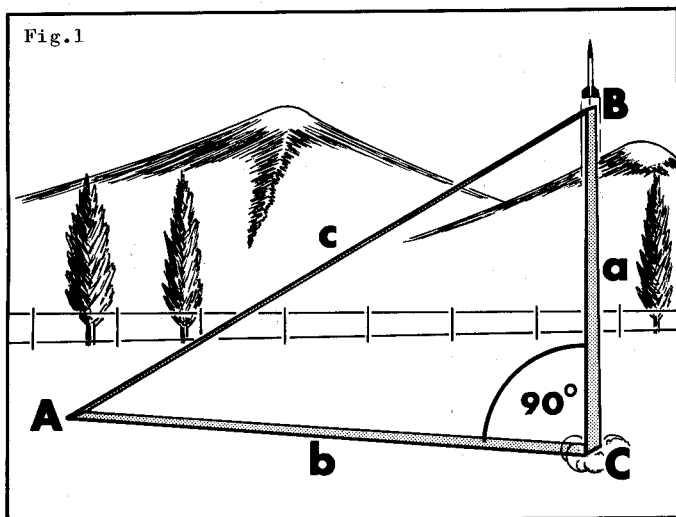
In the diagram above, point A represents the tracking station, B the rocket at its maximum altitude, and C a point on the ground directly below the rocket. The angle formed by the lines at C is then a right angle or 90 degrees. Since there are 180 degrees in the angles of a triangle, if we know angle A, we can find angle B, since B = 180 degrees - (A+C), or B = 90 degrees - A. (In trigonometry, a capital letter represents an angle, a small letter represents a side. The small letter "a" will always be used to represent the side opposite angle A, "b" the side opposite B, etc. Two capital letters together represent a distance. Thus BC represents the distance from angle B to angle C, or side "a".

At the firing range, A is found by the tracker when he locks his scope at the rocket's peak altitude. If we know the distance from A to C, or side b of the triangle, we can find side c and side a. Side a is the one in which we are interested. It is the height of the rocket. This of course assumes that angle C is a right angle.

If we only use one tracker, we have the problem of knowing only one angle and one side. This is not enough information to solve the other sides of the triangle. However, we can guess at one of the unknown angles, and obtain a good approximation of the height achieved by the rocket.

If only one elevation tracker is used, it is a good idea to station it at a right angle to the wind flow. For example, if the wind is blowing to the west, the tracker should be either north or south of the launcher. In this way we will keep the angle at C as close to a right angle as possible. By experimenting with a protractor and a straight edge, the rocketeer can demonstrate why the error would be less if the tracker is on a line at a right angle to the flow of the wind.


Fig. 2
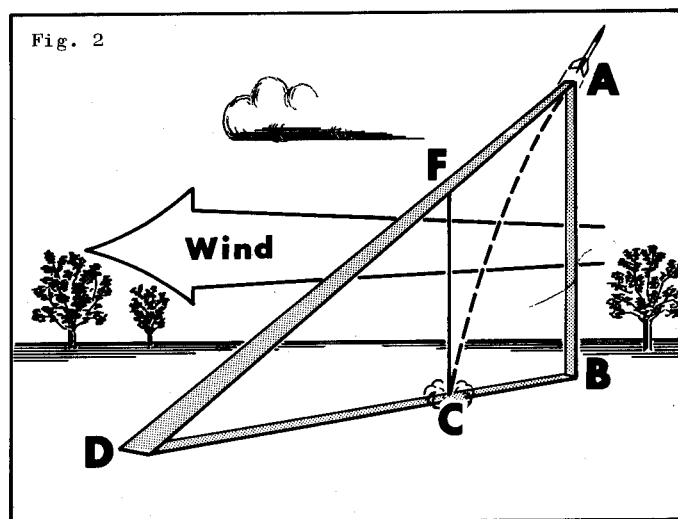
In the diagram above, the wind is blowing from B to D. The rocket is launched at point C, weathercocks into the wind, follows approximately line CA, and at its maximum altitude is at point A. If the tracker is downwind from the launcher, he will see the rocket at point F and compute the altitude as the distance from C to F. His computed altitudes will be considerably lower than the true altitudes. On the other hand, if the rocket drifts toward him, his computed altitude will be considerably higher than the true altitude.

However, if the tracker is at point X in figure 3 and the launcher at Y, then the rocket will appear to be at point A as in figure 1, although the distance from the tracker to point A will be slightly greater than the baseline used in computing the altitude, the error will not be nearly as great. Also, the small additional distance will serve to make altitude readings more conservative, as the baseline will be increased.

Fig. 3
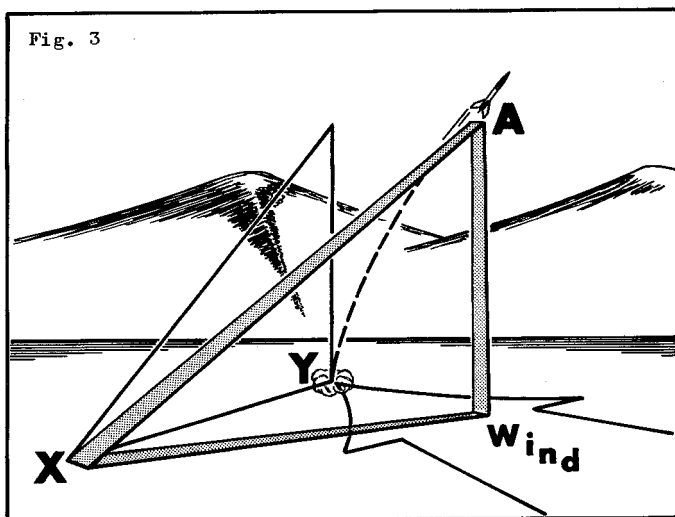
By observing the proper relation between wind direction and the position of the tracker, we can generally determine with 90 percent or better accuracy the altitude the rocket reaches from data given by only one elevation tracker. Of course, the closer the rocket flight is to the vertical, the more accurate will be the figures obtained. Therefore, on a calm day with a good model, we can approach almost perfect accuracy.

The method used to determine altitude with one tracker is outlined below. Bear in mind that this system assumes that the flight will be almost vertical, if not completely vertical. The rocketeer would do well to master this system before going on to more complex systems, as this method is used as a part of the more involved procedures.

Fig. 4
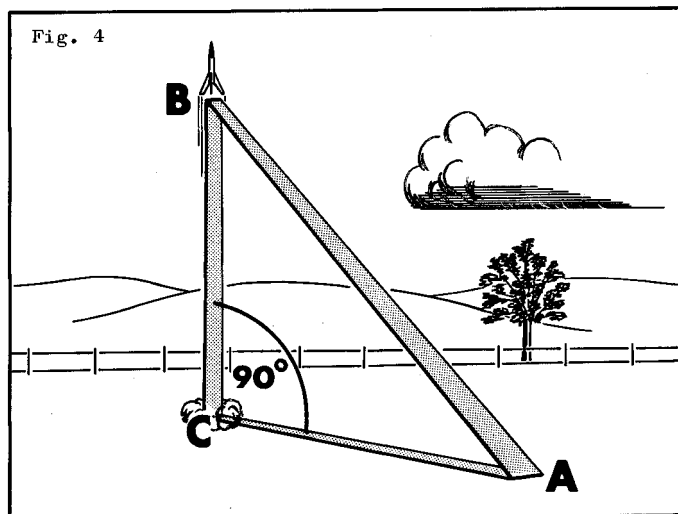
If we assume that the rocket flight is vertical, we can call C a right angle (90 degrees). In that case, B is equal to 90 degrees - A (the sum of the angles in a triangle is 180 degrees, half of this or 90 degrees taken by angle C). Then to find the distance from C to B or the height the rocket reached we take the tangent of angle A (abbreviated tan) times the distance from the tracker to the launcher (side AC of the triangle). For example, if the distance from the tracker to the launcher (baseline) is 250 feet and the angle observed by the tracker at the rocket's maximum height is 62 degrees, we will look in the table of trigonometric functions and find the tangent of 62 degrees. The tangent in this case is 1.88, so we multiply 1.88 times 250 to find our altitude, which is 470'. Altitudes for model rockets are normally rounded off to the nearest ten feet. If the calculated altitude had been 332 feet we would have rounded it off to 330 feet.

Why do we use the tangent to determine altitude? The tangent of an angle is the ratio of the opposite side to the adjacent side, or in other words, the opposite side divided by the adjacent side. In this case, the adjacent side is the distance from the tracker to the launcher, and the opposite side is the distance from the launcher to the rocket's maximum altitude.

_____ **Summary** _____

(1) In single station elevation tracking, we make sure that the line from the tracking station to the launcher in 90 degrees from the direction of wind flow.
(2) The angle of flight is assumed to be vertical.
(3) The tracking scope is locked at the rocket's maximum altitude, the angle read, and the tangent of the angle found.
(4) The tangent is multiplied times the distance from the tracker to the launcher, giving the rocket's altitude.

Two Station Tracking

A higher degree of accuracy is possible when two elevation tracking stations are employed. In such a case, we will have triangles with 2 angles and one side given, enabling us to determine the other parts of the triangle without guesswork.

When using two trackers without azimuth readings the tracking stations are set up on opposite sides of the launcher. Preferably, to obtain the greatest accuracy, the stations should be in line with the wind, unlike the system used in single station tracking. Thus, if the wind is blowing to the south, one station will be north and the other south of the launch area.

The distance between the two trackers is not critical. One might be 100 feet from the launcher and the other 500 feet away. However, for the greatest ease in data reduction, the distance should be equal. For the greatest accuracy, they should be as far apart as possible. A general rule is that the distance from the stations to the launcher should be equal to or greater than the maximum altitude the rocket is expected to achieve.

Some provision should be made to insure that the trackers lock their instruments at the same time. This is one of the greatest problems with any system using more than one station: The one tracker may lock his scope when the rocket appears to him to have ceased rising while the other tracker is still following the rocket. If a phone system is used, one of the trackers or a third party should call "mark", and the trackers should lock their scopes immediately. In the system described here this is especially important, as the elevation readings from the two trackers must be taken at the same point or the altitude computed will be somewhat incorrect.

In this more accurate system we will work with sines instead of tangents. To determine altitude, then, we will first have to find the unknown sides of the triangle, as we have no right angles to work with.

For example, stations A and B are located on a 1000' baseline with the launcher between them. Station A calls in an elevation of 34 degrees, and station B calls in an elevation of 22 degrees. The total of these two angles is 56 degrees, so angle C, located at the peak of the rocket's flight, is equal to 180 degrees - 56 degrees, or 124 degrees. We now have 3 angles and one side to work with. Our first step will be to list the angles and their sines. Since the sine

8

Fig. 5
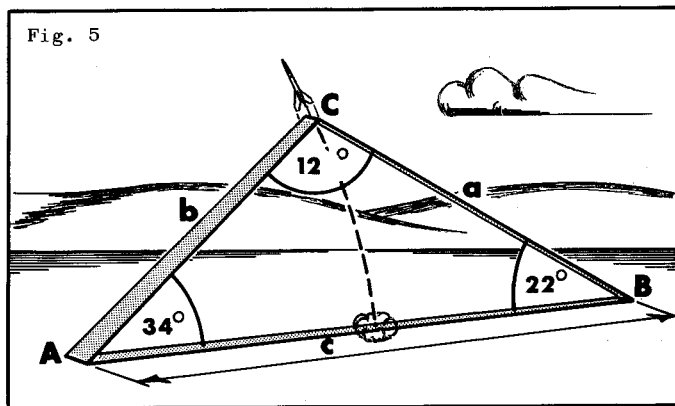
of any angle greater than 90 degrees is equal to the sine of the supplement of the angle, the sine of 124 degrees is equal to the sine of 180 degrees - 124 degrees, or 56 degrees.

| Angle A = 34° | Sine A = .5592 |
| Angle B = 22° | Sine B = .3746 |
| Angle C = 124° | Sine C = .8290 |

The law of sines states that $\dfrac{c}{SinC} = \dfrac{b}{SinB} = \dfrac{a}{SinA}$

c = 1000', sinC = .8290 Therefore, $\dfrac{1000}{.8290} = \dfrac{b}{.3746} = \dfrac{a}{.5592}$

We calculate that $\dfrac{1000}{.8290} = 1205$. We have

a dividend, divisor and quotient. In solving for side b, our dividend is b, our divisor .3746, and our quotient 1205. To find the dividend we multiply the divisor times the quotient. Now .3746 times 1205 = b, and b = 451. The same process is repeated to find side a:
$\dfrac{1205}{.5592} = a$, a = 1205 x .5592, a = 674'. We now have the three sides of the triangle.

Fig. 6
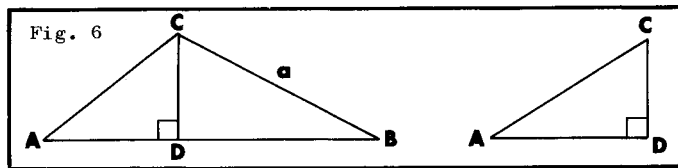
The altitude of the rocket is then the distance from C to D in the diagram above. The angle formed by the meeting of lines AB and CD is a right angle. Since the sine of an angle in a right triangle is the relation of the opposite side to the hypotenuse, and since we wish to determine the value of the opposite side, we find that the sine of A (34°) is .5592. Hence $.5592 = \dfrac{a}{451}$,

since $SinA = \dfrac{opposite\ side}{hypotenuse}$. .5592 x 451 = 252, CD = 252'. We now know the altidude reached by the rocket was 252'.

Fortunately, our computations to determine the altitude of the rocket can be simplified. To find the altidude we need only determine one of the unknown sides of the original triangle. If we find the distance BC (side a) on the triangle, we can multiply it times the sine of B to find the height CD.

So $\dfrac{c}{SinC} = \dfrac{a}{SinA}$. Since we have found $\dfrac{c}{SinC}$ equal to 1205

when C = 124°, $\dfrac{a}{SinA} = 1205$. Then 1205 x SinA =

side a = 674'. Now we have the one needed side of the triangle, so we can solve for distance CD in the right triangle BCD. The sine of an angle is equal to its opposite side divided by the hypotenuse. We take the sine of B, which is .3746, times the hypotenuse, or 674' to find the opposite side CD. Thus, .3746 x 674 = 252'.

The complete series of computations then would be $\dfrac{c}{SinC}$ x SinA = a, and a x SinB = CD.

However, if we can combine the formulas to make one formula, we can speed up our work considerably. Now $\dfrac{c}{SinC}$ x Sin A = A, so we can

substitute the experssion ($\dfrac{c}{SinC}$ x SinA) for a in the formula a x SinB = CD.

Our formula then becomes $\dfrac{c}{SinC}$ x SinA x SinB = CD. One of the basic

rules of algebra tells us that if the dividend is multiplied by a number and the result divided by the divisor, the result is the same as if the division were carried out first and the quotient multiplied by the number. For example, $\dfrac{10 \times 4}{5} = 8$, and

$\dfrac{10 \times 4}{5} = 8$.

We can change the expression $\dfrac{c}{SinC}$ x SinA x SinB = CD to read

$\dfrac{c \times SinA \times SinB}{SinC}$ = CD. So by performing two multiplications and one

division, we can find the altitude of the rocket. The division of SinC into the experssion (c x SinA x SinB) can occur at any point, as $\dfrac{c \times SinA \times SinB}{SinC}$ = CD,

and c x $\dfrac{SinA \times SinB}{SinC}$ = CD also.

This last form of the equation will give the same result as the first, and actually involves the same steps, but is generally easier to use.

──────── Summary ────────

1. In two station tracking without the use of azimuth readings we station the trackers on a base line approximately equal to twice the altitude the rocket is expected to reach.

2. The trackers are located in line with the wind.

3. The scopes are locked at the rocket's maximum altitude, the angles read, and the sines of the angels found.

4. The altitude is computed by the formula height = $\dfrac{c \times SinA \times SinB}{SinC}$

when A and B are the angles read by the trackers, c is the baselie distance, and C is the third angle formed by the meeting of the lines of sight of the two trackers.

Sines and Tangents

∠			∠		tan	∠		tan
1	.02	.02	28	.47	.53	54	.81	1.38
2	.03	.03	29	.48	.55	55	.82	1.43
3	.05	.05	30	.50	.58	56	.83	1.48
4	.07	.07	31	.52	.60	57	.84	1.54
5	.09	.09	32	.53	.62	58	.85	1.60
6	.10	.11	33	.54	.65	59	.86	1.66
7	.12	.12	34	.56	.67	60	.87	1.73
8	.14	.14	35	.57	.70	61	.87	1.80
9	.16	.16	36	.59	.73	62	.88	1.88
10	.17	.18	37	.60	.75	63	,89	1.96
11	.19	.19	38	.62	.78	64	.90	2.05
12	.21	.21	39	.63	.81	65	.91	2.14
13	.22	.23	40	.64	.84	66	.91	2.25
14	.24	.25	41	.66	.87	67	.92	2.36
15	.26	.27	42	.67	.90	68	.93	2.48
16	.28	.29	43	.68	.93	69	.93	2.61
17	.29	.31	44	.69	.97	70	.94	2.75
18	.31	.32	45	.71	1.00	71	.95	2.90
19	.33	.34	46	.72	1.04	72	.95	3.08
20	.34	.36	47	.73	1.07	73	.96	3.27
21	.36	.38	48	.74	1.11	74	.96	3.49
22	.37	.40	49	.75	1.15	75	.97	3.73
23	.39	.42	50	.77	1.19	76	.97	4.01
24	.41	.45	51	.78	1.23	77	.97	4.33
25	.42	.47	52	.79	1.28	78	.98	4.70
26	.44	.49	53	.80	1.33	79	.98	5.14
27	.45	.51				80	.98	5.67

For angles of 81° through 89° the sine is .99, the sine of 90° is 1.00. Tangents over 80° are not given, as no sensible data reduction is possible for angles that great.

ESTES

These reports are published as a service to its customers by Estes Industries, Inc., Box 227, Penrose, Colorado 81240

Introduction:

These are the preliminary findings of a research program conducted since March of 1962. Some fifty boost-glide vehicles have been constructed to date. To augment the findings, library research in aerodynamics has been conducted. Keep in mind that these findings are of a mainly qualitative nature, with expected accuracy in most other case (i.e.; quantitative findings) about plus or minus 10%, except as specified.
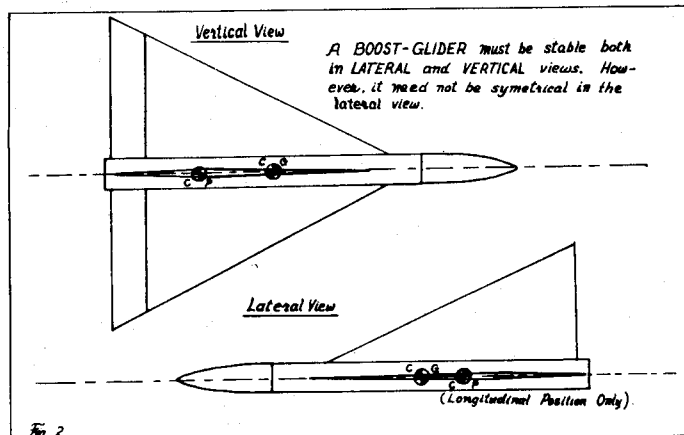
I. The Boost Phase:

A boost-glider is a model rocket which rises vertically in the manner of an ordinary fin-stabilized rocket, and returns in an aerodynamic glide. It is an aircraft and a rocket in one. Let us investigate the design requirements for

Fig. 1
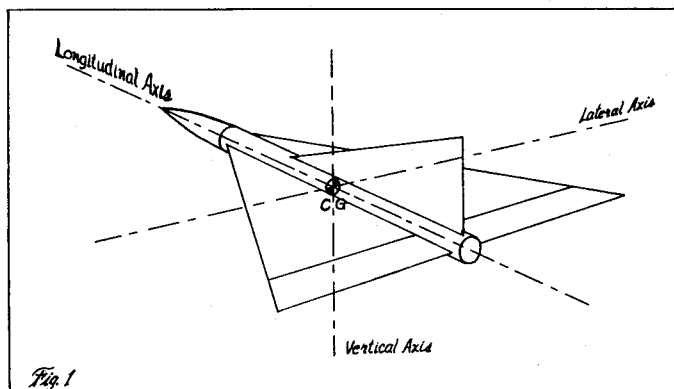
a vehicle of this type. The first thing we must bear in mind is that we are designing a rocket, which is stabilized by locating the center of pressure behind the center of gravity in the manner detailed in Technical Report TR-1.

This is going to have an obvious effect on the boost-glider. Its wings must be located so that they bring the CP of the top view behind the CG by a substantial margin, and also its directional stabilizing surface, the rudder(s) must be located so that it brings the CP behind the CG in the side view.

The distance between the CG and CP is called in physics a moment - arm, and the stabilizing force exerted by the moment arm, results in the corrective moment. This moment is, obviously, proportional to the force of the air hitting the surfaces, which in turn is dependent on two factors: The speed of the rocket and the angle that its longitudinal axis (body) makes with the relative wind. The ideal
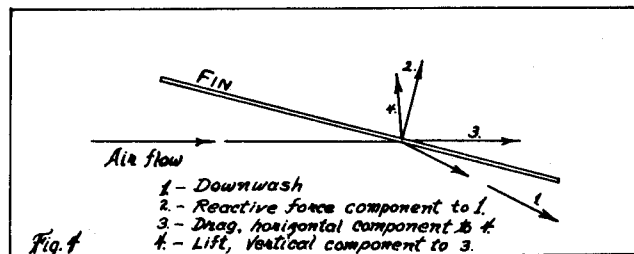

A BOOST-GLIDER must be stable both in LATERAL and VERTICAL views. However, it need not be symetrical in the lateral view.

Vertical View

Lateral View

(Longitudinal Position Only)

Fig. 2

case of rocket stability is one in which very little corrective moment is applied because the rocket flies with little oscillation directly into he relative wind.

While the air hitting the surfaces of an angle produces a component of force acting perpendicular to the body to push the rocket back into parallel with the

Relative Wind – Always acts opposite to direction of flight.

