MODEL ROCKETRY

The Educational Space-Age Hobby

Daily our newspapers, radio and TV stations feature stories telling of new developments in the field of rocketry. We hear of new shots into outer space, new fuels, new guidance systems and new discoveries in medicine. Every day space becomes a more important part of our lives as we learn more about our world and the universe beyond.

Countless young people of today's world look forward with great anticipation to the new developments tomorrow will bring. Will we inhabit the moon? To what extent is radiation a hazard?

Is there life on other planets? What new engine can be perfected to carry our scientists to outer space and new worlds?

The destiny of almost every great engineer, scientist, physicist, mathematician and chemist was started early in life. In his youth he was encouraged in his special field by a free pursuit of his own interests. When those interests fall in the field of rocketry and its associated scientific fields, model rocketry satisfies a special need for the young rocketeer's development and enjoyment. The principles of rocket design, acceleration, thrust, aerodynamics, stability, trajectory, tracking and many other fields are identical for model rocketry and professional rocketry. Through model rocketry much scientific knowledge is gained by the young rocketeer to enrich and supplement his normal academic studies.

Many youngsters and adults do not plan to become engineers or scientists. They are looking for an inexpensive hobby which offers pleasure, relaxation, excitement and competition. The sport of model rocketry is their choice. The fascination of this hobby can well be appreciated when it is realized that a small home built rocket weighing from a fraction of an ounce to only a few ounces can travel at speeds of several hundred miles per hour and attain altitudes of over 2,000 feet. Not only is it possible to achieve this fantastic performance but the same rocket can be built to return safely for many additional flights.

The growing interest in model rocketry is shown in the development of clubs, organizations and teams for group participation in the field of model rocketry. The hundreds of model rocket clubs in this country alone demonstrate the popularity of this space-age hobby. Through their organizations model rocketeers have developed systems of classification for their models and rules for competitive events. Safety rules and procedures established by model rocketeers stand among the best for any sport or hobby. In just a few years since its inception model rocketry has become a major national hobby and is spreading out to other lands.

ASTRON ROCKET SOCIETY SAFETY CODE

1) I will not attempt to compound propellants or other combustible chemicals or tamper with pre-manufactured rocket engines. I will not use model rocket engines for purposes other than those for which they are recommended by the manufacturer. I will inspect each rocket engine before use and never use an engine which shows signs of physical damage, remembering that any rocket propellant can be explosive under certain conditions.

2) I will not smoke near rocket engines, launch my rockets in the presence of highly combustible materials, use flammable recovery wadding or engage in any activity which would present a fire hazard.

3) I will never use any metallic rocket engines, will not construct my model rockets with substantial metal parts in the area of the engine, and will not launch any rocket over 16 ounces in weight or containing more than 4 ounces of propellant in compliance with Federal regulations.

4) My model rockets will be electrically ignited, using a launch system with either a switch protector or a safety interlock to prevent accidental ignition of the rocket engine, and I will remain at least 10 feet away from any rocket which is being launched. I will use only igniters of the type recommended by the engine manufacturer.

5) I will launch my model rockets using a launching rail or other suitable guide means aimed within 25 degrees of vertical to assure a safe and predictable flight path, and will launch only rockets whose stability characteristics have been predetermined.