Fig. 3
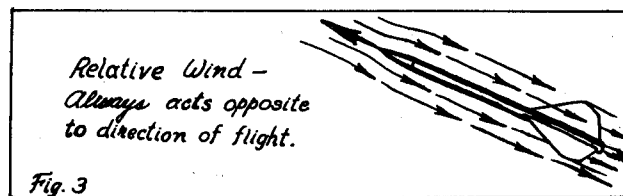
relative wind, it also produces a component of force pointing directly rearward from the rocket, and parallel to the relative wind. This latter force is drag, and the more the rocket oscillates, the greater will be both corrective moment (if the rocket is stable) and drag. Because of its large surfaces, it is best to design the boost-glider so that its stability is greater than the needed for most other rockets. Generally the center of pressure should be at least 3/4 the body diameter behind the center of gravity.

FIN

Air flow

1 – Downwash
2. – Reactive force component to 1.
3. – Drag, horizontal component to 4.
4. – Lift, vertical component to 3.

Fig. 4

II. The Glide Phase:

In glide phase, most rear engined boost-gliders use what is known as the flat-plate effect. (A fully symmetrical airfoil may be used, but it involves some difficulties in construction and alignment. The principles involved in this type of airfoil may be studied in most books covering aerodynamics.) The flat-plate effect simply makes use of the relative wind bouncing off the wing, which produces a component of force which is perpendicular to the wing (see Fig. 5). Since the wing is tilted at an angle to the relative wind, the force will also be tilted at this angle. Thus, when resolved into components parallel with and perpendicular to the relative wind, drag and lift, respectively, are determined for the wind surface.

For any lift to be produced in this manner, the wing must be inclined upward into the relative wind. This is accomplished by means of flaps located at the rear of the wind (in a delta or flying wing design), commonly called elevons. These elevons are tilted up at the rear, which means, by our previously stated principle, that air hitting these elevons will force the rear of the wing down. This, in turn, means that the forward end of the glider is forced up, meeting the relative wind at an angle, and the vehicle glides. Obviously, the extent of this force, called the moment of tail depression, is dependent on the speed of glide, the angle at which the elevons are set upward, and the size of the elevons.
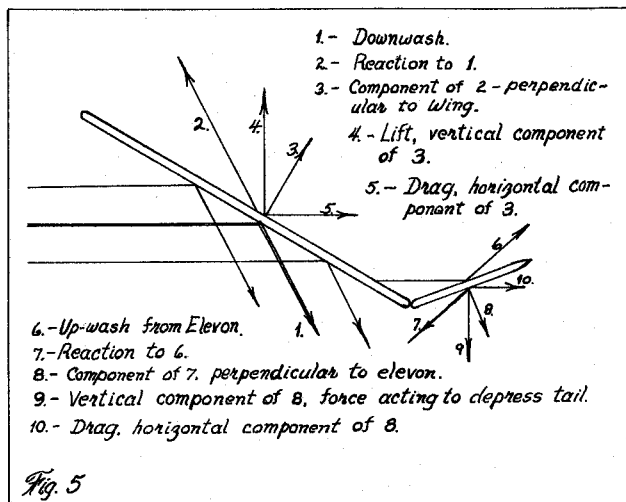
To discover what size of elevon is best for a given glider, we must first take into consideration that there must be some force which makes the glider travel forward in the first place. In glide phase, the engine has been expended, and the only forces acting on the glider are those of air and gravity. After the rocket reaches flight apex and expels its engine, it begins to fall towards the earth. This produces a relative wind which is directly opposite to the direction of travel, i.e.; the rocket is falling down so the relative wind will be up (see Fig. 3). In almost every design imaginable, the CP will remain behind the CG after

ejection of the engine. As a matter of fact, many designs experience a forward shift of CG as the engine ejects. Thus, the glider remains stable as a rocket, and with its corrective moments still effective, the nose turns toward the ground. However, since the elevons have been actuated by this time, the rear of the rocket is forced down by the air acting against them, and thus the nose is forced up and the flat-plate effect suspends the vehicle in gliding flight. In order to glide, the rocket corrective moment must be overcome by the flat-plate effect of the elevons.

Since setting the elevons up at an angle also produces drag, the boost-glider will, in glide, reach a terminal velocity of forward motion and will then keep this velocity rather constant. So we now know that our elevons, to be effective, must produce a depressive force greater than the rocket's corrective force <u>at the terminal velocity of glide.</u>
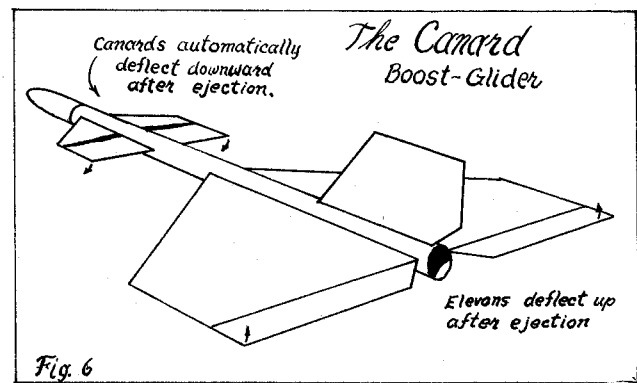
With these factors in mind, then, we can see that the size of the elevons required depends on: (1) the distance between the CP and the CG of the top view in glide and (2) the velocity of the vehicle in glide. The latter is itself dependent upon the size and the angle setting of the elevons, being from about five to fifteen miles per hour in the average glider. For a glider of approximately one half to one caliber rocket stability in glide phase and which has elevons located at the rear of the wing at an average distance from the CG, elevons of approximately 20 to 30 percent of the total wing area are needed for a good, easily adjustable glide.

This amount will vary down to about 10% for less stability in glide phase than in powered flight and up to about 35% for greater stability in glide phase. Any glider requiring more than 35% is not properly designed, and probably possesses an engine located very far to the rear for excessive rocket stability.

1.- Downwash.
2.- Reaction to 1.
3.- Component of 2 - perpendicular to Wing.
4.- Lift, vertical component of 3.
5.- Drag, horizontal component of 3.
6.- Up-wash from Elevon.
7.- Reaction to 6.
8.- Component of 7, perpendicular to elevon.
9.- Vertical component of 8, force acting to depress tail.
10.- Drag, horizontal component of 8.

Fig. 5

An interesting variation on elevon-controlled gliders is the canard design. Canard gliders may be constructed in several ways. First, an explanation of "canard" might be in order. A canard is defined as any lateral stabilizing surface (that is, one that prevents pitching) located forward of the main lifting surface. Canards may also provide lift. When equipping canards with flaps, we must remember that, since the canards are forward of the CG, to induce the nose to angle upward we must deflect air downward by means of our canard-mounted elevons. Therefore, while we build rear mounted elevons to flip upwards at engine ejection, we must construct canard flaps so that they flip downwards at this time. Construction of mechanisms or various types of flap actuation will be covered in Part III. One advantage of canard flaps is that, besides inducing an inclination to the relative wind of the main lifting surfaces, they also provide a small amount of lift themselves, since they deflect air downward and by the principle of action and reaction are acted upon by this air in an upward direction.

Designs which have only canard-mounted elevons usually are of rather high aspect ratio (the aspect ratio is the wing span divided by the average wing width, or chord) than other designs, and experience a slight rearward shift of CG after ejection. Since they have a longer moment-arm through which to act, canard flaps usually do not need to be as large as the flaps in other designs. Canard designs offer slightly more drag then others and are all but useless when the nose is very heavy, since this shortens the moment-arm through which the flaps can act. Very successful canard designs have been constructed with elevons on both the main wing and on the canards, connected by thread to each other. However, these also suffer when the nose is heavy and consequently must be built with very light noses.

Canards automatically deflect downward after ejection.

The Canard Boost-Glider

Elevons deflect up after ejection

Fig. 6

There is no definite rule as to the best aspect ratio for delta or flying wing designs. It seems that high aspect ratio wings give faster response to thermal currents than low aspect ratio wings. Low aspect ratio wings are slower to recover from dives. However, structural considerations also come into the picture, as we shall see in Part III.
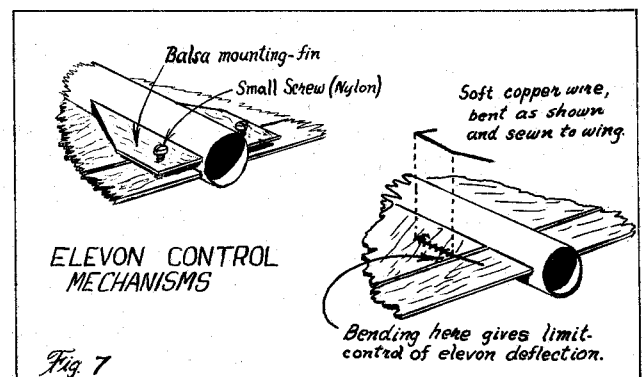
Just about any rudder large enough to give stability as a rocket in a side view is sufficient to directionally control the vehicle in glide. It has been noted, however, that a glider is more susceptible to spiral diving during turns when its center of directional guidance (the center of lateral area of the rudder) is more than 3/4 caliber behind the center of lift (the center of lateral area of the wing in flat-plate airfoil models). This has been found to be at least partially caused by a flow of air crosswise on the forward part of the wing, allowing excessive side slip and turning, which results in a spinning, nose-down attitude.

A boost-glider will have better resistance to rolling in glide when its center of directional guidance lies above the CG, as when the rudder is located on top of the body tube. There are yet no definite rules for wing-tip rudders and for dihedral angle of lifting surfaces. However, it is known that dihedral angle in moderate amounts improves glide by giving a "pendulum effect" while it does not detract noticeably from rocket performance. The glider need not be symmetrical in side view, as are most rockets.

Another factor to be considered in designing boost-gliders is wing loading. This figure is widely used in professional engineering, and is arrived at by dividing the area of the lifting surfaces by the weight of the vehicle in glide condition (without engine). The higher the wind loading, the greater will be the rate at which the glider descends during glide. Obviously then, one way to attain a good glide is to use wings as large as possible and body tubes as light as possible. However, this too is subject to structural limitations. Increase in lift may also be obtained by increasing the angle of attack to the relative wind. However, this also increases drag, and past a certain point drag slows the vehicle to the point where lift begins to decrease again.

III.   Structural and Flying Practice:
It would indeed be gratifying if we could use as high aspect ratios, as large surfaces, and as light construction as its dictated by ideal theory. Unfortunately, structural practice is controlled by the forces which a boost-glider must withstand in flight, and the dictates of these stresses often run opposite to those of theory.

Balsa mounting-fin
Small Screw (Nylon)

Soft copper wire, bent as shown and sewn to wing.

ELEVON CONTROL MECHANISMS

Bending here gives limit-control of elevon deflection.

Fig. 7

The extent of these forces, caused by acceleration and air drag, is dependent upon the size of engine used and the number of engines or stages. The greater the acceleration and the duration of that acceleration, the greater the speed and hence the drag. In first considering the forces acting

on the aerodynamic surfaces at constant acceleration, the force will vary as the square of the velocity, as stated in the equation for drag. In general, a balsa thickness of 1/16" has been found adequate to withstand all air forces produced by Series I engines, provided the aspect ratio of the wing or other surface does not exceed about 4; that is, if the span of the wing divided by the width, or chord, does not exceed this number. Above this number, the wind begins to twist the surface, producing the same effect as warp.

Fig. 8
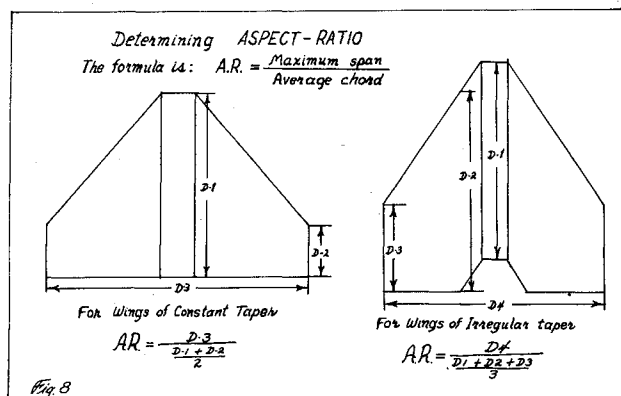
Also of importance is the effect of acceleration during boost. A one-ounce model's wings may weigh 23 times their normal weight for a short time during boost. For this reason, wings should be kept as light as possible consistent with adequate aerodynamic strength. Also, wings which have their CG closer to the body tube, or with low aspect ratios, will be more resistant to being torn loose from the body tube by acceleration forces.

The strongest wing-body joints are possible when the wings are joined together with each other and the body at the underside of the body and the connection reinforced by 1/2 inch wide strips running parallel to the body at the joint. The grain on these strips should be at a right angle to the end by the use of gauze or silk reinforcing, by using thicker balsa for the wings, and by using the longest practical wing-body joint.

Internally-operated elevon actuators, such as pistons driven by the ejection gases, have been tried, but have been found to be not as reliable and more difficult to construct than those actuated by the ejection of the engine. The simplest system to employ is one in which a piece of wire or balsa is held depressed by the engine casing.

When one end of the actuator is held in place by the engine, the other end of the stiff wire or balsa is attached to the elevon, so that the elevon is in neutral position with the casing in place. A piece of elastic thread is fastened to the elevons in a manner which will pull them up (or canard flaps down) when the engine leaves the body tube and allows the wire depressor bar to travel to the actuating position (see Fig. 9). When the depressor bar runs rearward from the elevon to the casing, it should be held down by the casing; when forward it should be held upward by the casing, which will push the elevon down to neutral.

Systems have been tried in which the arrangement is one continuous bar fastened to both wings, and where there are two bars, one for each wing. The latter has been found to be more practical, as it allows individual setting of each elevon. Setting is accomplished either by a small balsa brace with a set screw which, depending on how far the screw is turned up or down, will regulate the elevon accordingly, or by a single-strand, soft copper wire, which can be bent to the degree of elevon desired, and will stop the elevon's upward travel depending on how far it is bent.

With early types of gliders, in many cases the engine was set forward of the aft end of the body tube to move weight forward further. This, after a number of firings, tended to burn away some of the body tube. This was corrected by the application of a solution of sodium silicate (waterglass), a chemical used as a flameproofer and egg preservative, to the inside rear of the body tube. Waterglass has the disadvantage of blistering and ablating into the exhaust gases, leaving a flaky residue and unsightly appearance, as well as impairing the fit of the engine into its mountings. For applications involving the protection of elevons or rudders from exhaust gases, aluminum oil was found much more satisfactory, the foil being glued to the surface in question.

An even better alternative involves the use of an expended engine casing to shift weight forward. The nozzle is drilled or chipped out of the old casing and the casing is then glued or taped to the front of a live engine. Thus, when the engine is ejected, it will take the expended casing with it, lightening the nose for a good glide. This method gives much greater boost stability. The current world's record holder of glide duration was equipped in this manner.

For the early recessed-engine models, and for multi-staging, it has been found necessary to arrange some system by which the depressor bars will not interfere with the stage joint. Obviously, a system using depressor bars which extend rear of the body tube to be operated by an engine which sticks out of the rear of the tube is impossible in recessed engine models, and interferes with mating of the stages. Instead, ports are cut in the body tube forward of the elevons, and the depressor bars are operated through these ports. This adds to drag and is more difficult than external-bar arrangements, but is the only proven method of meeting these special requirements. This method is also used to operate canard flaps, which are located far forward on the body.

Ports too near the front of the engine casing have caused ejection failure. In general, ports should not be cut less than about 3/4 inch to the rear of the point where the forward end of the engine casing will rest in flight. In this way, pressure does not escape from the ports at ejection charge activation.

Fig. 9
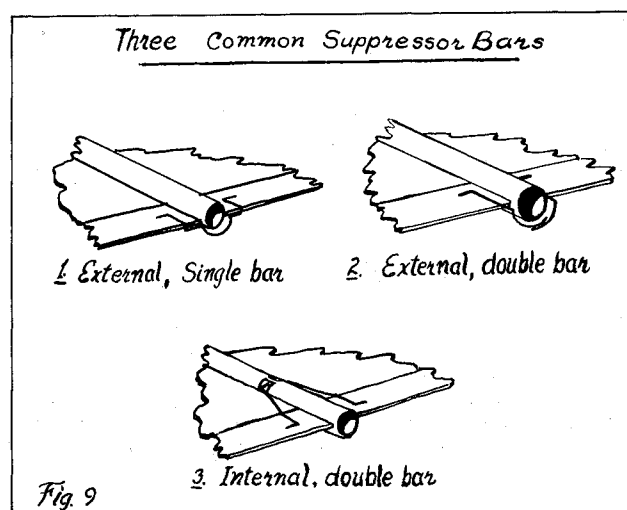
Elevons in the rear and canard flaps in the front can be operated together if the rear elevon actuator is made according to standard practice, and then strands of ordinary thread are attached to the elevons, as far to the rear as possible. The thread is then brought forward, crossed over the body tube, and attached to the canard flaps. Thus the left elevon will, when released, lower the right canard flap, and the right elevon the left canard flap. The canard flaps are, of course, equipped with elastic thread to pull them down when the thread is slackened, which happens when the rear elevons are actuated. Gliders using this system can be made to stay in the air for more than two minutes, single staged.

Research on cluster-engined boost-gliders has so far shown that they are not as practical to build and fly as single-engined gliders, due to the large concentration of weight at the rear of the body. This requires that rocket stability be increased by placing the wings very far to the rear, with the result that the CG moves forward a considerable distance at the ejection of the engines. This in turn makes extremely large elevons a necessity.

CONCLUSION:

The design and construction of good boost-gliders is still an art and requires a high degree of skill in the modeler. But there are few things in any area of modeling which can compare with the satisfaction of building and flying a good glider. This is a field with a genuine challenge for the builder and those who accept the challenge will find themselves plunged into a search for new methods, materials, and principles that results not only in an expanded knowledge of the physics of flight, but also in contributions to the entire art of model rocketry.
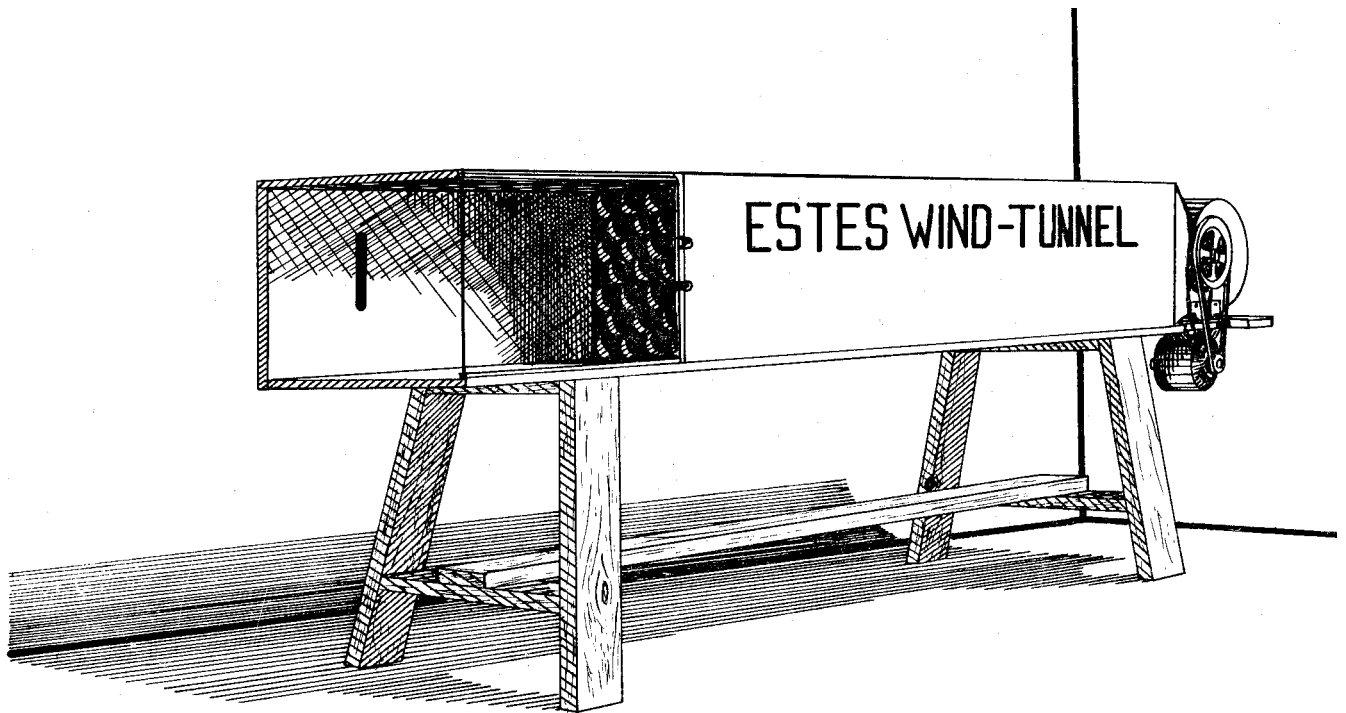
ESTES

Building a Wind Tunnel

OBSERVATION - END VIEW

This shows how 52 pieces of BT-60 are installed to muffle turbulence and direct the flow of air. (Note: 1 3/4" aluminum tubing used on original.)

1/4 round moulding used on both sides of screen, since considerable pressure develops here. (See side view - 1/2" moulding used on original.)

11 1/4" x 12" Plexiglas

Screen suppressor placed into tunnel 14 1/2" from blower outlet.

3/4" x 12" x 31" Front Pc.

1/4" Window Channel

Bottom Pc. 3/4" x 12" x56"

11 1/4" I.D.

3/4" x 12" x 43"

11 1/4" I.D.

3/4" x 12" x 43"

2" x 4"

2" x 4"

10"

2" x 4"

Approximate wind velocity 22 feet per second.

Estes Wind Tunnel

*Designed and developed by Vernon Estes 1961*
Scale: 3" = 1'
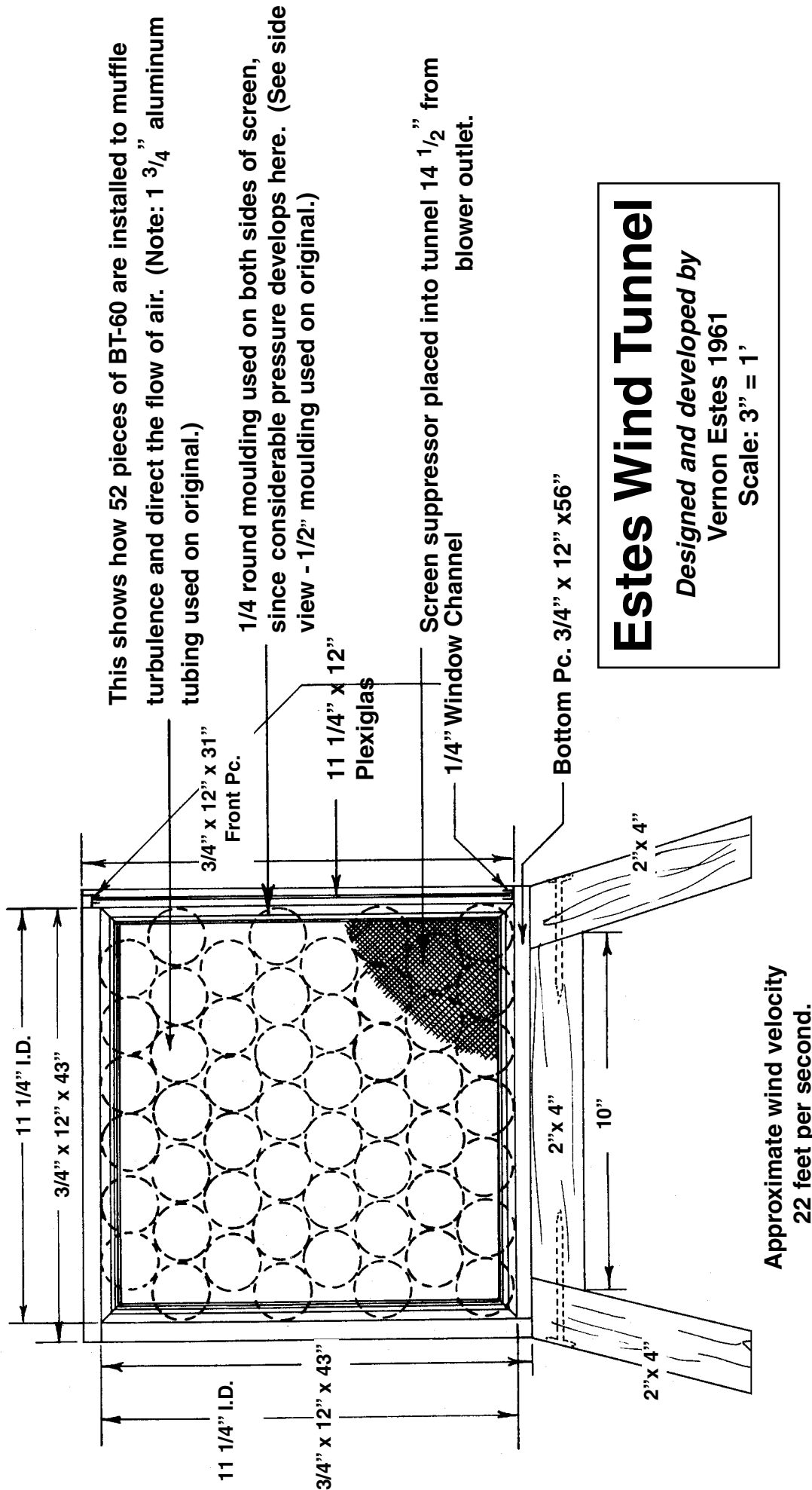
Minimum Friction Calipers

(Useful accessory in determining C.G. and stability of your model rocket.)

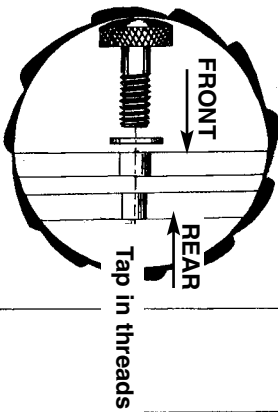**Bill of Materials:**
1 piece 1/8" welding rod, 28" long
2 pieces aluminum bar stock 3/16" x 8" x 3/4"
2 acoustical phonograph needles
1 bolt and wing nut (optional) thumb screw

FRONT

REAR

8"

4"

3/16"

3/8"

Cutaway shows depth to drill for needle seat.
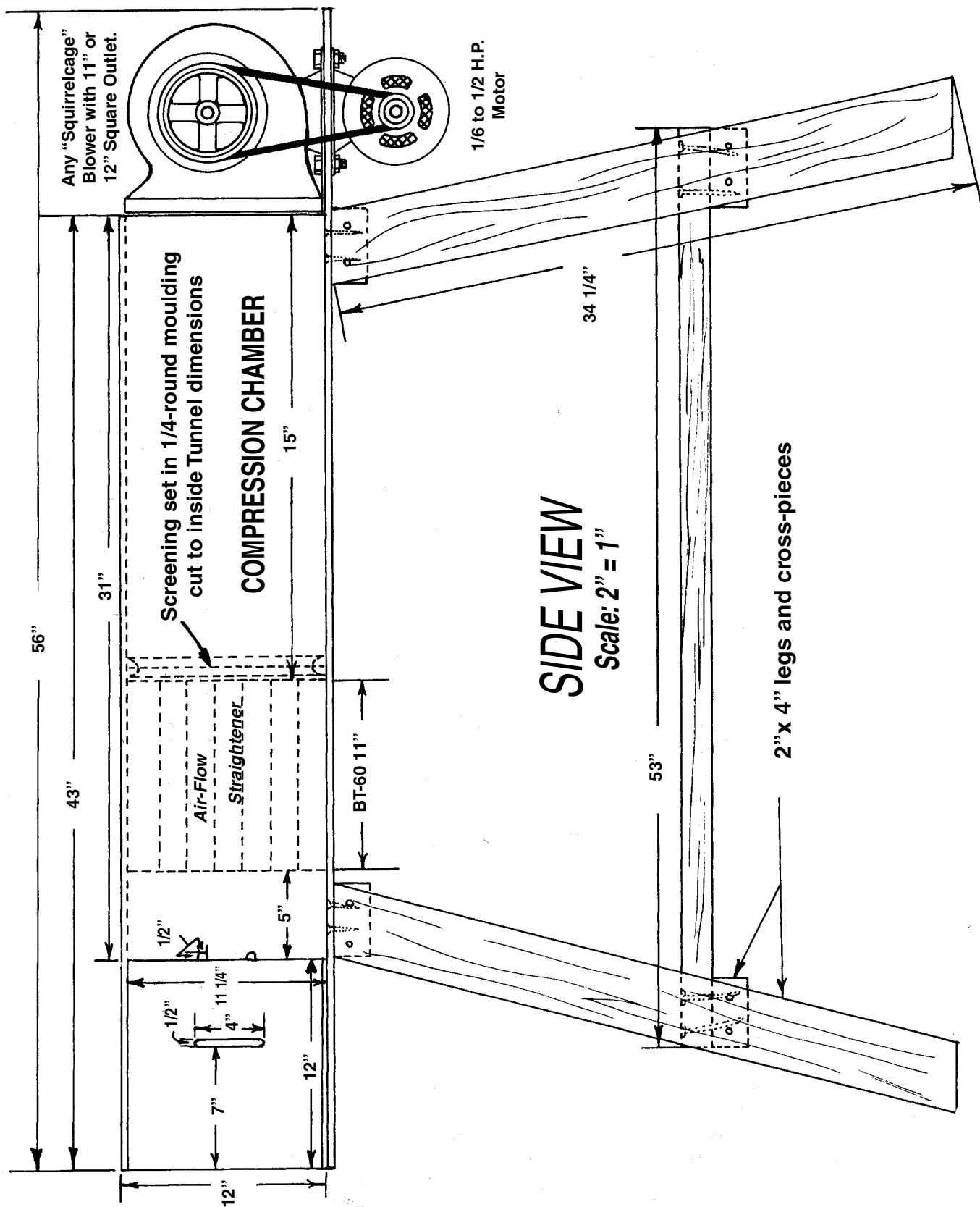
11 3/8"

3/4"
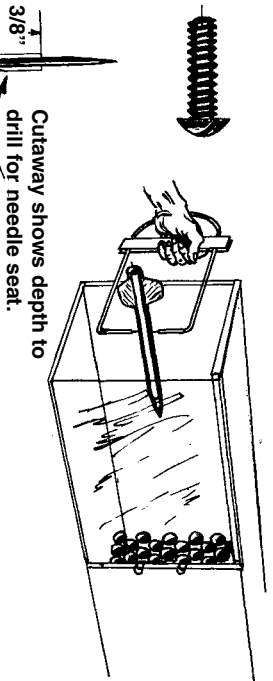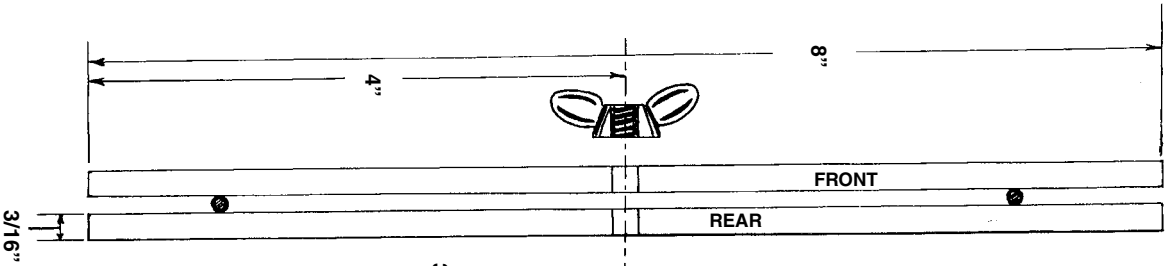
Drill to size of bolt or thumbscrew

If thumbscrew is used, drill one bar with drill at least one size smaller than the other to allow threads to be tapped. See inset.

FRONT

REAR

Tap in threads

Rod can be bent around a coffee can to get a smooth radius curve.

Any "Squirrelcage" Blower with 11" or 12" Square Outlet.

1/6 to 1/2 H.P. Motor

Screening set in 1/4-round moulding cut to inside Tunnel dimensions

COMPRESSION CHAMBER

15"

56"

31"

43"

Air-Flow

Straightener

1/2"

5"

BT-60 11"

1/2"

11 1/4"

4"

4"

7"

12"

12"

34 1/4"

53"

2"x 4" legs and cross-pieces

SIDE VIEW
Scale: 2" = 1"

16

Wind Tunnel Assembly Instructions

The Estes Wind Tunnel was designed especially for checking the stability of model rockets, and can be easily built by the modeler with moderate experience in woodworking. Modifications in this wind tunnel design allow the use of materials the rocketeer already has on hand should not hurt its performance to any great extent.

The blower used in this wind tunnel is a standard furnace blower, and it should be possible to obtain one from your local plumbing-heating contractor for a reasonable price if you specify a used one and tell him what you are going to use it for. The motor can be almost any 1/6 to 1/2 horsepower, 115 volt unit. The ratio of the sizes of the pulleys will depend on the output speed and power of the motor and the rated speed of the blower.

The first step in assembly is to cut out the front, back, top, and bottom pieces from 3/4" plywood. These pieces should be cut out carefully so they will match up properly when attached to each other. Sand the four pieces on all sides and then nail them together to form the tunnel body as shown in the plans. Use 6d finishing nails and apply white glue to the joint before pressing the wood together and nailing. Support the tunnel body during this operation to insure that it remains perfectly square.

Paint the inside and outside of the tunnel with enamel paint. Be especially careful to give the inside of the tunnel a smooth finish to reduce turbulence and give a more even air flow.

Nail four pieces of quarter round moulding into the tunnel to form the rear (blower end) frame for the screen as shown in the plans. Press the screen into position and nail the other four pieces

of molding into place to form the front frame. (The screen should be nailed to place without any moulding if minimum turbulence is desired).

Cut and drill the bottom piece to match the mounting holes of the blower and the motor. Be sure that the holes are drilled to position the blower firmly against the rear of the tunnel. The blower should be adjusted so the flow is as even as possible.

Cut, miter, and sand the 2 x 4 pieces for the tunnel stand. Nail the stand together using 16d nails. Nail the stand and the tunnel together, then paint the stand.
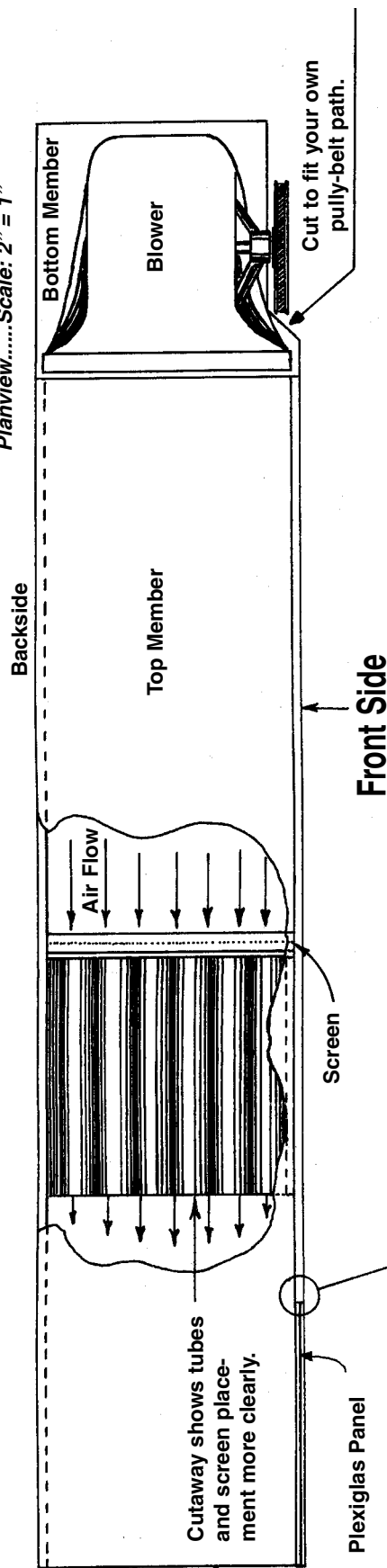
Mount the blower, motor, and belt at the rear of the tunnel. The exact mounting procedure will vary with the type of motor and blower. Make sure the belt has a firm grip against the pulleys on both blower and motor.

Put the flow straightener tubes in place in the tunnel. These tubes should have a thin wall, and either metal tubing or BT-60 may be used. When all tubes are in place the assembly should make a tight press fit inside the tunnel body. (There are several other possibilities for the flow straightener. It may, for example, be made from heavy posterboard arranged to form a rectangular grid.)

Make a belt guard to keep fingers out of the moving parts of the wind tunnel. This guard should be designed to fit the pulleys and belt used on your wind tunnel, and may be made from sheet metal, cardboard, plywood, or other materials which may be available. Attach the aluminum window channel at the front of the tunnel. Slide the plexiglas window into place and the wind tunnel is completed.

Top View
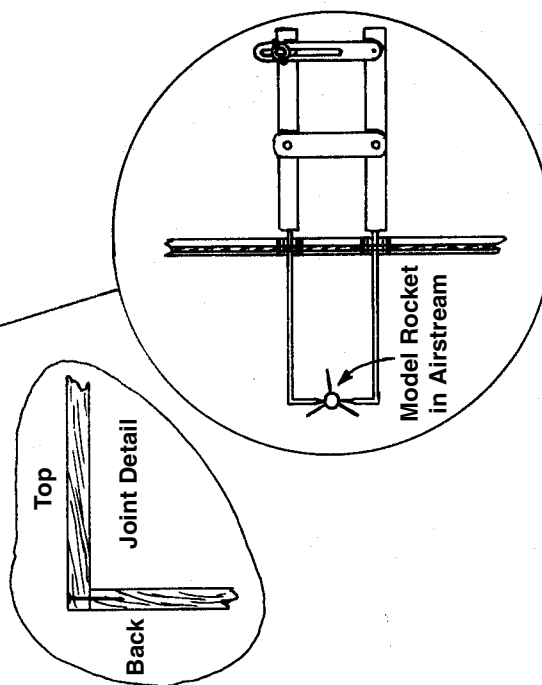
Planview......Scale: 2" = 1"

Bottom Member

Blower

Cut to fit your own pully-belt path.

Backside

Top Member

Front Side

Air Flow

Screen

Cutaway shows tubes and screen placement more clearly.

Plexiglas Panel

Top

Joint Detail

Back

Model Rocket in Airstream

Use of low-friction pivot-points is shown here, protruding through the slots adjacent to plexiglas *"Window"*

Open End Permits Test of Larger Models...
But, results may be inconclusive due to "Outside Air" mixing into straight flow, causing turbulence at varying distances from tunnel-end.
Suggest nose of vehicle under test be placed well into tunnel.

PLEASE NOTE:
Though this unit is ideal for stability tests, it is not recommended for checking drag. Flow-velocity is too low at 22 feet per second.

18

Testing Rockets for Stability

DETERMINING CENTER OF GRAVITY

The first step in checking the stability of a model rocket is to locate its center of gravity. As you know from reading the technical report on rocket stability, the center of gravity is the balance point of the rocket and the point about which the rocket will rotate in the air.

First locate the approximate center of gravity by balancing the rocket on a finger. Then set the rocket on a flat surface, spread the jaws of the calipers apart, and put them into position on the rocket in the area located previously. The two points of the calipers should be on directly opposite points on the body. Pick up the rocket with the calipers. If the nose of the rocket points down, set the rocket down and move the calipers ahead slightly. If the tail of the rocket points down, move the calipers rearward slightly. Continue this until the rocket balances perfectly. This balance point is the center of gravity. The center of gravity is always determined with a loaded engine in place in the rocket. A string and soda straw may also be used to balance and hold the rocket. For details on this system, see technical report TR-1 on Rocket Stability.

CHECKING FOR STABILITY

When the rocket has been balanced correctly, turn on the wind tunnel, and holding the calipers vertically as in the illustration on the previous page, insert the rocket nose first into the wind tunnel. If the rocket remains pointing nose first into the tunnel with nothing but the calipers touching it, it is stable. The string and soda straw (see TR-1) may be used in place of the calipers.

It still remains to determine just how stable the rocket may be. It is not enough if the rocket remains pointed into the wind when aimed in that direction, it must

also be able to recover and point back into the wind when pointed in the proper direction when a rotating force such as an off-center engine or a side gust of wind interferes with the rocket's flight. Also, a heavier rocket must be more stable than a light rocket, since the heavier rocket is going slower when it leaves the launch rod and gets less corrective force from its fins at the lower speed.

Any model rocket must be able to "recover" and point back into the wind when it is pointed 5 degrees out of line. A good general rule to follow is to require an additional five degrees of recovery for every ounce of rocket weight. When we

put the rocket into the wind tunnel's air stream we want to see how far out of line we can point it and still have it swing back into line. The greater the angle from which the rocket can recover, the better it will fly. A one-ounce rocket which barely recovers from 5 degrees out of line is only marginally stable, while one which can recover from 20 degrees or more is stable enough to fly under almost all conceivable conditions.

FINDING THE CENTER OF PRESSURE

A more accurate measure of stability can be made by locating the center of pressure (see technical report TR-1 on Rocket Stability). This is done best by marking the center of gravity on the rocket body, moving the calipers rearward on the body slightly, and placing the rocket back in the wind tunnel air stream to see if the rocket will still point into the wind. The calipers are moved backwards until the point at which the rocket no longer will point into the wind, but begins to rotate freely in the air stream is located. This point is the center of pressure, and should be marked on the rocket body.

The rocket's center of pressure should be at least 1/2 the diameter of the rocket body behind the center of gravity for proper stability. The diameter of the rocket is called its caliber, and it is common to talk about the stability of the rocket in terms of calibers. Thus a model which has its center of pressure 1/2 caliber behind the center of gravity is said to have 1/2 caliber stability.

CHECKING MULTI - STAGE ROCKETS

The procedures outlined above are also used in determining the stability of multi-stage rockets. However, some extra steps must be taken with such a model. A multi-stage rocket must be checked in all the shapes in which it will fly. Thus, a two-stage rocket is checked with both stages joined together and then the upper stage is checked alone.