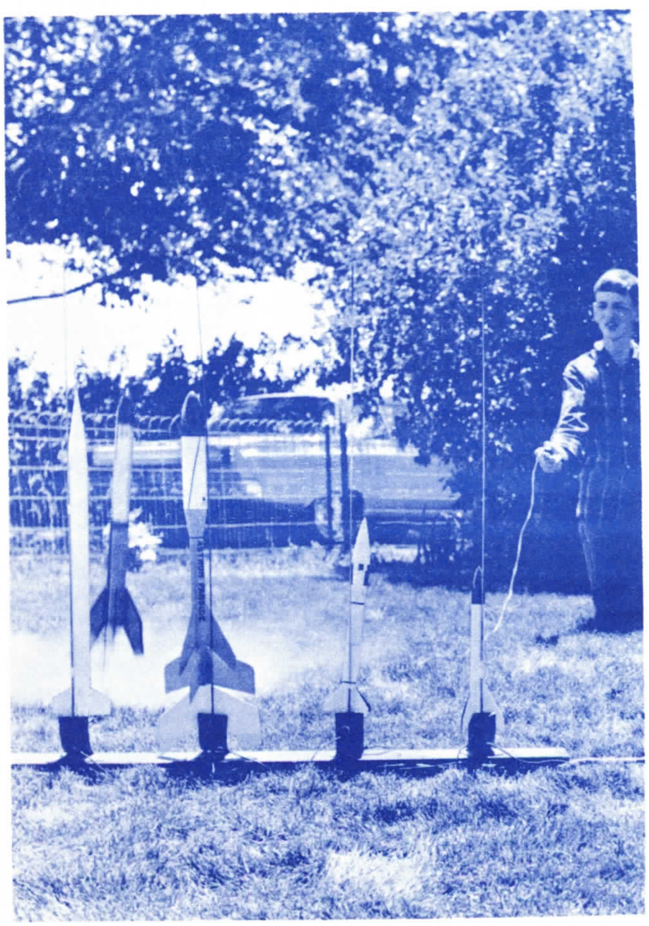
6) I will not fly model rockets in high winds, conditions of low visibility, in the vicinity of low flying aircraft, near tall buildings, near people not aware of the launching, or under any conditions which might endanger property or persons.

7) I will not launch rockets so that their ballistic trajectory will carry them against targets on the ground, and will never use an explosive warhead or other pyrotechnic payload in a rocket.

8) My model rockets will contain recovery devices which will deploy at an altitude of at least 50 feet to return the rocket safely, and undamaged. To insure proper operation of my rocket's recovery system I will make a careful pre-launch inspection of all the recovery components with special attention to tightness of the engine and nose cone.

9) To prevent accidental eye injury I will always either place the launcher so the end of the rod is above eye level or cap the end of the rod with my hand when approaching it. I will not place my head or body over the launching rod.

10) When conducting research activities with unproven designs or methods I will, when technically possible, determine their reliability through pre-launch static tests, and I will conduct launchings of unproven designs in complete isolation from persons not participating in the actual launching.



Model Rocketry

Why is model rocketry today as safe as flying model airplanes, playing golf, boating or swimming? One of the most important reasons is the availability of commercially made rocket engines.

Commercial engines are built completely free of all metal parts. They are extremely reliable, are less expensive and will out-perform anything the rocketeer could attempt to build himself. Each engine is a cylindrical unit which fits easily into the rocket and is replaced in its entirety after each flight. The model rockets illustrated here are all designed to use only commercial engines.

Each engine is simply constructed. It consists of a tubular body, nozzle, propellant charge, delay charge, ejection charge and paper end cap. Estes Industries, Inc. manufactures and sells these propellant devices. They are also available through hobby stores in many localities.

Types of Rockets

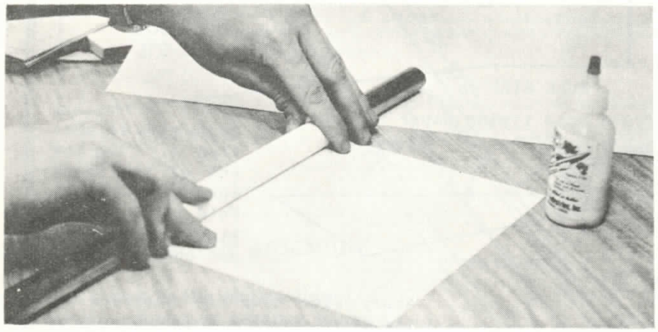
Most model rockets are easily constructed at home. This booklet contains plans and technical information on some of the basic design types which are popular among model rocketeers. The beginning modeler will do well to follow instructions exactly at first, leaving variations of basic designs for later experimentation as his knowledge increases. Materials for building the rockets in this book are available in hobby shops which carry Estes rocket supplies or may be ordered directly from Estes Industries.