In addition to determining the stability of all stages together, the upper stage alone, etc., it is also important to check the stability of the booster by itself as it would be after upper stage ignition and stage separation. In this case, however, we want results completely different from those for an upper stage. A booster stage should be unstable by itself. This is so that it will tumble to earth instead of streamlining in. When we pivot the lower stage on the calipers at its center of gravity, we want it to rotate freely and not point into the wind.
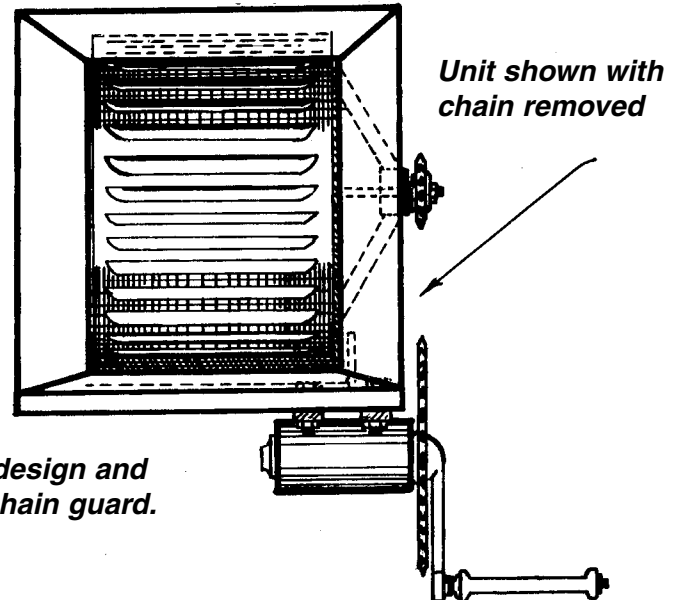
HAND-POWER for your
MODEL WIND TUNNEL

SIDE

END

Unit shown with chain removed
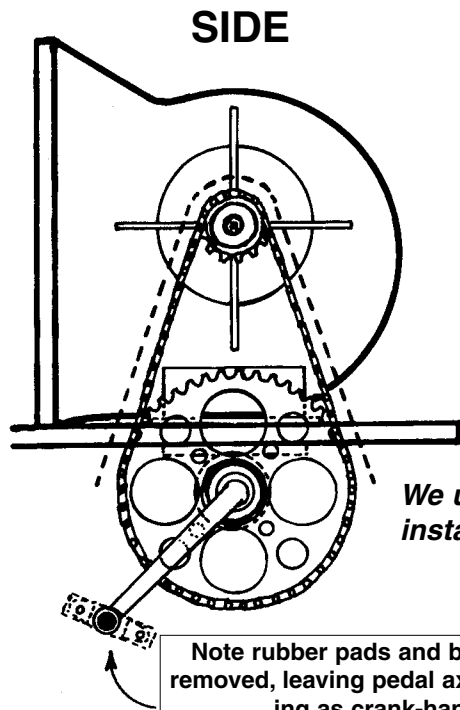
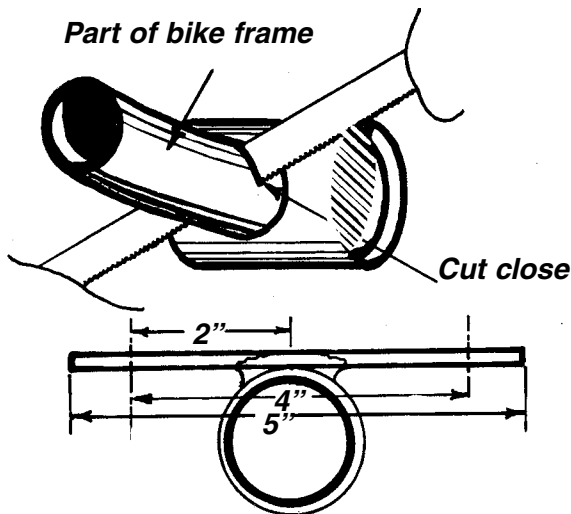*We urge builders to design and install an adequate chain guard.*

Note rubber pads and brackets are removed, leaving pedal axle and housing as crank-handle.

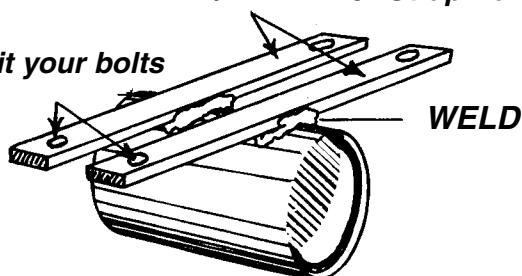## BOTTOM "PEDAL" UNIT DETAILS

Part of bike frame

Cut close

2"

4"
5"

1/2" x 1" x 5" Strap Iron

Drill to fit your bolts

WELD

If your wind tunnel is to be used on the firing range, chances are that electric power won't be available to run a motor. To allow the range control officer to check any rockets of questionable stability, you might build your wind tunnel for hand power.

The parts for the drive unit on the hand-powered wind tunnel can be salvaged from a used bicycle. The bearing carrier for the pedal-sprocket unit is cut from the frame, and the pedal on the side away from the sprocket is cut off completely. The mounting for the rubber blocks on the remaining pedal are removed to make a hand crank.

Two pieces of strap iron are welded to the bearing carrier as in the drawing. This unit is then mounted at the rear of the wind tunnel under the blower. The sprocket on the blower can be one from the rear wheel of the bicycle, although a smaller sprocket will give a higher speed. Be sure that the teeth on both sprockets fit the chain. The chain should be adjusted to fit fairly tight around the two sprockets (about the same fit as for a bicycle). Design and install an adequate chain guard to protect the operator.

These reports are published as a service to its customers by Estes Industries, Inc., Box 227, Penrose, Colorado 81240

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 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

2 Parallel
3 Parallel
3 Cluster
3 Boosters Center Sustainer
4 Square
4 Parallel
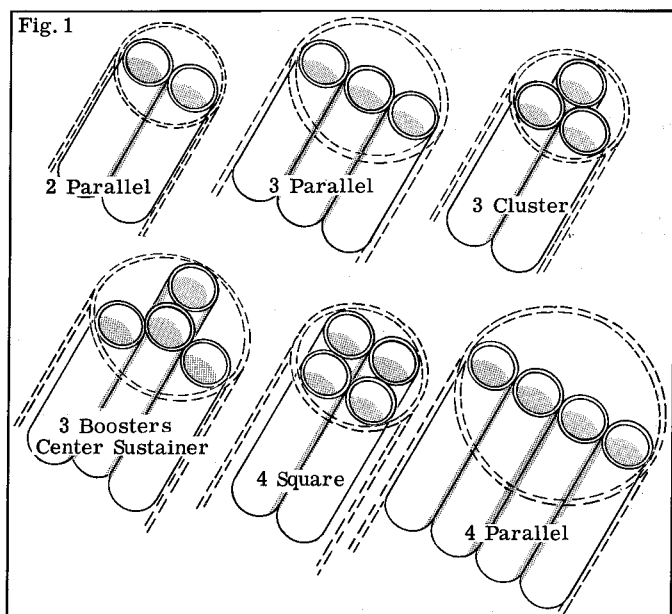
When designing a cluster rocket, first make sure that thrust will be balanced around the centerline of the rocket. An unbalanced arrangement will normally cause the rocket to veer off course. Similarly, all engines located away from the centerline of the rocket should develop the same amount of thrust. 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 B6-6, the other one must be a B6-6.

All engines should be located fairly close together. Avoid way-out 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 slight 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.

Fig. 2

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 hooks. 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 hooks do not weight 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.
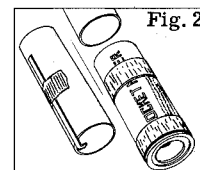
Figure 3 shows typical engine mounting systems for a three-engine model. Note that when engine hooks are used, the spaces between tubes are sealed at the front of the engine mounting tubes, When masking tape is to be used to secure the engine in place, the spaces can be sealed at the extreme rear of the rocket. The same considerations apply to any other cluster model, regardless of the number of engines it uses.

Fig. 3
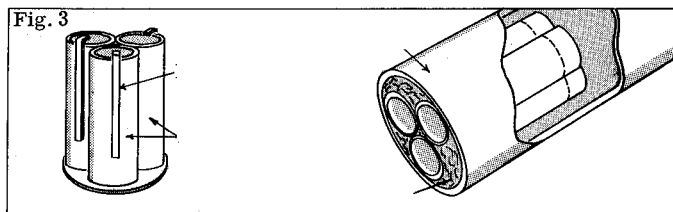
If a body tube is large enough to hold three engines, it can also hold two engines. Figure 4 illustrates techniques which

Fig. 4
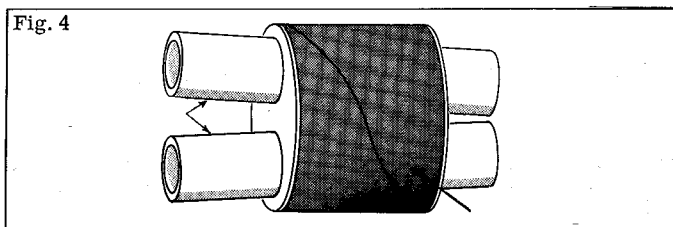
can be used to position and align engine mounting tubes which would otherwise fit too loosely in the rocket body tube. When it is necessary to make special rings to position and support the tubes, the rings should be cut from fairly heavy cardboard such as is used in show boxes.

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 cutout 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.

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

Fig. 5 — Engine Tube — Fairing — Body Tube — Tissue/Glue Putty
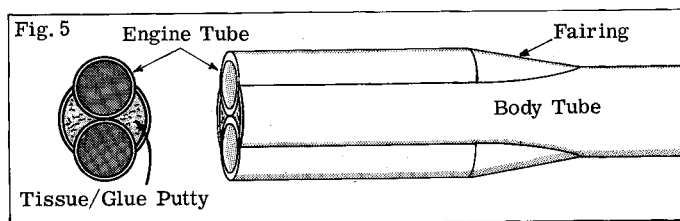
gas to blow forward, just about any system will work. In any case, the engine mounts must be strong enough to stand up to the engines' maximum thrust. The best way to make sure the engine mounting system will be strong enough is to use plenty of glue when building it.

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 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 of 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 model, it will probably 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 — Sheet Balsa — PRM-1 — Rib
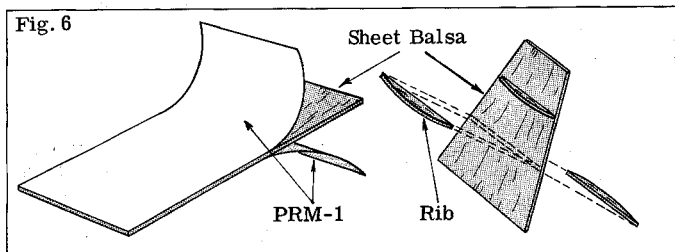
Fin stock thinner than 1/8" can be used, but it should be reinforced for best results. Two reinforcing methods are commonly used: Self-adhesive paper can be applied to both sides of the fin or strengthening ribs can be glued to the fin, parallel to the root edge and spaced evenly along the fin as shown 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.

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.

Fig. 7 — Spin Tab — Canted Fin — Non-symmetrical Airfoil
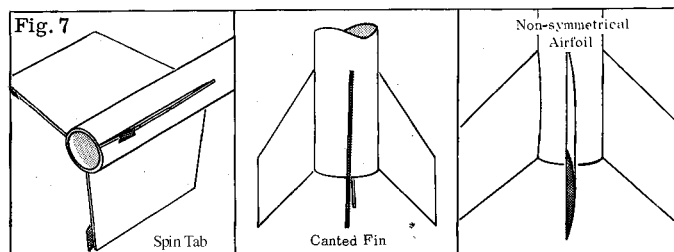
Use either a wind tunnel or the string method described in Technical Report TR-1 to make sure the model will be stable. If the model is tested by the string method it should have at least a 15° to 20° "margin" of stability. If the rocket is not stable, you can either make it longer, add nose cone weights 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.

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 — Body Tube — Stuffer Tube — Centering Ring
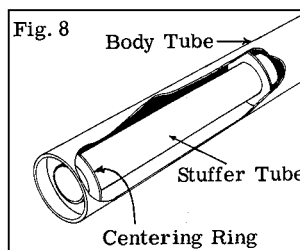
To reduce fin breakage, the recovery system can be attached to the outside rear of the body instead of the front. This is done by gluing one end of a string in a hole in the body about one inch from the rear. The other end of the string is tied to the shock cord. The string should be long enough to reach up the side of the body tube and back two or three inches into the inside of the body tube.
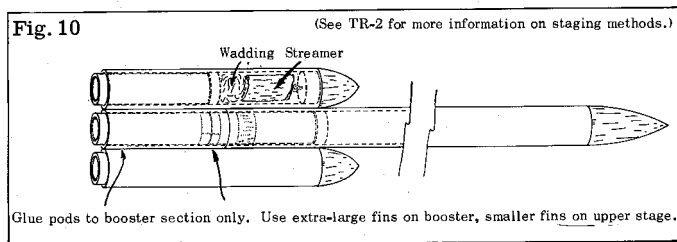
Fig. 9 — Hole in fin or body
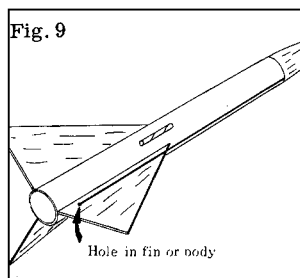
The best way to protect parachutes from the heat of ejection gases is to use an adequate amount of flameproof wadding. Use enough loosely packed wadding to fill the body for at least twice the diameter of the tube. Stuff the wadding into the tube just far enough to allow space for the parachutes, shroud 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. The 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 along side 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.)
Wadding Streamer

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. 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 propellant and still start the engine. There must be direct contact.
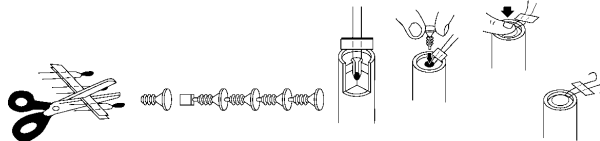

The second point to remember is that the igniter must not "short" or touch itself. The one lead should follow one side of the nozzle; the other lead should follow the opposite side of the nozzle. If these leads cross and short circuit, the current cannot reach the part of the igniter which is against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

Finally, push the igniter plug in tight. When the igniter plug 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
Launch controller unit
12 Volt Source
SCHEMATIC FOR PARALLEL WIRING
Igniters
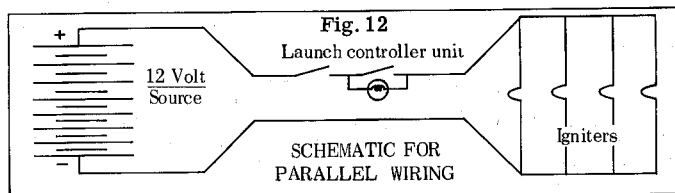
There are several good ways to connect the launcher leads to the igniter leads. In a parallel cluster the simplest method is to use two straight pieces of stiff wire (a straightened paper clip will do) for buss bars as shown. A pair of tweezers can be used to wrap the igniter leads around the wires - 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.
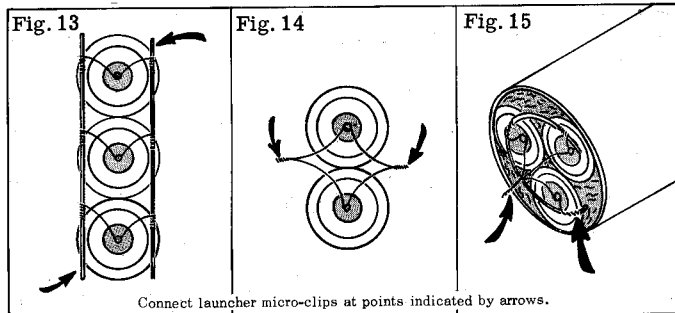
A combination of these two methods can be used for three engine circular clusters. First, the engines are placed in the rocket so one igniter lead is toward the inside and the other toward the outside. The inner leads are twisted together. A wire loop (a large paper clip makes good raw material) is then 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.


Fig. 16   Fig. 17
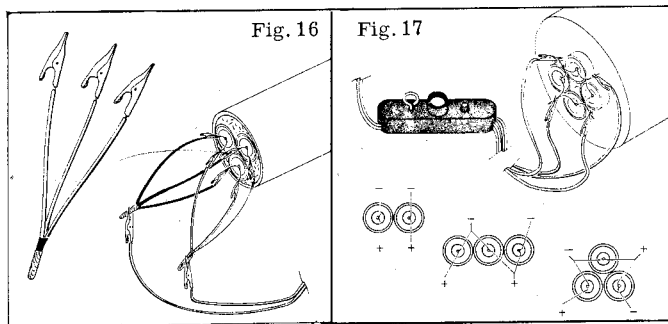
A variation of the clip whip system uses four micro-clips, permanently attached so two fork off from each launcher lead. The leads should be marked so the pairs of clips which are connected to the same lead can be easily identified. This system was developed for use with the four engine cluster in the 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 <u>must</u> be in parallel, they should be connected as close in to the nozzle as practical and the micro-clips <u>must</u> 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.


Fig. 18
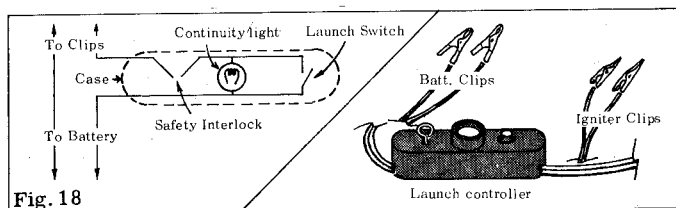
To connect the battery to the rocket and control the electrical current, a heavy duty launch system should be used. The Estes "Command Controller" (Cat No. 2234) or a similar unit is ideal. Make all connections in the system carefully. If possible, solder all permanent joints; a soldered joint conducts 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 if reasonable size. Even so, special care should be taken.

Fig. 19   Solder   Lower rod   Upper rod   Apply heat to joint
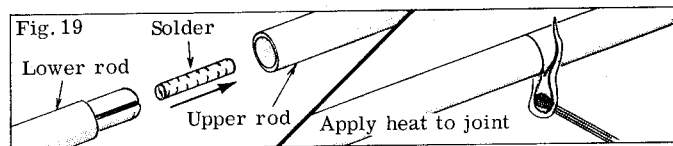
First, the legs should be spread as wide as possible, locked tightly in position, and held down with rocks or bricks. A two-piece rod should be fitted tightly. If the joint between the rod sections is even slightly loose, it can be tightened by soldering (see Fig. 19).

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.

Fig. 20   Hole for rod   Cut here   Bend here   Nail   Coffee can with top and bottom removed
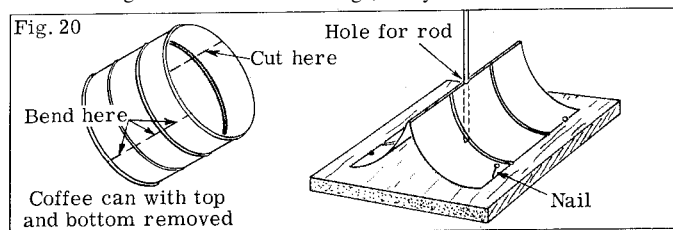
A two foot square piece of 3/4" thick plywood makes a good base. The round (Cat. No. 302241) blast deflector works well with most rockets. A good deflector can also be made from a coffee can as shown.

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.

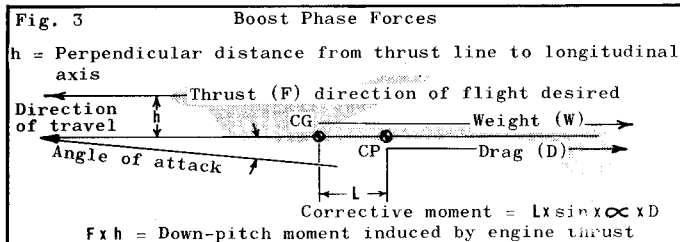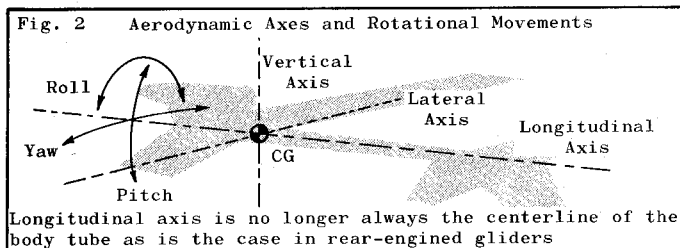☐ 5   ☐ 4   ☐ 3   ☐ 2   ☐ 1   *LAUNCH!*

Introduction

Perhaps the most revolutionary development in model rocketry since Estes Industries created the first boost-glider in 1961 has been the introduction of the forward engine boost-glider. The new type of glider is so radically different from its conventional predecessor that many formerly accepted ideas about design must be changed to fit the special cases encountered in forward engine design if the best configuration is to be achieved. This report contains the finds of a research program conducted since June, 1963, which succeeded in determining the requirements for good forward engine design. As flight testing was the major research method, many criteria are qualitative, but due to the fine tolerance demanded in forward-engine design the uncertainty in quantitative data is only plus or minus 5%.
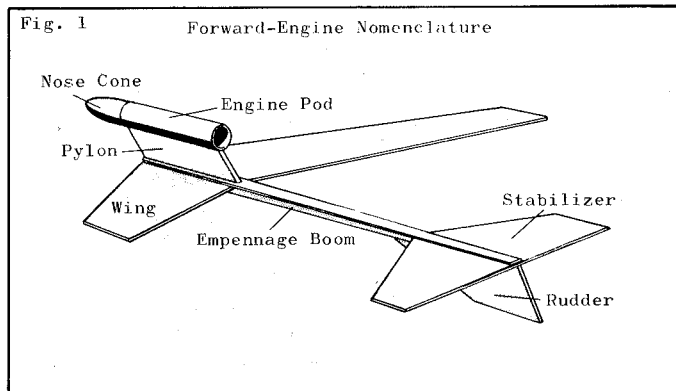
The Boost Phase

Despite its airplane-like appearance the front engine boost glider must, to meet the definition of its type, be capable of a vertical liftoff without relying on lifting surfaces. It must have a straight and true boost trajectory and must enter quickly and smoothly into the gliding recovery phase of flight after engine ejection. Here, as elsewhere, conflicting demands of aircraft and rocket design must be met to obtain a workable vehicle. As detailed in Technical Report TR-4, the glider must have it surfaces located so as to grind the center of pressure far enough behind the center of gravity to produce enough corrective force in case of oscillation. Fortunately, the arrangement of the front engine model makes this fairly easy since weight is concentrated in the nose when the engine is in place. In building and flight testing nearly fifty vehicles, not a single case of instability due to misplaced CP location was encountered.

This aid to design is countered by several undesirable features including the high degree of asymmetry of most forward engine models. The most serious of the results of asymmetry is the offsetting of the thrust line from the CG along the vertical axis. This produces a down-pitching effect whose moment-arm is equal to the offset distance and whose magnitude is equal to this distance times the engine's thrust (Figs. 2 and 3). If the CP is similarly displaced, as it often is, the resulting pitching will also affect the flight. This effect, however, is normally small.

Fig. 1   Forward-Engine Nomenclature

loop is readily countered by normal positive stability and an additional type of stability which we shall call stick, or trailing member, stability. This inherent stability, possessed by some front engine and many oddball designs, is present when the engine nozzle (or point of origin of thrust) is located ahead of the CT. The CG tends to trail or hang below the suspending and accelerating force of the rocket engine, thus adding to the model's stability.

When the various opposing factors are combined and the results analyzed by flight testing, we find that minimum stability for front engine boost-gliders is about 3/4 the body diameter.

Fig. 2   Aerodynamic Axes and Rotational Movements

Longitudinal axis is no longer always the centerline of the body tube as is the case in rear-engined gliders

Fig. 3   Boost Phase Forces

h = Perpendicular distance from thrust line to longitudinal axis

Corrective moment = $L x \sin x \propto x D$

$F x h$ = Down-pitch moment induced by engine thrust

By using low pylons and large amounts of dihedral (the angle of the "V" formed by two-panel wings) the engine-induced down-pitch moment can be greatly reduced and sometimes entirely eliminated. Carrying the practice to extremes is not wise since the structure will be weak and exhaust blast may damage the tail section of the glider. Within normal limits the tendency to pitch or

The Glide Phase

The big advantage of the front engine boost-glider lies in its method of attaining and maintaining a gliding attitude following engine ejection. Although a number of front engine designs use ailerons and other high-lift devices to increase the lift/drag ratio, the basic front engine configuration has no moving parts. It relies solely on the shift of the CG and the loss of weight that accompanies ejection to initiate the recovery phase. This design can be more reliable than many conventional designs.

There are two major methods of designing the glider to automatically initiate glide. One is the addition of negative incidence to the horizontal stabilizer, i.e., placing a small shim of balsa under the stabilizer trailing edge so that the stabilizer forms a slight negative angle with the empennage boom. This angle, never exceeding one degree, makes possible the use of very thin wings, and even wings with no airfoil at all. Its disadvantage is that it often produces poor boost characteristics, especially a nose-up pitching moment which greatly reduces altitude and occasionally results in loops and crashes. An extremely delicate

Balance must be maintained between the nose-down engine moment and the nose-up stabilizer moment, a balance far more critical than that commonly found in free-flight model airplanes. Such a condition can not be easily produced, and once produced, can not be reliably duplicated. It is thus unacceptable for general use.

Fig. 4A   Pitch Stability
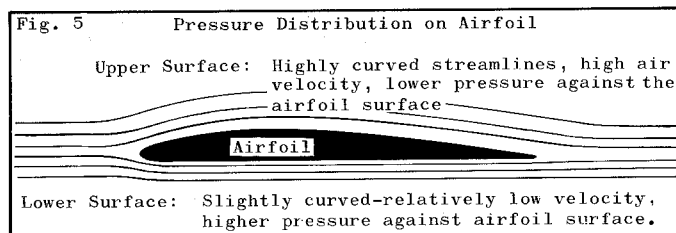by Negative Incidence in Stabilizer
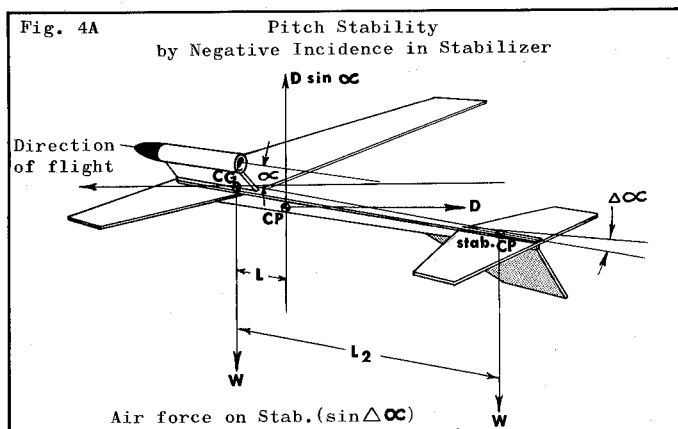
A second method which largely solves the problems encountered with the first is the use of an airfoiled wing. The wing airfoil operates on a principle discovered by the Swiss physicist Daniel Bernoulli, producing a lifting force even when held at zero angle of attack to the relative airstream. Bernoulli found that when air moves rapidly its pressure decreases. The upper side of the wing, being more highly curved than the often flat and sometimes undercambered lower side, forces the air to move more rapidly around it. This produces a low-pressure area directly above the wing into which the wing is forced by the relatively high pressure below it. Since such a wing may be mounted at zero angle of attack and since it "stalls" or loses lift when at a high angle of attack, it produces little pitch-up moment in boost phase, allowing a smoother vertical flight while producing a superior glide.


Fig. 4B   Pitch Stability by Lifting Wing

Angles here and in Fig. 4A are exaggerated for clarity. In actual flight, direction of flight is angled slightly down, and force in direction of flight is produced by the component of gravity acting in the direction of flight.
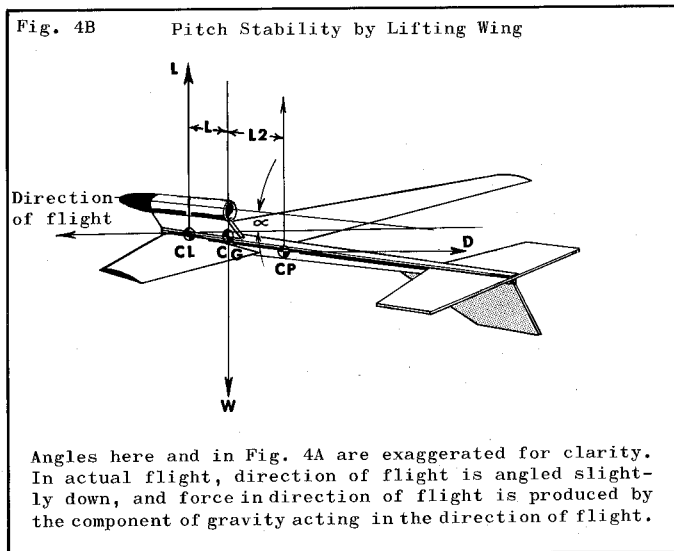
─────── Airfoil Shape ───────

There are many airfoil shapes, some more efficient than others. The boost-glider is an unusual case of very small size and low velocity (when gliding), both of which tend to make the Reynolds Number quite small. Boost-glider Reynolds Numbers range from 25,000 to 100,000 in most cases, while those for full size aircraft are well up in the millions. A full discussion of Reynolds Numbers is not in order here, and may be found in most aerodynamics texts if further information is desired. The important effect, however, is that airfolds suited for larger
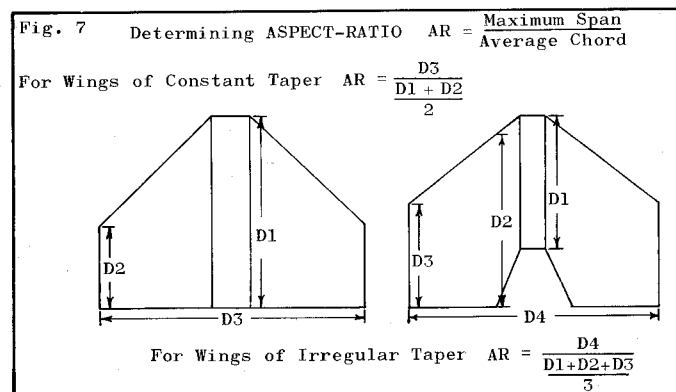
and faster vehicles are relatively poor on the boost-glider. It has been found that thin, flat-bottomed sections with a maximum thickness of seven to ten percent of the wing chord (the distance from the leading to the trailing edge) and with the maximum thickness between 25% and 35% back on the wing are satisfactory. Little work has been done with airfoils other than flat-bottomed, but experience to date indicates that the range of available types is quite broad.

Fig. 5   Pressure Distribution on Airfoil

Upper Surface: Highly curved streamlines, high air velocity, lower pressure against the airfoil surface

Airfoil

Lower Surface: Slightly curved-relatively low velocity, higher pressure against airfoil surface.
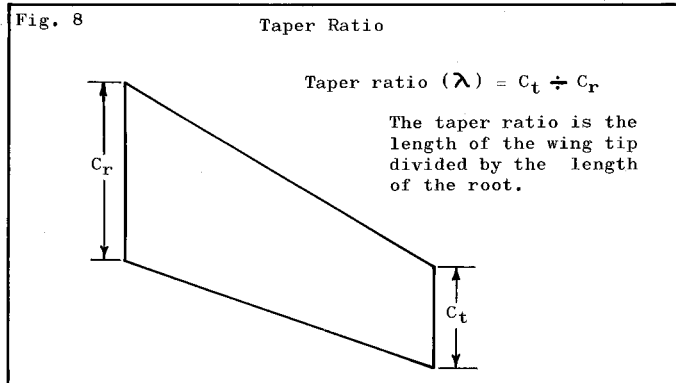
The proportions and areas of the various parts of a forward engine boost-glider and their relations to each other have great effect on its performance. For instance, front engine boost-glide designs operate best with a wing area between 20 and 40 square inches. Less area results in high wing loadings and a rapid descent, while more area results in excessive drag and susceptibility to warping. The balsa impinge boom must not be too short, or a loss of stability results, while too much length adds weight. The best length is between 0.9 and 1.1 times the wing span. The area of the horizontal stabilizer would not fall below 30% of the wing area when zero-incidence airfoiled wings are used, but areas over 40% add excessive weight and drag. The rudder area, including stabilizer tip plates (if any) should generally be between 8% and 15% of the wing area, since less are results in loss control and more in unnecessary drag. As the rudder is normally below the empennage boom to avoid the exhaust gases, a large one will also reduce roll stability and may result in spiral diving. There is a wide range of usable dihedral angles for wings. Values between 0° and 28° have been used successfully. Best results come between 4° and 16°. In this range the dihedral does its job of increasing roll stability without any shortcoming.

Fig. 6   Basic Airfoil Types

Flat bottom

Undercambered

Convex-concave
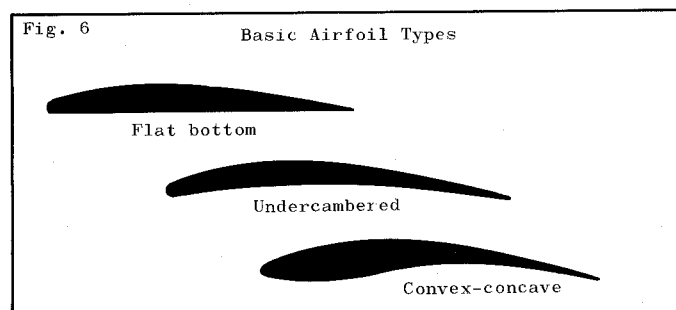
Front engine gliders can usually use higher aspect ratios than rear engine models (normally up to 4.5) with the upper limit imposed by structural requirements. Taper ratio (fig. 8) should be between 0.3 and 0.6. Lower ratios reduce roll stability and higher ones are subject to structural limitations. There is a wide variation allowable in the selection of sweep angle. Successful models have been built with sweeps from 15° to 55°, but the best compromise between structural and aerodynamic requirements lies between 40° and 45°. The sweep of the wing (within certain limits) increases the effectiveness of dihedral.

Fig. 7   Determining ASPECT-RATIO $AR = \dfrac{Maximum\ Span}{Average\ Chord}$

For Wings of Constant Taper $AR = \dfrac{D3}{\frac{D1 + D2}{2}}$

For Wings of Irregular Taper $AR = \dfrac{D4}{\frac{D1+D2+D3}{3}}$
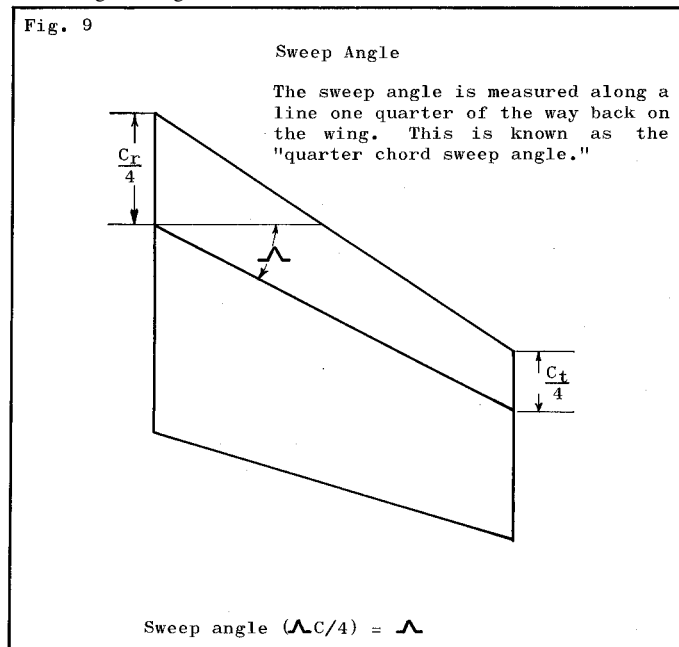
ESTES

A final item to consider with forward engine designs is wing loading. This is the factor which, along with the highlift/drag ratio, helps explain the superior performance of a well-designed front engine glider. The average loading for a forward engine model is between 0.17 and 0.3 pounds per square foot as compared with 0.25 to 0.7 for most rear engine designs. Loadings higher than these result in rapid descent and short duration, while lower ones raise doubts as to structural strength.

Fig. 8   Taper Ratio

Taper ratio $(\lambda) = C_t \div C_r$

The taper ratio is the length of the wing tip divided by the length of the root.

C_r

C_t

Structural Considerations

Structural considerations as limiting factors for aspect ratio, wing loading, etc. have already been discussed. Some other criteria specific to front engine designs also deserve mention, including wing structure. There are two basic types of wing construction: sold and built-up. The first is the common sheet balsa wing with a sanded-in airfoil and the second is a framework of ribs and spars with a covering of silk or treated paper such as "silkspan". In large model airplanes, the built-up wing is used almost exclusively since it offers a considerable savings in weight.

Fig. 9

Sweep Angle

The sweep angle is measured along a line one quarter of the way back on the wing. This is known as the "quarter chord sweep angle."

$\dfrac{C_r}{4}$

Λ

$\dfrac{C_t}{4}$

Sweep angle $(\Lambda C/4) = \Lambda$

The advantage of the built-up wing, however, is not so great on the boost-glider as the actual weight saving often amounts to only a few tenths of a gram. The difference in wing loading between solid and built-up versions is usually negligible and the built-up wing is worth the extra effort only when the most exacting requirements are enforced. Even here the builder must choose his rib and spar arrangement carefully or he may actually exceed the weight of a solid wing.

In selecting an empennage boom, the builder must consider the forces produced by the stabilizer and rudder as well as the likely accelerative loadings. For most models, boom cross sections of from 1/4" square to 1/4" by 1/2" are adequate. A "T" shaped cross-section made up of 1/8" or 1/16" sheet balsa often gives more strength with less weight than a solid boom.


Fig. 10

Simple type of Built-Up Wing (Single Spar)
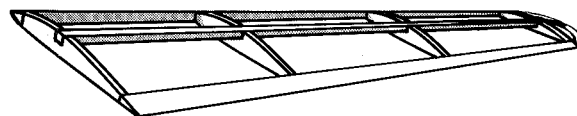
From a structural standpoint the standard tail configuration of a horizontal stabilizer with a single sub-rudder (and sometimes small tip plates) is best. A "V" shaped, or butterfly, tail has produced a good glide but is more apt to break and tends to catch the firing clips during launch. This tendency is also present with standard tails, but can be combated by mounting the firing leads on a short length of dowel or rod about three inches from the launch rod. The clips will then fall to a position along the "gantry" rod rather than vertically along the launch rod.

Fig. 11   Wing Angles

Dihedral

Three-Panel Polyhedral

Four-Panel Polyhedral
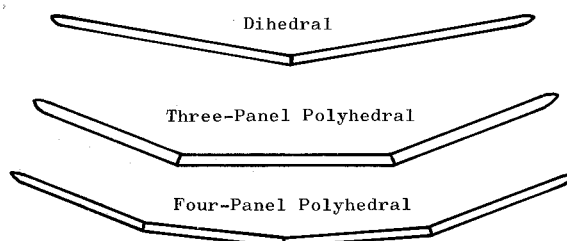
The best height for the engine pod pylon is approximately a half-inch. Higher pylons are weaker and result in greater nose down moment during boost. Lower pylons generally result in exhaust damage to the empennage boom and tail structure. It is helpful to have the pylon angled as far forward as possible to increase both aerodynamic and trailing-member stability; the maximum forward sweep, however, is limited to an angle of 15° or more with the longitudinal axis. Less angle results in engine damage to the pylon trailing edge and often in a nose heavy configuration. Pylon angles of 30° to 45° are generally best.

Structural strength could impose an upper limit on wing dihedral, but in practice this limit need not be considered as maximum aerodynamic efficiency is reached at a point well below the structural maximum. Polyhedral wings, however, will encounter difficulties if they are not sufficiently thick to resist warping caused by accelerative and aerodynamic loads on the wingtips.

Flying Practice

Front engine boost-gliders have been multi-staged with some success, the booster stage simply consisting of a length of body tube. However, stability is reduced, the stages are difficult to retrieve undamaged and the larger, multi-staged gliders often give shorter duration then small, light single stage vehicles.

One last structural requirement arises when it is not desirable to allow the engine to fall free following ejection. This requirement can be met by constructing the engine pod from a larger diameter body tube that is a glove-fit for the engine and taking up the added diameter with streamer material taped on the engine. A six to eight inch streamer may be used on the engine casing and will unroll from the engine after ejection.

Technical Note TN-1

MODEL ROCKET ENGINES

Engine Types and Classification

All engines sold by Estes Industries are stamped with a code designation which, when understood, will give the rocketeer important and useful data on the engine's performance capabilities. Here's how to read this coding: (refer to engine illustration).

Engine Coding for Quick-N-Easy Identification

1. **Label color indicates recommended use of the engine.**
   a. Green - Single Stage Rockets
   b. Purple - Upper stage or single stage for very light rockets.
   c. Red - Booster and intermediate stages of multi-stage models.
2. **Code designation stamped on the engine gives useful and important information on its performance capabilities.**
   a. This portion indicates total impulse or total power produced by the engine.
   b. This portion shows the engine's average thrust in newtons and helps you choose the right engine for your rocket's flight.
   c. This number gives you the delay in seconds between burnout and ejection charge. Lets you choose the engine with the delay time you want for any flight.

Igniters and complete instructions are included with Estes engines.

B6-2 SINGLE STAGE
TYPE AND PRMARY USE

HOW HIGH WILL YOUR MODEL GO? The chart below shows the approximate altitudes that can be achieved with single stage rockets.

TOTAL IMPULSE CLASSIFICATION

Code	pound-seconds	newton-seconds
1/4A		0.00-0.625
1/2A	0.14-0.28	0.625-1.25
A	0.28-0.56	1.25-2.50
B	0.56-1.12	2.50-5.00
C	1.12-2.24	5.00-10.00
D	2.24-5.00	10.00-20.00

Engine Size	Altitude Range (depending on rocket size and weight)	Approximate Altitude in a typical 1 oz. model
1/4A3-2	50' to 150'	100'
1/2A6-2	100' to 400'	190'
A8-3	200' to 650'	450'
B6-4	300' to 1000'	750'
C6-5	350' to 1500'	1000'

(Some high performance models will reach higher altitudes than shown above.)

MINI-ENGINE SELECTION CHART

Cat. No. & Engine Type	Total Impulse lb.-sec.[1]	n.-sec.[2]	Time Delay (± 15%)	Maximum Lift-off Weight	Maximum Thrust	Thrust	Initial Weight oz.	g.	Propellant Weight oz.	g.
SINGLE STAGE ENGINES										
1/4A3-2T	0.14	0.625	2 sec.	1 oz.	23 oz.	0.18 sec.	0.173	4.9	0.031	0.88
1/2A3-2T	0.28	1.25	2 sec.	2 oz.	28 oz.	0.36 sec.	0.198	5.6	0.062	1.75
A3-2T	0.56	2.50	2 sec.	3 oz.	28 oz.	0.86 sec.	0.254	7.2	0.124	3.50
A3-4T	0.56	2.50	4 sec.	2 oz.	28 oz.	0.86 sec.	0.268	7.6	0.124	3.50
A10-3T	0.56	2.50	3 sec.	5 oz.	48 oz.	0.26 sec.	0.277	7.9	0.133	3.78
UPPER STAGE ENGINES*										
1/4A3-4T	0.14	0.625	4 sec.	0.75 oz.	23 oz.	0.18 sec.	0.187	5.3	0.031	0.88
1/2A3-4T	0.28	1.25	4 sec.	1.00 oz.	28 oz.	0.36 sec.	0.212	6.0	0.062	1.75
A3-6T	0.56	2.50	6 sec.	1.25 oz.	28 oz.	0.86 sec.	0.282	6.0	0.124	3.50
BOOSTER ENGINES										
1/2A3-0T	0.28	1.25	none	3.50 oz.	28 oz.	0.36 sec.	0.166	4.7	0.062	1.75
A3-0T	0.56	2.50	none	3.50 oz.	28 oz.	0.86 sec.	0.226	6.4	0.124	3.50
A10-0T	0.56	2.50	none	5 oz.	48 oz.	0.26 sec.	0.235	6.7	0.133	3.78

Each pack of 4 engines includes 4 igniters. Designed for specific launch and flight functions, rocket engines are expendable — not reusable.

*Or single stage engines if used in very light rockets.
Shipping Wt. for mini-engine is 2½ oz. for a pack of 4.
Mini-engines are 1.75 in. long and 0.500 in. dia.