Printed in the United States of America by
ESTES INDUSTRIES, INC., BOX 227, PENROSE, COLORADO

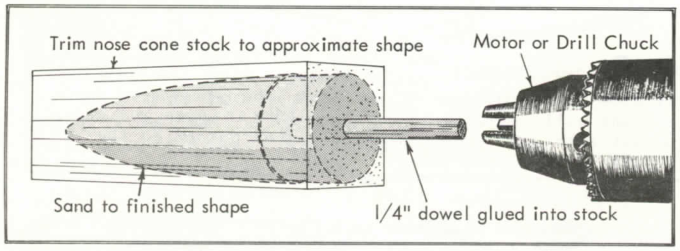
Before starting to build your model rocket, study carefully these general instructions as well as the instructions for the rocket you are going to make. Determine the function of each part and how it fits with the other parts before doing any cutting or gluing. By doing this, the model will go together more easily and will perform better.

Large metal parts should not be used in model rockets, particularly around the engine. Not only are such metal parts more dangerous than balsa and paper, but they are also heavier and will reduce the performance of the model.

BODY TUBES: Although a wide variety of body tube sizes is commercially available, it may sometimes be necessary for the rocketeer to roll his own to fit a certain design. Almost any kind of paper will be suitable, although a bond paper is generally the easiest to work with. Apply an even layer of hard drying paper glue or paste (flour and water will work) and wrap tightly around the proper size form. A wood dowel, metal rod, tubing, etc. will make a suitable form. Always remove the tube immediately after wrapping. It generally takes a bit of practice to make a good tube--the first attempt is apt to be pretty poor.

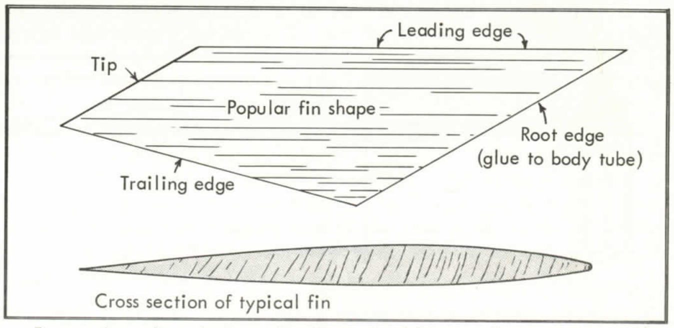


NOSE CONES: Certain rocket designs demand that the rocketeer make his own nose cone. The nose cone can be built from soft wood or plastic, but not metal. Balsa wood has proven to be the best material for nose cones. A rounded nose cone is safer than a pointed one and will give better performance at the speeds the model rocket will travel.



Nose cones can be turned on a lathe, but generally a more satisfactory result will be obtained by drilling a 1/4 inch diameter hole 1 inch deep into the center of the base end of a balsa block. Glue a two inch long 1/4 inch diameter hardwood dowel into the hole. After the glue has dried thoroughly, chuck the dowel in a high speed electric drill. Carve off the corners of the block, start the drill and sand the block to the desired shape with fine grit sandpaper. When the nose cone has been shaped, cut off the protruding dowel. Balsa stock as well as finished plastic and balsa cones are available from Estes Industries.

MAKING THE FINS: Sheet balsa either 1/16" or 3/32" thick makes ideal material for stabilizing fins. Cut the fins from the balsa sheet using a sharp knife or single edge razor blade. The grain of the wood must follow the leading edge of the fin to provide adequate strength (see fig. 3). For best results the leading edge of the fin should be rounded and the trailing edge sanded to a long tapered knife edge.