ROCKET ENGINE SELECTION CHART

Cat. No. & Engine Type	Total Impulse lb.-sec.[1]	n.-sec.[2]	Time Delay (± 15%)	Maximum Lift-off Weight with Engine	Maximum Thrust	Thrust Duration	Initial Weight oz.	g.	Propellant Weight oz.	g.
SINGLE STAGE ENGINES					**GREEN LABEL**					
1/2A6-2	0.28	1.25	2 sec.	2.5 oz.	46 oz.	0.20 sec.	0.53	15.0	0.055	1.56
A8-3	0.56	2.50	3 sec.	4.0 oz.	48 oz.	0.32 sec.	0.57	16.2	0.110	3.12
B4-2	1.12	5.00	2 sec.	4.0 oz.	48 oz.	1.20 sec.	0.70	19.8	0.294	8.33
B4-4	1.12	5.00	4 sec.	3.5 oz.	48 oz.	1.20 sec.	0.74	21.0	0.294	8.33
B6-2	1.12	5.00	2 sec.	4.5 oz.	48 oz.	0.83 sec.	0.68	19.3	0.220	6.24
B6-4	1.12	5.00	4 sec.	4.0 oz.	48 oz.	0.83 sec.	0.71	20.1	0.220	6.24
B8-5	1.12	5.00	5 sec.	5.0 oz.	5 lb.	0.60 sec.	0.68	19.3	0.220	6.24
C5-3	2.25	10.00	3 sec.	8.0 oz.	5 lb.	2.10 sec.	0.90	25.5	0.450	12.70
C6-3	2.25	10.00	3 sec.	4.0 oz.	48 oz.	1.70 sec.	0.88	24.9	0.440	12.48
C6-5	2.25	10.00	5 sec.	4.0 oz.	48 oz.	1.70 sec.	0.91	25.8	0.440	12.48
UPPER STAGE ENGINES[3]					**PURPLE OR BLUE LABEL**					
1/2A6-4	0.28	1.25	4 sec.	1.0 oz.	46 oz.	0.20 sec.	0.54	15.3	0.055	1.56
A8-5	0.56	2.50	5 sec.	2.0 oz.	48 oz.	0.32 sec.	0.62	17.6	0.110	3.12
B4-6	1.12	5.00	6 sec.	1.5 oz.	48 oz.	1.20 sec.	0.78	22.1	0.294	8.33
B6-6	1.12	5.00	6 sec.	2.0 oz.	48 oz.	0.83 sec.	0.78	22.1	0.220	6.24
B8-7	1.12	5.00	7 sec.	2.5 oz.	5 lb.	0.60 sec.	0.72	20.4	0.220	6.24
C6-7	2.25	10.00	7 sec.	2.5 oz.	48 oz.	1.70 sec.	0.95	26.9	0.440	12.48
BOOSTER ENGINES					**RED LABEL**					
A8-0	0.56	2.50	none	4.0 oz.	48 oz.	0.30 sec.	0.51	14.2	0.110	3.12
B6-0	1.12	5.00	none	4.0 oz.	48 oz.	0.80 sec.	0.58	16.4	0.220	6.24
B8-0	1.12	5.00	none	6.0 oz.	5 lb.	0.60 sec.	0.60	17.0	0.220	6.24
C6-0	2.25	10.00	none	4.0 oz.	48 oz.	1.68 sec.	0.80	22.7	0.440	12.48

Shipping wt. of each package is approximately 4 oz. Each package of 3 engines includes 3 igniters.

MIGHTY "D" ENGINE SELECTION CHART

Cat. No. & Engine Type	Total Impulse lb.-sec.[1]	n.-sec.[2]	Time Delay (± 15%)	Maximum Lift-off Weight with Engine	Maximum Thrust	Thrust Duration	Initial Weight oz.	g.	Propellant Weight oz.	g.	Recommended Use
D12-0	4.49	20.00	none	14.0 oz.	6.3 lb.	1.70 sec.	1.44	40.9	0.879	24.93	Booster Engine
D12-3	4.49	20.00	3 sec.	14.0 oz.	6.3 lb.	1.70 sec.	1.49	42.2	0.879	24.93	Single Stage
D12-5	4.49	20.00	5 sec.	10.0 oz.	6.3 lb.	1.70 sec.	1.52	43.1	0.879	24.93	Single Stage
D12-7	4.49	20.00	7 sec.	8.0 oz.	6.3 lb.	1.70 sec.	1.55	44.0	0.879	24.93	Single or Upper

Shipping wt. of each engine is approximately 2-1/3 oz.

D engines are 2.75 in. long and 0.945 in. dia.

NOTES:

Complete instructions and igniters (2301) are included with each rocket engine ordered from Estes Industries.

Regular engines are 2.75 in. long and 0.690 in. diameter.

[1]pound-seconds. (Figures shown are maximum.)
[2]newton-seconds (Figures shown are maximum.)

[3]OR Single stage engines if used in very light rockets.

ESTES

ROCKET ENGINE DESIGN

The Series 1 and Mini-engines (T Series) engines are a solid propellant type with a dual thrust level design. There is a slight center bore at the very tip of the nozzle end of the propellant grain which serves two purposes. First, it provides for easy ignition. Second, as you will note from the thrust curves, this special design produces a high initial thrust which accelerates the rocket to a suitable flying speed quickly. This is because the slight center bore provides a relatively large burning area, resulting in faster consumption of the fuel.
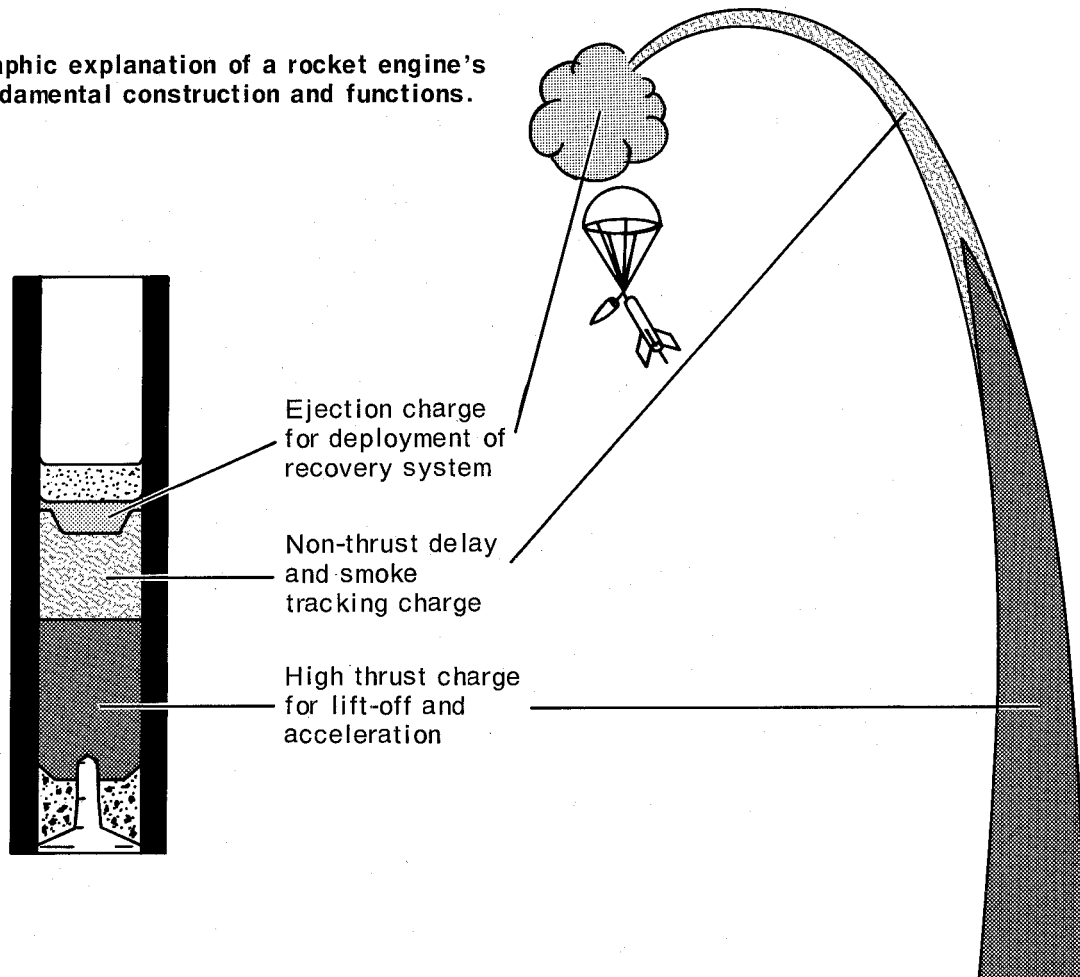
After this initial high thrust, a transition to an end burning grain is made, and the thrust drops to a sustained level (except on low total impulse engines which burn out by this time). Data from wind tunnel tests shows that dual thrust level to be the most effective design for rocket engines which are used to propel lightweight model rock-ets at subsonic speeds.

The slow-burning delay and tracking charge is ignited at the burnout of the propellant grain. This slow-burning, smoke-producing charge provides no thrust, but permits the rocket to coast upward to its peak altitude. At the burnout of the delay charge a recovery system ejection charge is ignited which pressurizes the forward end of the rocket body tube, activating the recovery system. For further information, see the performance graphs and cutaway drawings.

The B8- engines have a modified center-burning grain. This provides a greater propellant burning area than engines of the same total impulse but which are end burning. The larger burning area provides a higher initial thrust level but a short thrust duration. The B8- engines are especially useful for high acceleration studies, as boosters on heavier rockets and for drag races.
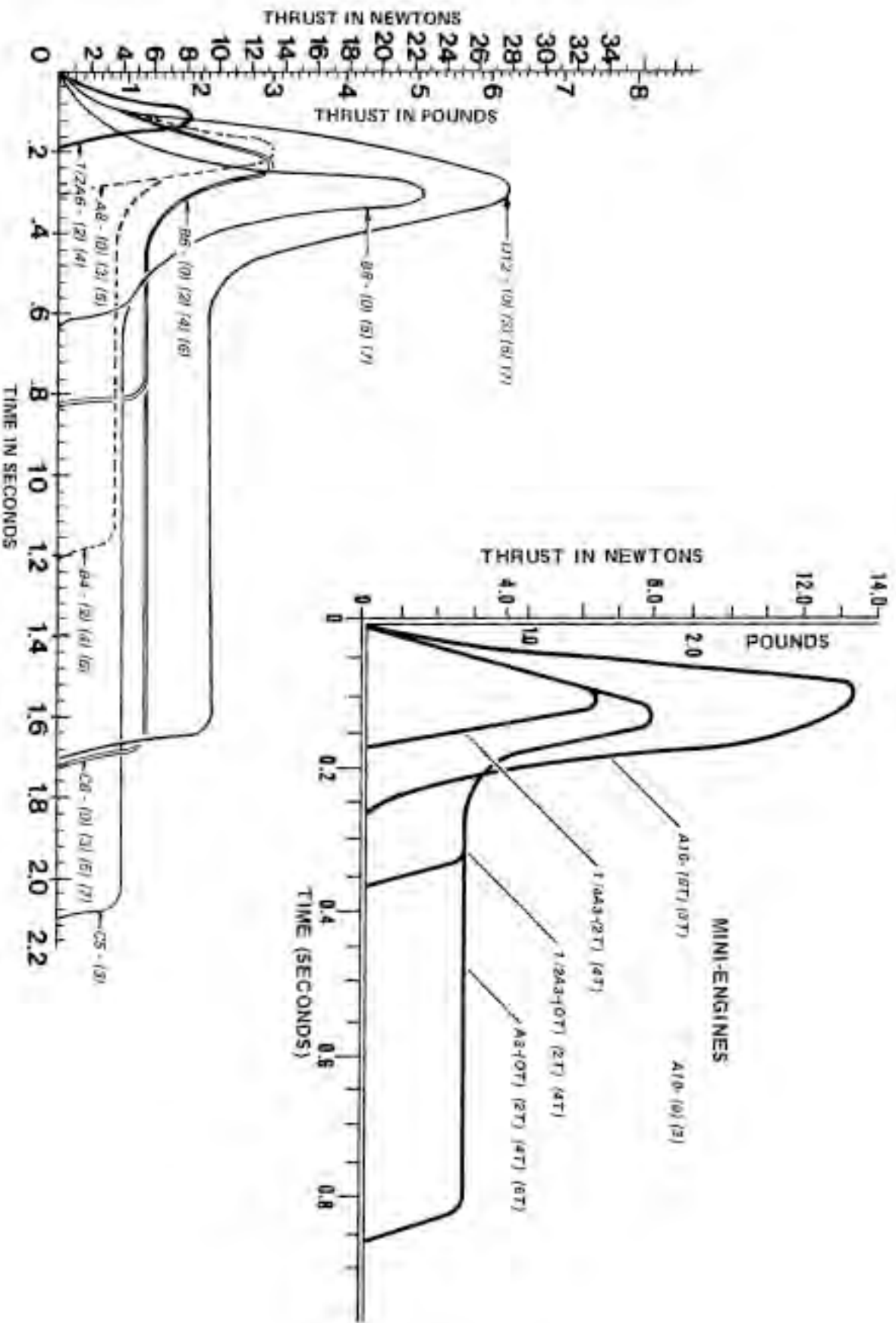
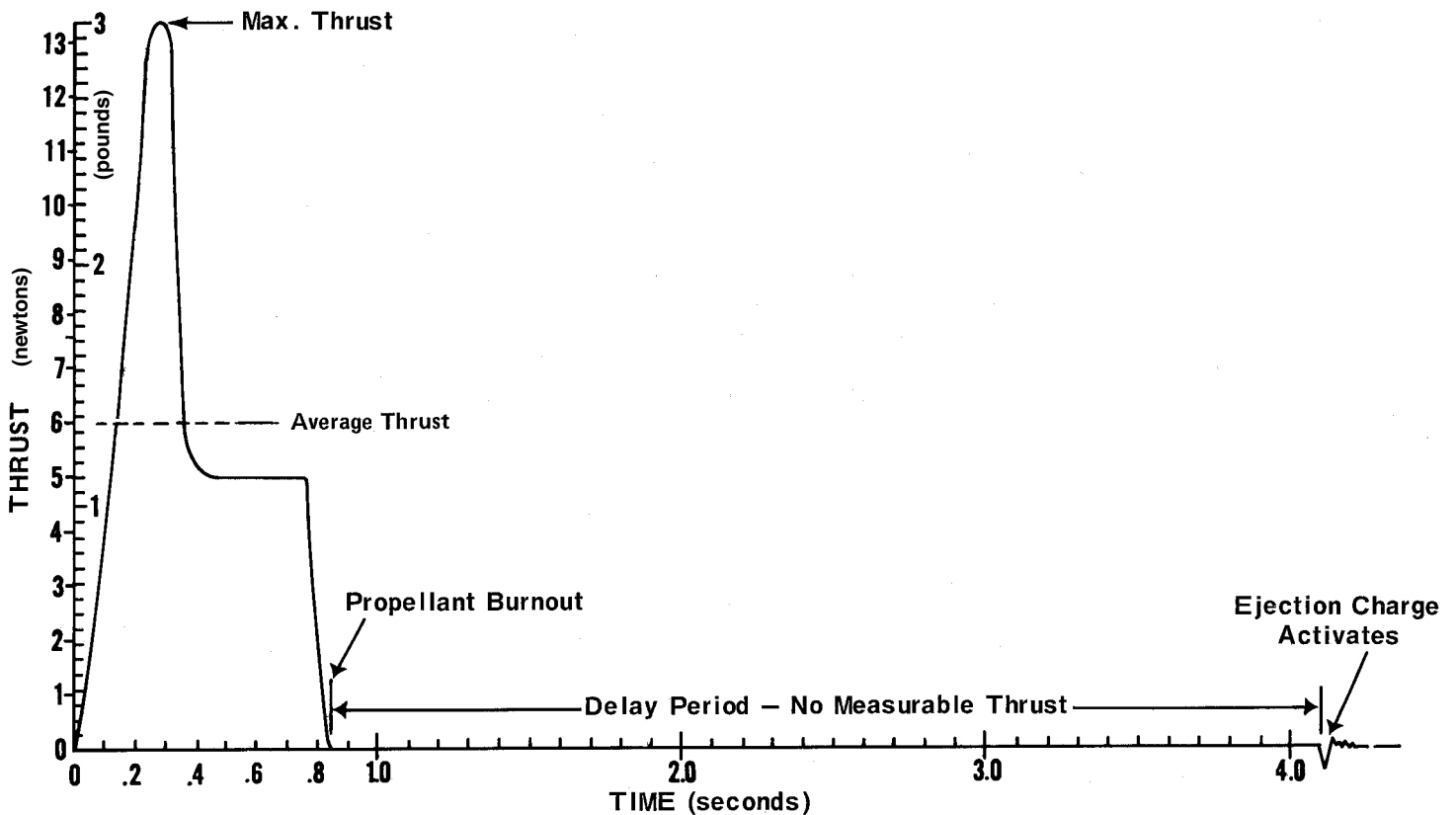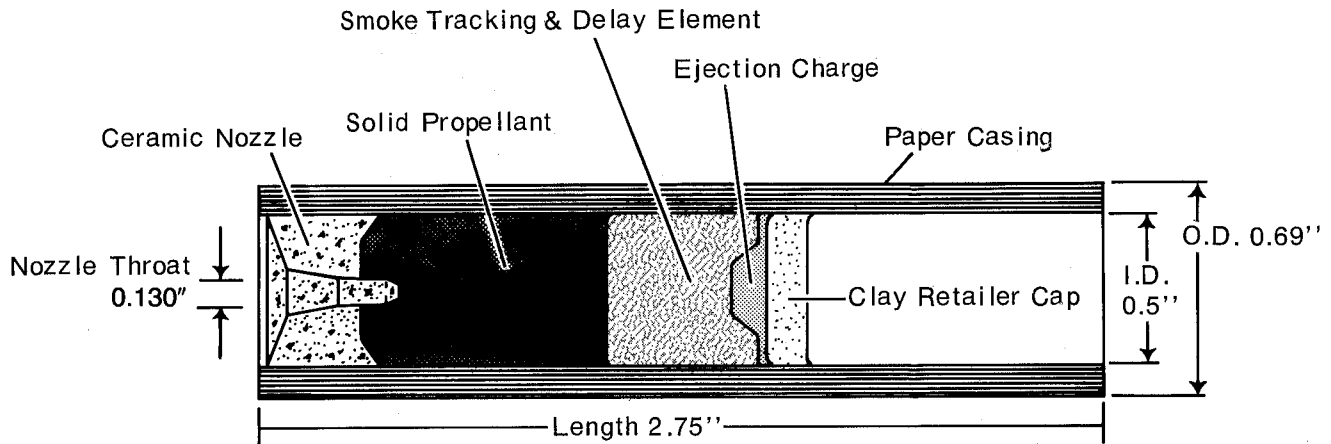Graphic explanation of a rocket engine's fundamental construction and functions.

Ejection charge for deployment of recovery system

Non-thrust delay and smoke tracking charge

High thrust charge for lift-off and acceleration

COMPARATIVE TIME/THRUST CURVES

TYPICAL TIME/THRUST CURVE
OF B6-4 SERIES I

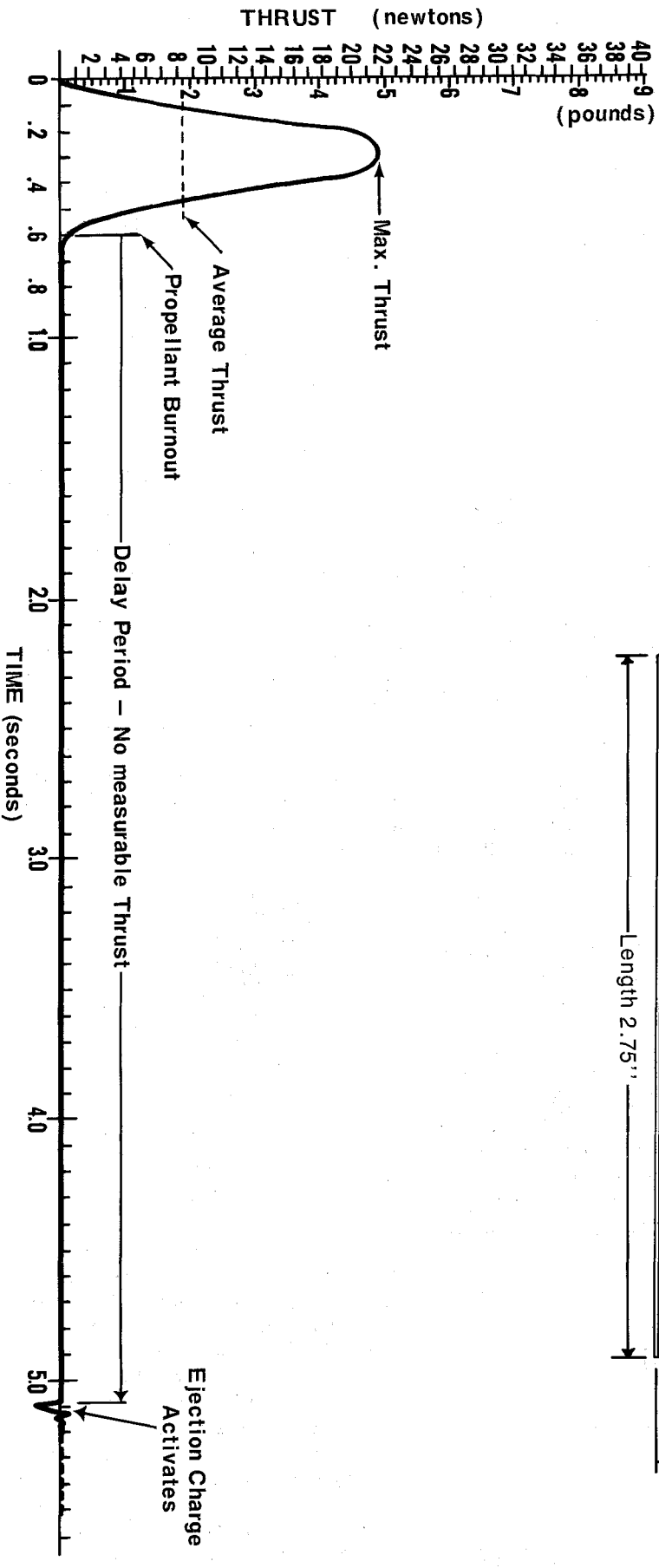**Specific Impulse — 80-83 lb.-sec. per lb.**
Exhaust Velocity — 2550-2650 ft./sec.

Smoke Tracking & Delay Element

Ejection Charge

Ceramic Nozzle   Solid Propellant   Paper Casing

Nozzle Throat
0.130"

O.D. 0.69"

I.D.
0.5"

Clay Retailer Cap

Length 2.75"

THRUST (newtons)   (pounds)

Max. Thrust

Average Thrust

Propellant Burnout

Ejection Charge
Activates

Delay Period — No Measurable Thrust

TIME (seconds)

32

TYPICAL TIME/THRUST CURVE
B8-5   SERIES II

Exhaust Velocity — 2550-2650 ft./sec.
Specific Impulse — 80-83 lb.-sec. per lb.

THRUST   (newtons)

(pounds)

Max. Thrust

Average Thrust

Propellant Burnout

Delay Period — No measurable Thrust

Ejection Charge
Activates

TIME (seconds)

Nozzle Throat
0.140"

Centerbore

Ceramic Nozzle

Paper Casing

Solid Propellant

Smoke Tracking &
Delay Element

Ejection Charge

Clay Retainer Cap

Length 2.75''

I.D.
0.5''

O.D. 0.69''
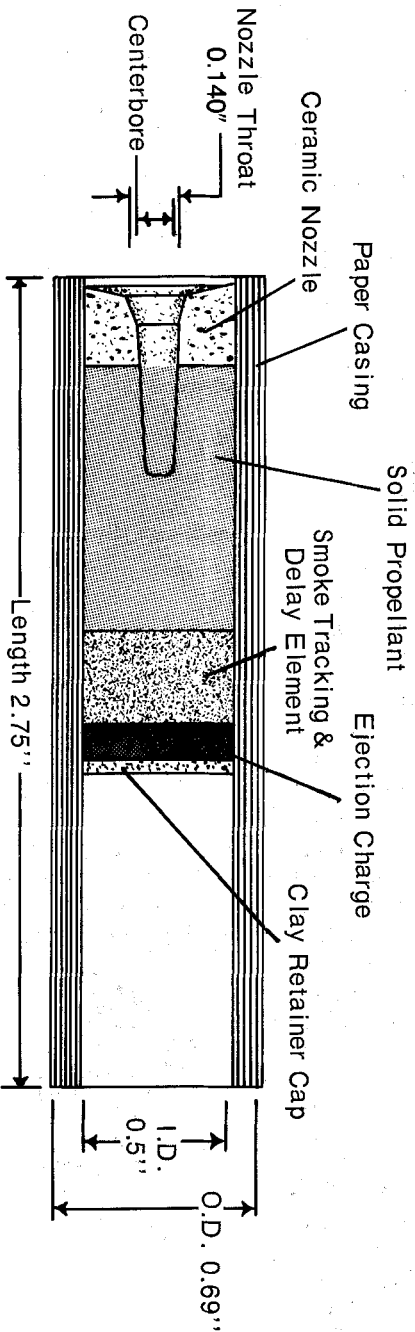
Technical Note TN-3

IS THAT PARACHUTE TOO BIG?

By Robert L. Cannon

Recovery systems have one function - the safe return of the model rocket. The rocketeer has a choice of several recovery systems, the most popular of which is parachute recovery.


Featherweight Recovery

Parachute Recovery

Tumble Recovery

Helicopter Recovery

Streamer Recovery
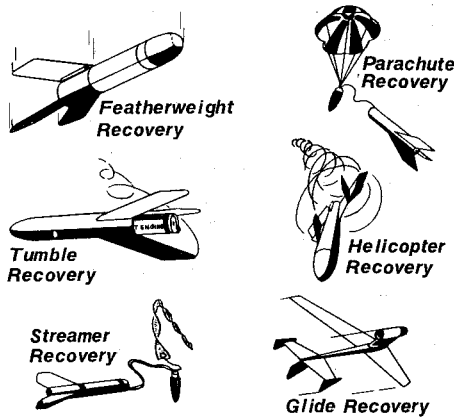
Glide Recovery

Regardless of the recovery system chosen, it must let the rocket fall back to the ground gently. To accomplish this the rocket must not undergo "free fall". A lightweight model rocket of balsa and cardboard can fall fairly rapidly. The streamlined shape of the rocket permits it to fall at close to the maximum possible acceleration for a body falling freely through the air. This rate of acceleration is 32 feet per second per second. This means that an object will be falling 32 feet per second faster at the end of each second than it was falling at the start of that second. The actual maximum velocity a freely falling body can reach is called its terminal velocity. This velocity is less than the theoretically possible velocity because the air through which it is falling slows down the rocket, just as it slowed the rocket's powered flight. This drag slows the rocket's movements.

Various devices are used to increase the effect of this aerodynamic drag so that the rocket falls very slowly. The greater the drag for a given weight, the slower the rocket falls. Too little drag could let the rocket fall fast enough to be damaged on impact. With too much drag, a breeze may cause your model to drift a great distance downwind before it returns to the ground.

The higher your rocket is at apogee, the longer it will take to return with a parachute of a specific size. The bigger the parachute, the longer the rocket will stay in the air. If you consistently launch your rockets to high altitudes or if you live in a windy area, having too much parachute can be a big problem! There are several ways of letting your rockets fall faster yet still be safely recovered by parachute.

One simple way to reduce the drag a parachute creates is to "reef in" the shroud lines. This is done by effectively shortening the shroud lines to keep the parachute from coming fully open. This can be done by "shortening" the shroud lines with masking


Masking tape
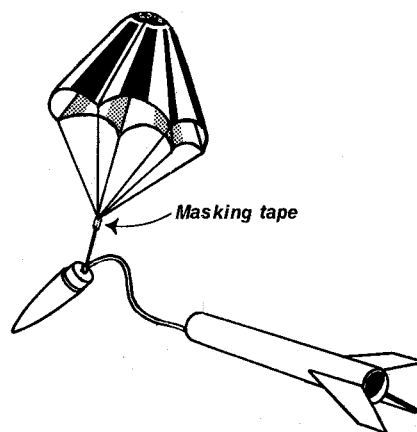
tape or a piece of string.

Another method of reducing the drag caused by a parachute is to cut a circular hole out of the center of the 'chute. Experiment to determine the best size of hole for the parachute in the rocket you are using. Start with a small hole and slowly enlarge it until the rocket falls fast enough so it doesn't drift far, yet slowly enough to be recovered safely. Be careful so that the hole is always round and has no sharp edges. The shock of opening can exert tremendous force on the parachute so any cut or sharp corner can rip under the stress.

Of course, you can speed the descent of your rocket by selecting a smaller-sized parachute. This is very easy if a snap swivel is attached to
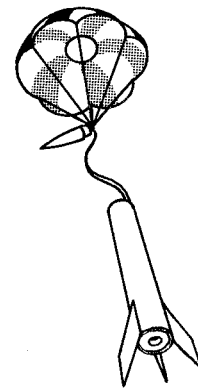
each of your parachutes. Pre-test the size of the parachute for safe recovery by hand-tossing the model into the air with the parachute hand-wadded but outside the body tube or by dropping the rocket with the parachute unfurled from a high elevation, such as a second or third floor window.

Streamers can also be used. Test carefully since streamers work best on very light weight-models.

Technical Note TN-4

THE FINE ART OF PAYLOAD LAUNCHING

Whatever Goes Up…

by Robert L. Cannon

Why do you launch model rockets?
Is it for fun? Sure it is! But is that all there is to it?

Probably not. If all you want to do is see your rocket go up and then come back safely so you can launch it again, you are in the minority among model rocketeers. Most modelers want to know why things happen and how to make them happen. Specifically, they want to make the best rockets they can.

Once the model rocketry bug has taken a firm bite on you, you soon become involved in center of gravity-center of pressure relationships, fin area experiments, weight-optimizing problems and other previously abstract studies.

One of the first challenges you set for yourself is probably to get your rocket the highest with a given size of engine.

After you become proficient at reaching high altitudes, the parachute-duration fever may become "your" disease. After winning a few (meets) and losing a few (birds), you will probably want something else with which to test yourself. The payload passion may be your next mania.

Why is something put in a rocket before the rocket is launched? The professional may be sending up an instrument package to secure data on the atmosphere. The payload may be a scientific satellite to study Earth or to secure information on stars. Some payloads are spacecraft whose missions are to study other planets. Occasionally, a rocket carries men on a mission to the moon.
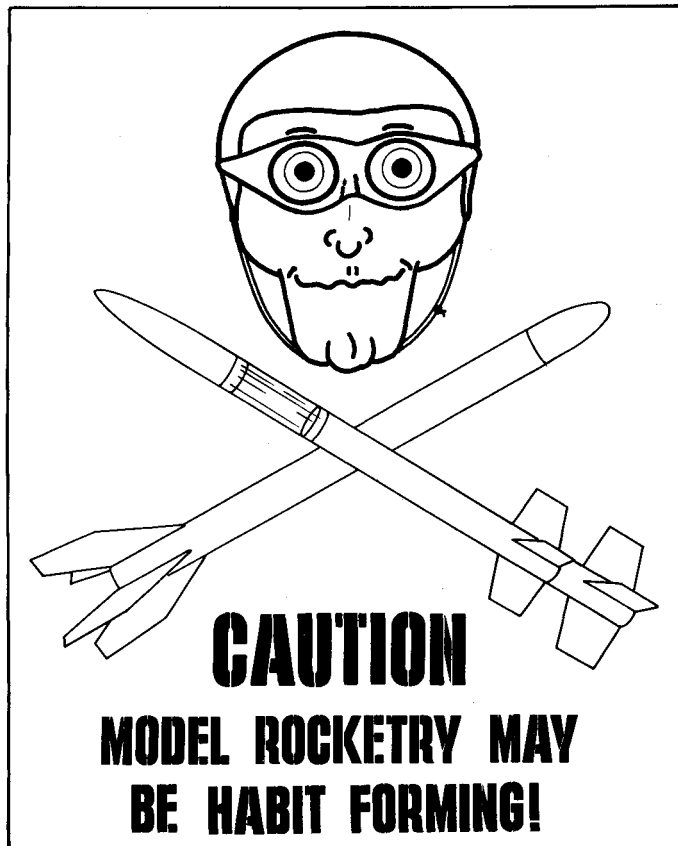
You realize right away that a model rocket is not designed for orbital missions. In fact, you don't want your rocket to get far enough away to even stand a strong chance of losing it!

The question keeps re-occurring - "What can I launch?" It need not be anything scientific. The payload plague has struck and you are now past all chance of avoiding it. Your only hope now is to control the course of the disease.

You notice your hand twitches uncontrollably. After nearly every twitch, it is holding some small object. Compulsively you heft the object to get an idea of its weight. Your eyes squint as they calculate the size of payload compartment the object will require. Your arm jerks as you estimate whether the g-forces of take-off will damage the object.

SPECIMEN	WEIGHT (Typical) in grams & oz.	LENGTH (Typical) in mm & inches	WIDTH (Typical) in mm & inches
Grade A large chicken's egg	64 grams 2.25 oz.	70 mm 2.8 in.	50 mm 2.0 in.
Grade A small chicken's egg	58 grams 2.04 oz.	57 mm 2.25 in.	40 mm 1.5 in.
Grasshopper	2 grams 0.07 oz.	37 mm 1.5 in.	10 mm 0.4 in.
Fly	0.25 grams 0.01 oz.	10 mm 0.4 in.	5 mm 0.2 in.
Spider	0.25 grams 0.01 oz.	10 mm 0.4 in.	3 mm 0.1 in.
Earthworm	4 grams 0.14 oz.	64 mm 2.5 in.	3 mm 0.1 in.
Beetle	0.5 grams 0.02 oz.	25 mm 1.0 in.	5 mm 0.2 in.
Cricket	0.3 grams 0.01 oz.	25 mm 1.0 in.	7 mm 0.3 in.
Guppy	0.5 grams 0.02 oz.	37 mm 1.5 in.	10 mm 0.4 in.

Pretty soon a compulsion strikes. The object in your hand has got to go! Maybe you will launch it tomorrow, maybe it can't wait. The blue sky beckons, and the rocket awaits!

Soon you have several "space launches" behind you. Most of them were pretty good, I hope. Did you lose any payloads because the nose cone wasn't tight enough on the payload compartment? Did any
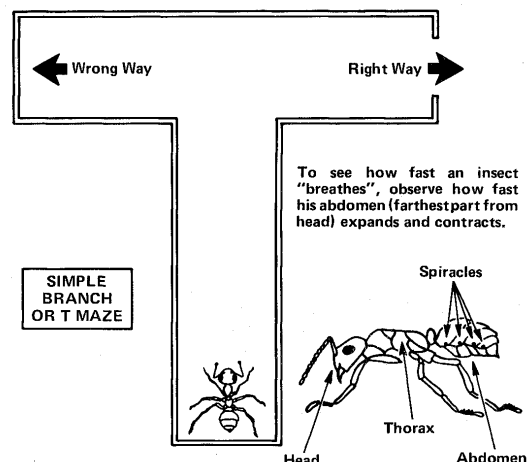
payloads, complete with rocket, make an unexpected swift re-entry with a very compact parachute (rolled too tightly, stuck in the body tube or just plain melted)? Did a "Rocketus eatumupus" manage to snag one as it drifted past?

At this point you probably begin to lose interest in launching payloads. Don't! Payload launching can be very worthwhile and can be a lot of fun for a long period of time. After your first few launches of rocks, payload weights and handy insects, you can really get down to serious payloading.

For performance tests of your "bird", launches of official payload weights are hard to beat. (Official one ounce payload weight, PL-1). Careful selection of the best engine for the mission, proper construction of that special payloader and precise packaging of the payload weights are all important parts of the game before you push that button to launch your bird for the official tracked flight.

If you feel the desire to launch a small biological payload, do so with care. Wasps and bees make compact passengers for all but the very smallest payload compartments. However . . .

Cat. No.	Body Mat'l.	Fits	Inside Dia.	Inside Length	Overall Length	Wt. in oz. Net	Ship
PS-20A	Clear Plastic	BT 20	.710"	2"	4.00"	.16	1
PS-20C	Clear Plastic	BT 20	.950"	3"	7.00"	.40	4
PS-30B	Regular Tube	BT 30	.725"	2"	3.75"	.24	1
PS-50A	Clear Plastic	BT 50	.950"	3"	6.50"	.39	4
PS-50C	Clear Plastic	BT 50	1.59"	4"	10.50"	1.00	11
PS-50E	Clear Plastic	BT 50	1.75"	4"	10.50"	1.10	11
PS-55B	Regular Tube	BT 55	1.28"	3"	7.63"	.53	11
PS-60A	Clear Plastic	BT 60	1.59"	4"	9.50"	.98	11
PS-60C	Clear Plastic	BT 60	1.75"	4"	9.50"	1.00	11

Payload sections include nose cone, body tube, adapter or bulk head.

Wrong Way   Right Way

SIMPLE BRANCH OR T MAZE

To see how fast an insect "breathes", observe how fast his abdomen (farthest part from head) expands and contracts.

Spiracles

Thorax

Head   Abdomen

ESTES

Crickets, grasshoppers and flies may be launched. Even if you goof, these creatures stand an excellent chance of surviving an error on your part. But don't launch them and recover them and expect to learn much by just looking at them. Some rocketeers "train" their passengers to do a simple one-branch maze or something similar, then test their reactions after flight. The results won't mean much if the specimen was damaged by poor handling or packaging in the payload compartment. Another problem can be that the effects you attribute to the g-forces experienced on the flight may be caused instead by a shortage of air in a too-small payload capsule.

Insect launches are not likely to lead to the discovery of much valuable data, but they can be one step in becoming proficient in handling payloads. A well-designed experiment can provide meaningful research data on the effect of rocket flight on an insect.

When you feel that you are good at handling biological payloads, I mean really good, then don't launch a hamster or a mouse! It appears that about nine out of ten launches of live hamsters or mice end successfully. About every tenth launch, however, the passenger suffers serious injury or death due to a human error. It is about as kind to stomp the poor mouse to death as it is to let him die because of your mistake, and he probably won't be scared half-to-death for anywhere near as long. Also, it is against the Model Rocket Safety Code to launch anything other than insects.

To really test your biological payload handling capabilities, launch a chicken's egg. Use a raw one. (Hard-boiling is not fair.) If you can properly handle, package, launch and recover the egg in good condition, excellent! If not, you can always have scrambled eggs for breakfast. This, unfortunately, leaves the payload compartment of your rocket in a "yucky" condition. Place the egg in a ziplock bag to avoid this mess.

Launching and safely recovering a raw chicken's egg is not as easy as it sounds. If you think it is easy, just try it.

When you are ready to get into instrument payloads, you have a wide-open field.

Aerial photography is very exciting. Use the Estes AstroCam® 110 or AstroCam® RTF to take single exposure, color photographs of your selected area. Launching the AstroCam® to a high altitude lets the camera take a photograph of a very large area. Launch to lower elevation results in a photo in which a smaller area is photographed, but everything appears bigger.

HIGH ELEVATION SHOT

LOW ELEVATION SHOT

To make a photographic map of a very large area, a mosaic (composite made up of many small parts) is made of a number of different aerial photo-

graphs, each of which has been photographically enlarged or reduced so that the photos appear to have been taken from the same elevation. A project of this nature can be challenging, very rewarding and a lot of fun. An aerial map makes a great science project.

Instruments other than cameras may be launched. These instruments can be self-recording or may radio their data back to the ground by telemetry.

Working within the size and weight limitations of model rocketry and producing accurate scientific instruments is quite a challenge. A number of different instrument systems are possible. They need not be complex, but should be simple and able to withstand the forces encountered in model rocket flight.

TN-6
RECOVERY
TECHNIQUES

By Wayne Kellner

TN-6 Recovery Techniques

Finders, Keepers Part I

By Wayne Kellner

First installment in a three part technical report on model rocket recovery - techniques, types, and tips. In this article we look at a simple, but effective method for finding your rockets.

Before reading further, please check the appropriate box or boxes below.

☐ My last name is Bill Gates.
☐ My mailing address is Fort Knox, Kentucky.
☐ I just inherited $1,000,000 provided I spend it all on model rockets.
☐ None of the above.

If you checked one or more of the first three boxes, go out and buy some more rockets. This article is definitely not for you. But, if you're like me and thousands of other rocketeers, "a rocket found is a rocket earned" (apologies to Ben Franklin).

No rocketeer enjoys spending many hours building and finishing a super-nifty model only to lose it on its first flight. That's really grimsville. Perhaps you are about to launch an unusual payload or instrumented device. Or maybe you've just blown your life savings on a model rocket to land on Mars. Whatever the case, losing them to the Great Golden Chute Hook in the Sky can be expensive in time and materials. Well, don't despair, 'cause we're gonna lay some suggestions on your grey matter to help you find those rockets and possibly have more fun at the same time.

Line Search Method

The military "line search" method is the most reliable way to locate a rocket's exact touchdown location. Here's how it works. Before launching, you should know in which direction the wind will be drifting your bird during recovery.

Look for obvious wind direction signs such as movement of trees, tall grasses, or smoke. You might even wish to construct a simple wind direction indicator as shown
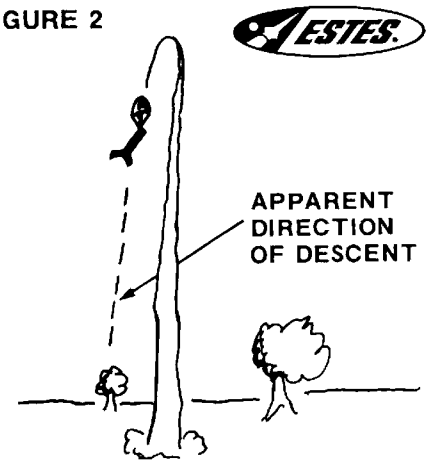
FIGURE 1
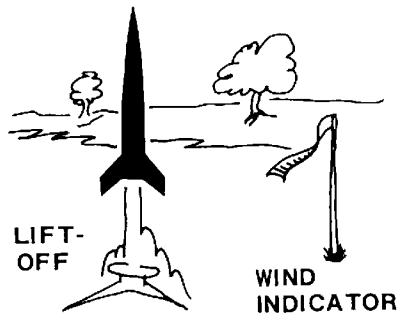
in Figure 1. Attach an 18" long, brightly colored crepe paper streamer to a 3-foot wooden dowel. Place this into the ground near your launch pad. The streamer will keep you constantly informed as to wind direction and speed.

Should you be launching multi-stage rockets or "D" powered birds, try flying a wind marker rocket first. It is not unusual for the wind to be traveling in different directions and speeds at various low altitudes. Select an Alpha-size rocket, preferably something you can afford to lose. Launch it with a B or C engine. Watch the rocket closely to get an idea of changes in winds aloft and recovery drift conditions for your flying site. Once you have flown the marker rocket you can determine exactly where to place your launch site. This will greatly increase your chances of keeping all rockets within your

FIGURE 2

APPARENT DIRECTION OF DESCENT

launch and recovery area. Then as in Figure 1, preflight and launch your rocket as usual.

Figure 2 shows the rocket's flight path to the point of parachute deployment. Watch it very closely now. Try to anticipate which direction it will be drifting as it nears the ground. As the rocket finally lands, select a prominent landmark as close to the point of touchdown as possible. This might be a tree, bush, telephone pole, fence post, outhouse, or oil well as shown in Figure 3. If there isn't any landmark close by, select something farther in the distance. The landmark must be in a straight line between you and the rocket.

Once you have chosen that landmark, DON'T take your eyeballs away for even a second. Keep them peepers glued right on and start walking. Walk as STRAIGHT a line as you can towards the landmark until reaching the rocket. Almost without exception, you will walk right up to it. Or, on top of it as I've done a couple of times. An Estes AstroCam® camera sure makes a funny sound as it is being stepped on!

Should your rocket land behind a hill or other obstacle, merely select a landmark where the rocket disappeared from view. Now, walk towards that point. If you reach the landmark without sighting the rocket, select a second landmark and continue

FIGURE 3

NEAREST LANDMARK
ROCKET LANDED HERE
WALK THIS LINE
WRONG
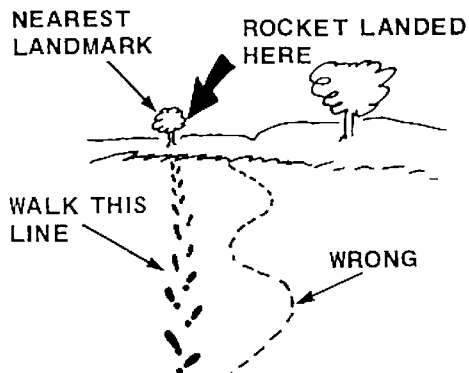
walking. The second landmark MUST also be in line with the direction you have been traveling. Continue walking until you locate the rocket.

Keep one additional thing in mind. Distances are very deceiving to the eye. Your rocket will always be a bit closer than you think. Our next article tells you how to find your way back to the launching site, so try not to get lost in the meantime!


NOW THAT'S THE FOURTH ROCKET I'VE LOST AROUND HERE THIS WEEK...
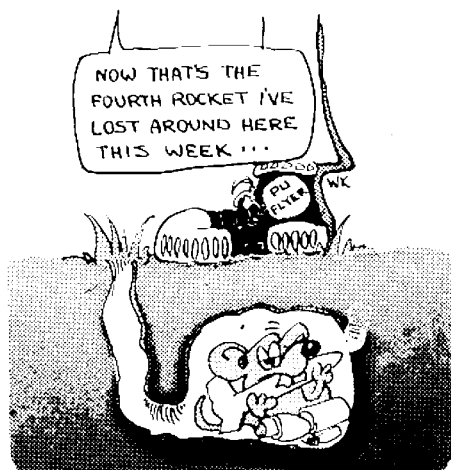
SUMMARY

Let's summarize briefly the line search recovery method:

☐ 1. Check wind direction to determine which way rocket will drift during recovery descent.

☐ 2. Pre-flight and launch in the normal manner.

☐ 3. Follow rocket carefully during recovery phase of flight.

☐ 4. Select a prominent landmark nearest the touchdown point.

☐ 5. Glue your eyes to that spot and walk as straight a line as possible towards the landmark until reaching your rocket.

☐ 6. An unusual crunching sound may be your rocket.

☐ 7. Happiness is finding your rocket.

Aw 'Chute'

Part II

By Wayne Kellner
Reprinted from Model Rocket News, Vol. 13, No. 3

NO, I THOUGHT YOU PACKED THE 'CHUTES
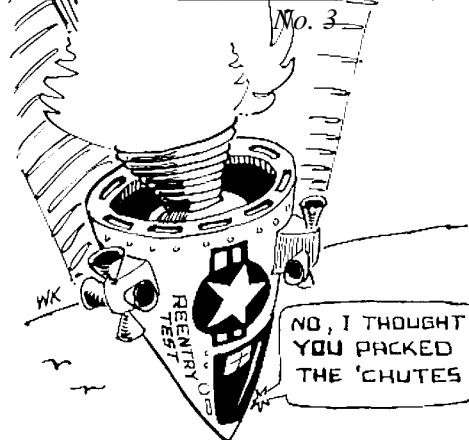
Second installment in a three part technical report on model rocket recovery - techniques, types, and tips. In this article we pass along a bagful of suggestions and tips on rocket tracking and parachute recovery techniques.

Now that I've got your attention, let's look at a few ideas to help you follow a rocket during its flight.

PAINTING

We will consider here primarily sport flying rockets, payload and contest rockets, or any bird where a specific paint scheme is not required.

First, examine your flying field. You will want to select a contrasting paint color which will make your rocket stand out from the recovery area background. Is the launch and recovery area rather dark in color - trees, bushes, green grass, etc? If so, paint the rocket a bright contrasting color such as white, yellow, or orange. When flying against a light background color, use a dark contrasting paint. Bright red, orange, perhaps even blue or black will show up well.

Obviously, for winter launching a white rocket would be somewhat difficult to locate in the snow. Or, for our Amazon friends, I wouldn't recommend flying green rockets. A bright red-orange fluorescent paint is best

for most flying conditions. This color is easy to follow during flight and especially easy to spot on the ground. For brightest and best results, always apply a fluorescent color over a white undercoat. Fluorescent paints are slightly transparent by themselves and

FIGURE 1

PAINT UPPER SURFACES FLUORESCENT
PAINT LOWER SURFACES BLACK
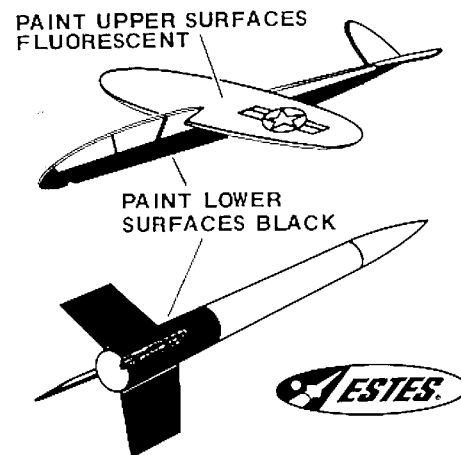
will allow wood grain or any dark base surface to show through.

Black, believe it or not, is the easiest color to follow during flight. Although it may not always be easy to spot on the ground, you might try the following idea. For gliders, paint all bottom surfaces black in order to help you follow it during flight. See Figure 1. Then paint all upper surfaces fluorescent orange so that you have a bright color to help locate the glider on the ground. For rockets, paint the lower 1/3 black, then paint the remainder of the rocket a fluorescent color. Why not experiment to determine which colors are best for your flying area?

A quick note here about weight. Paint adds weight to any bird, much more than you would imagine. The darker the color is, the more color pigment it has. Therefore, the darker the color the heavier the paint. If you are building a model which you wish to keep ultra-lightweight, finish it with white, yellow, or orange paint. A very light coat (or "dusting") of paint may be sufficient to color the model.

KEEP ON TRACKIN

Have you ever tried attaching shiny silver foil to your rocket? During flight, sunlight reflecting from the foil looks just like a bright blinking light. Especially for those "outasight" D-powered birds, the flashing foil will help you track the rocket clear to touchdown.

FIGURE 2

A LUMINIZED STREAMER MATERIAL
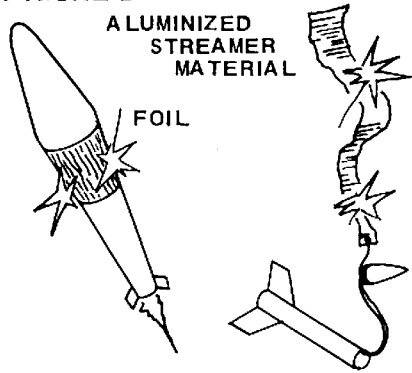
FOIL

Some rocketeers have even attached small foil streamers to the corners of their parachutes for added visibility. Whether you add model aircraft silver Monocote, chrome mylar foil, stick-on silver foil, or ordinary aluminum foil, make a neat job of it. You don't want unnecessary drag or loose corners affecting the rocket's stability. Double-sided sticky tape or contact cement work well for attaching aluminum foil. You might even try building an all-foil-covered research-looking rocket.

Now, for you "try anything once" rocketeers. Next time you're out at the flying field, put a small amount of

FIGURE 3

FOIL STREAMERS ADDED TO 'CHUTE

FOIL COVERED ROCKET
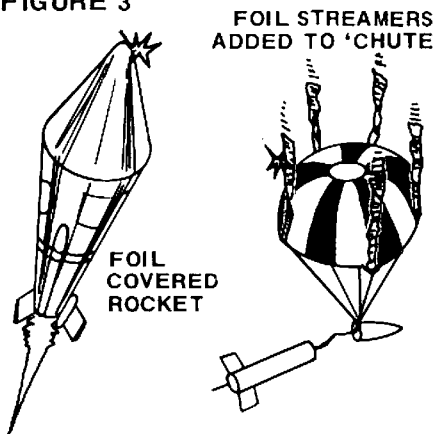
flour, talcum powder, or colored tempra powder paint into the rocket's parachute compartment. At ejection, the powder will quickly disperse into a small puff or cloud. This technique is often used at contests to give tracking stations a visual marker of a rocket's peak altitude. Pack your recovery wadding and parachute first. Then insert a square of wadding atop the parachute. Use more wadding for larger body tubes. This will prevent the powder from sifting down into the body tube. Add the powder and secure the nose cone. When launching against a clear blue sky, use a light colored powder. A dark color is easiest to

spot on an overcast or cloudy sky background. It is a fun technique, but be prepared to find your rocket a bit messy after a couple of flights.

When launching a multi-stage bird, everyone wants to watch the whole show. But after the launch, no one seems to know what happened to the booster stages. Always assign one person to watch the first stage, another to watch the second stage, and so on as in Figure 4. The same procedure should be used when a payload is recovered separately, or for those rockets which eject the engine or power pod. Then you will be sure to recover all portions of your rocket.

Flameproof recovery wadding is designed to protect your recovery sys-

FIGURE 4

ESTES

3RD STAGE

2ND STAGE

1ST STAGE
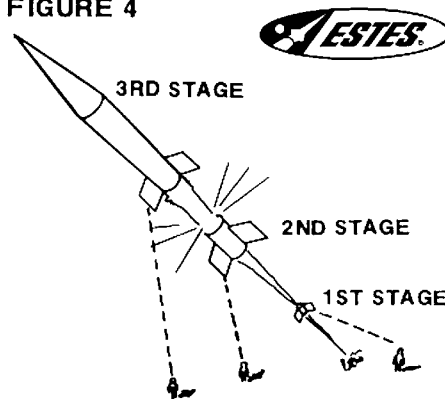
tem from the heat of the ejection charge. Always use enough wadding to fill the rocket body for a distance of 1-1/2 to 2 times the body diameter. Before launching, check each rocket's assembly instructions for the exact amount of wadding required. DO NOT pack it so tightly that it cannot be ejected. Loosely packed wadding works best. If your 'chute returns looking like Swiss cheese or a burnt shish kebob, then you're not using enough wadding. Be sure to wrap one end of the rocket engine with enough masking tape so that it makes a snug airtight seal in the engine tube. This will prevent leakage of ejection gases past the engine.

FIGURE 5

A   B
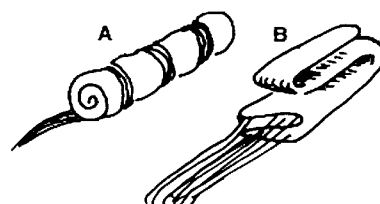
Considerable controversy still exists as to which is the best way to pack a parachute. Some prefer a

tightly rolled and wrapped 'chute as in Figure 5A. This method is good when you must pack a large parachute into a small space. A tightly wrapped parachute will however, take longer to open. Others prefer a loosely packed 'chute (B). Our observation and experience has been that the loosely packed (even sloppy) method gives the most reliable recovery. This is due to the ability of the loose edges and folds to catch the wind. The plastic material also has a tendency to "spring back" when loosely crumpled. Plastic 'chutes also have a special tendency to take a "set" after being stored for a while. When cold, they become stiff and are very stubborn to open. So just before launching, remove the parachute, open it, refold, and repack it. For best results, always dust the 'chute lightly with talcum powder before folding, every other flight or so. This prevents the plastic from sticking to itself.

PARACHUTE MOD'S
FIGURE 6

SPILL HOLE

A   B

MASKING TAPE OR KNOT
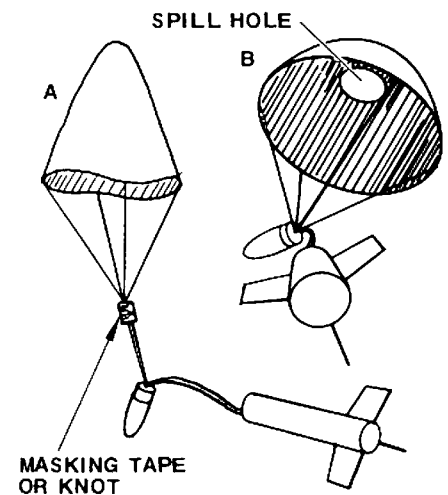
There are several ways to modify a parachute in order to make your rocket fall faster but safely. You can "reef in" or shorten the shroud lines as in Figure 6A by taping them or typing a knot in the lines. The shorter you make the lines the less your 'chute can open. Shorten the shroud lines all the way and your parachute becomes an instant streamer. Or you can cut a "spill hole" (B) out of the parachute center. This decreases the parachute's drag and also seems to reduce the rocket's swaying movements during descent. Don't make the hole too large or the parachute will not open at all.

Third and final article in a technical report on model rocket recovery - techniques, types, and tips. In this article we examine the basic mechanics and types of solid-propellant model rocket recovery systems.

As soon as one has grown tall enough to fall over, you quickly discover Mother Nature's own recovery system, gravity. Gravity has been doing its thing in the Universe for some time now. So when model rocketry came along, we needed to make some refinements to this business of "what goes up must come down". Our rocketry safety code states that "a model rocket will always use a recovery system to return it safely". Not only is this important to the safety of our hobby, but it insures that you can recover your bird in the same number of pieces as when it was launched. The owner of your flying field might also get a bit up-tight should you begin excavating the local ecology trying to find the remains of an afternoon's launching. Well, writing rules and safety codes are easy, but here is how Estes and many rocketeers have solved this problem.

To fully understand and appreciate any recovery method, we must first know something about the heart of the system, the rocket engine. Each Estes engine first contains a precisely measured propellant section (Figure 1). At ignition, the propellant burns to provide the necessary thrust to lift the model from the launch pad and accelerate it to a high velocity. After pro-
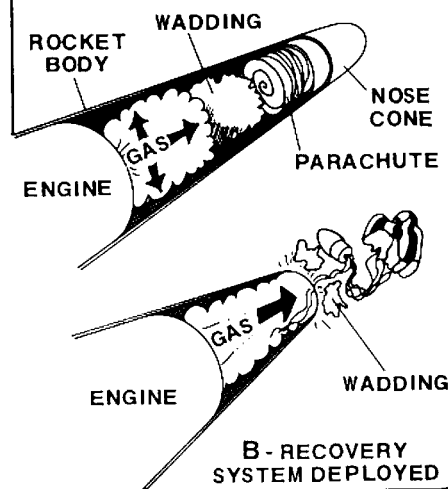

FIGURE 1
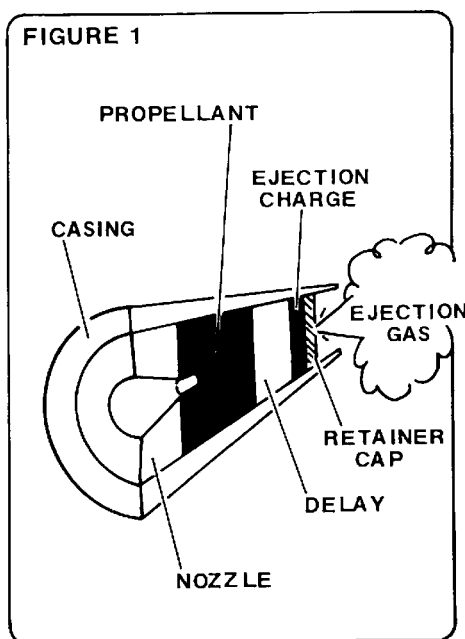
pellant "burnout", the delay element continues to burn producing a "non-thrust" yet visible smoke-tracking trail. This also allows the rocket to coast upwards to peak altitude. Finally, the delay element ignites the ejection charge. A sudden burst of gas pressure is generated which breaks through the clay retainer cap. This gas is released from the engine to activate

the model's recovery system.

The popular parachute or streamer recovery systems use this ejection gas to pressurize the forward end of the rocket. The engine acts effectively as a


rear gas seal so that the gas must exit the front of the rocket as shown in Figure 2. (A very small amount of gas will escape back through he engine nozzle. This loss is minimal, but it is always good flight insurance to be sure that the nose cone does not fit exceptionally tight). Flameproof recovery wadding required for each flight protects the parachute or streamer material from the heat of the ejection gas. The wadding also acts as a forward gas seal and a piston to help push out the recovery device and nose cone.

RECOVERY TYPES

Nearly all recovery systems depend on drag or wind resistance to slow the rocket and return it safely. Each system changes the model from a streamlined object to one which the air can "catch against" and slow its decent. The seven main recovery methods used by rocketeers today are shown in Figure 3.

Featherweight recovery is used with very small, ultra-lightweight rockets. At peak altitude, the engine is ejected from the model. Both engine and rocket tumble or free-fall to the ground. The descent of the lightweight body is slow enough that it presents no hazard to spectators or models.

FIGURE 3 FEATHERWEIGHT
STREAMER
HELICOPTER
TUMBLE
PARACHUTE
BREAK-APART
GLIDE
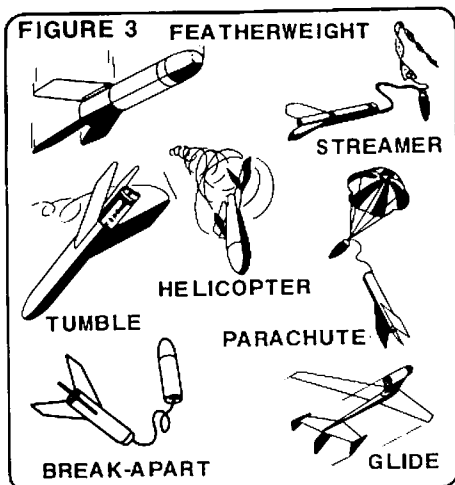
A tumble recovery model uses the ejection charge to move the engine rearward in the rocket. By moving the center of gravity (CG or balance point) to the rocket's rear, it becomes unstable and tumbles harmlessly to the ground. The added engine weight causes the model to fall faster than the featherweight bird. Therefore, you should expect occasional fin or body damage. These models must be built stronger to withstand a harder landing.

Break-apart recovery models are becoming increasingly popular. The rocket's streamlining is broken by simply ejecting the nose cone or separating the body in the middle. Both rocket sections must remain connected with a length of shock cord. Some wadding may be necessary to prevent scorching the shock cord. This method is ideal for very high altitude sport models and medium sized rockets when flown from small launch sites. Surprisingly, this type of model is seldom damaged upon landing.

FIGURE 4 ESTES
REAR ENGINE
FRONT ENGINE
POP-POD
PARASITE
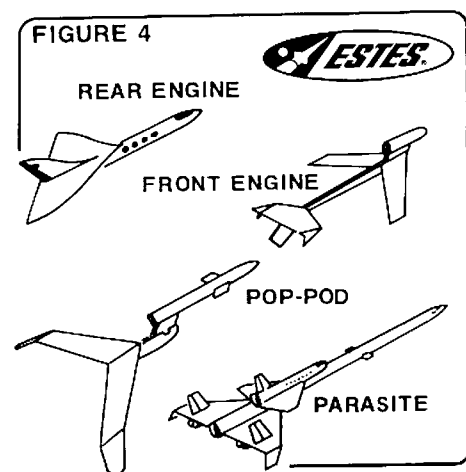
Glide recovery models are launched straight up like any other rocket. But they return to earth in a glide configuration like a model airplane. A boost-glider's grace-

ful gliding return is spectacular to watch. Sometimes the glide is not so graceful in the case of a poorly trimmed model, but still exciting just the same. Boost-gliders are more difficult to construct and fly. However, the added challenge is important as you advance your model rocket knowledge and building skills.

There are four main boost-glider types (Figure 4). Once again the ejection charge activates the glide recovery system. It may be used to: eject an internal power pod (rear engine); change the model's center of gravity (eject the engine as in front engine type); separate an external power pod (action-reaction principle used with pop-pod systems); or release a piggy-backed parasite glider (action-reaction principle again).

ROGALLO FLEX-WING IN FLIGHT

A fifth glider category would include the many weird and more complex glide recovery systems. An experimental Rogallo Flex-wing device shown in the photograph is one example. The plastic wings fold for storage in the rocket body during launch, then eject to return the payload section. Sorry, no plans available.
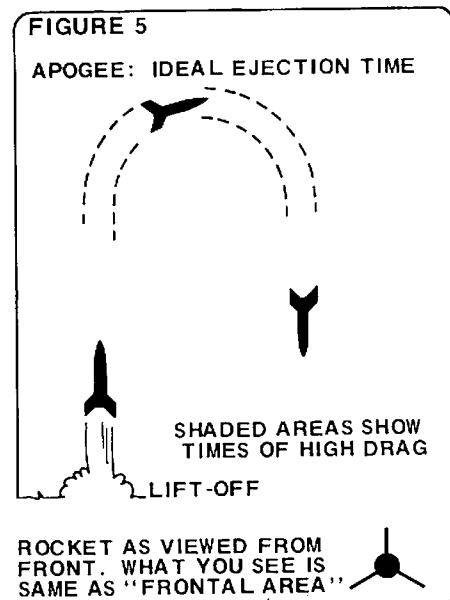
Helicopter recovery (Figure 3) is another interesting system. (No, it doesn't mean buying a helicopter to find your rockets). This method deploys flaps, blades, or other fin surfaces to cause high drag. These drag surfaces are held inside or against the rocket in a streamlined position during launch. The model usually spins or rotates as it returns.

SUGGESTIONS
Always select an engine so that the timed ejection occurs when your

model has reached its peak altitude. At this high point (apogee), the wind resistance will be lowest. This is extremely important for rockets using an unusual or complicated drag device. Ejection should not occur during "fast coast" or too late when the model has streamlined into a fast free fall return. A recovery device suddenly exposed to high-speed wind resistance may turn into a mass of aerial confetti.

Rockets with large body diameters (BT 80 or larger) have a large frontal

FIGURE 5
APOGEE: IDEAL EJECTION TIME
SHADED AREAS SHOW TIMES OF HIGH DRAG
LIFT-OFF
ROCKET AS VIEWED FROM FRONT. WHAT YOU SEE IS SAME AS "FRONTAL AREA"

area, see Figure 5. Again, if ejection occurs too soon or too late, the wind resistance pushing against the nose cone may be greater than the pressure of the ejection charge. The recovery system will then be unable to eject from the rocket body.

Ejection charges build up a gritty residue inside the rocket body. Models which use internal, sliding power pods or piston devices must be cleaned occasionally. A toothbrush works well to brush away the residue. Frequent cleaning will prevent moving parts from sticking or binding and causing recovery failure.

Keep in mind the ejection charge "energy". You can put it to work pushing devices out of the rocket, moving internal actuating pistons, ejecting or relocating the engine. The possibilities are endless. Recovery is really half the enjoyment of flying. Experiment and have fun. That's model rocketry.