In most rocket designs the fins should be as large as possible and as far rearward on the rocket as is practical. They must be carefully aligned and securely glued to the rocket body. Avoid placing any sort of fin on a rocket ahead of its center of gravity (the balance point with engine and all other components in place) since forward fins will reduce the stability of the rocket. More information on stability is provided later in this book.

RECOVERY SYSTEMS: There are many different ways of returning a rocket safely to earth so it is not damaged and can be flown again. The plans in this book cover several of the more popular recovery systems. The first three plans cover the streamer ejection system, the break-up system and the balance shift system. Each recovery system has advantages and disadvantages. By studying the plans and building the models, the rocketeer will gain knowledge in rocket recovery which will be quite valuable when he starts to design his own models.

ENGINES

Single stage and upper stage model rocket engines contain, in addition to the propellant, a time delay section and an ejection charge. As the propellant burns out, the delay section is ignited. The delay burns slowly, producing tracking smoke but no thrust, allowing the rocket to coast upward as it loses the speed developed while the propellant was producing thrust. When the forward wall of the delay section burns through, the ejection charge is activated, producing a quantity of hot gas at the front of the engine. This gas can be used to pressurize the body tube ahead of the engine to operate the recovery system.

PLANS

By ejecting a short streamer which is connected to the rocket body and the nose cone, the stability of the model is broken. The streamer provides enough drag at the front of the rocket to turn it on its side. As a result, the model tumbles and flutters down sideways to a safe landing. Streamers are generally made of crepe paper or plastic. A streamer must be protected from the hot ejection gases by packing wadding between it and the engine. The nose cone, body and streamer are held together by a shock cord, normally a length of model airplane contest rubber. The shock cord must be anchored solidly at its ends to the nose cone and body tube to prevent separation at ejection and resulting damage to the rocket. Plan No. 1 makes use of this system.

Typical Streamer Recovery System

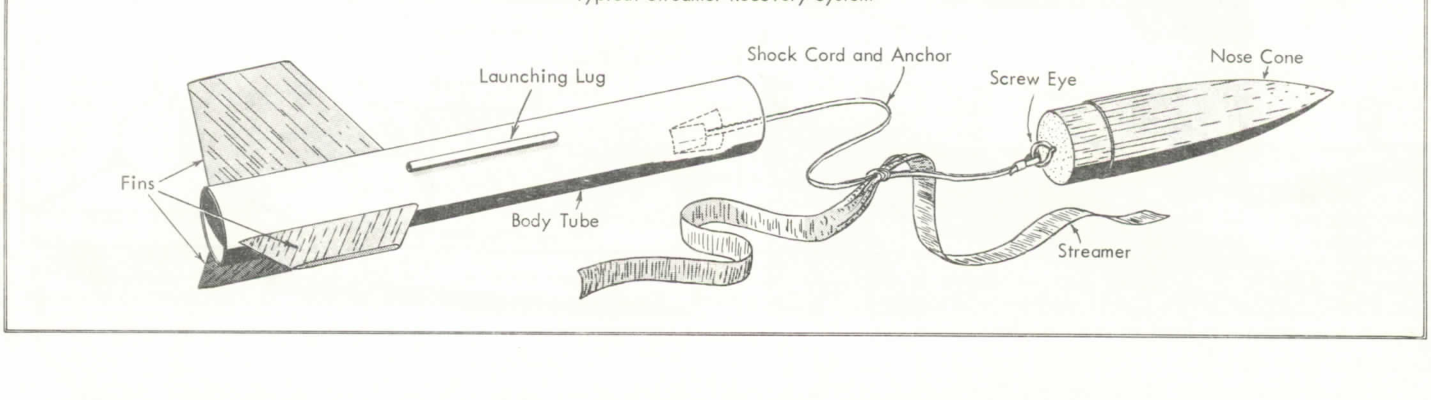
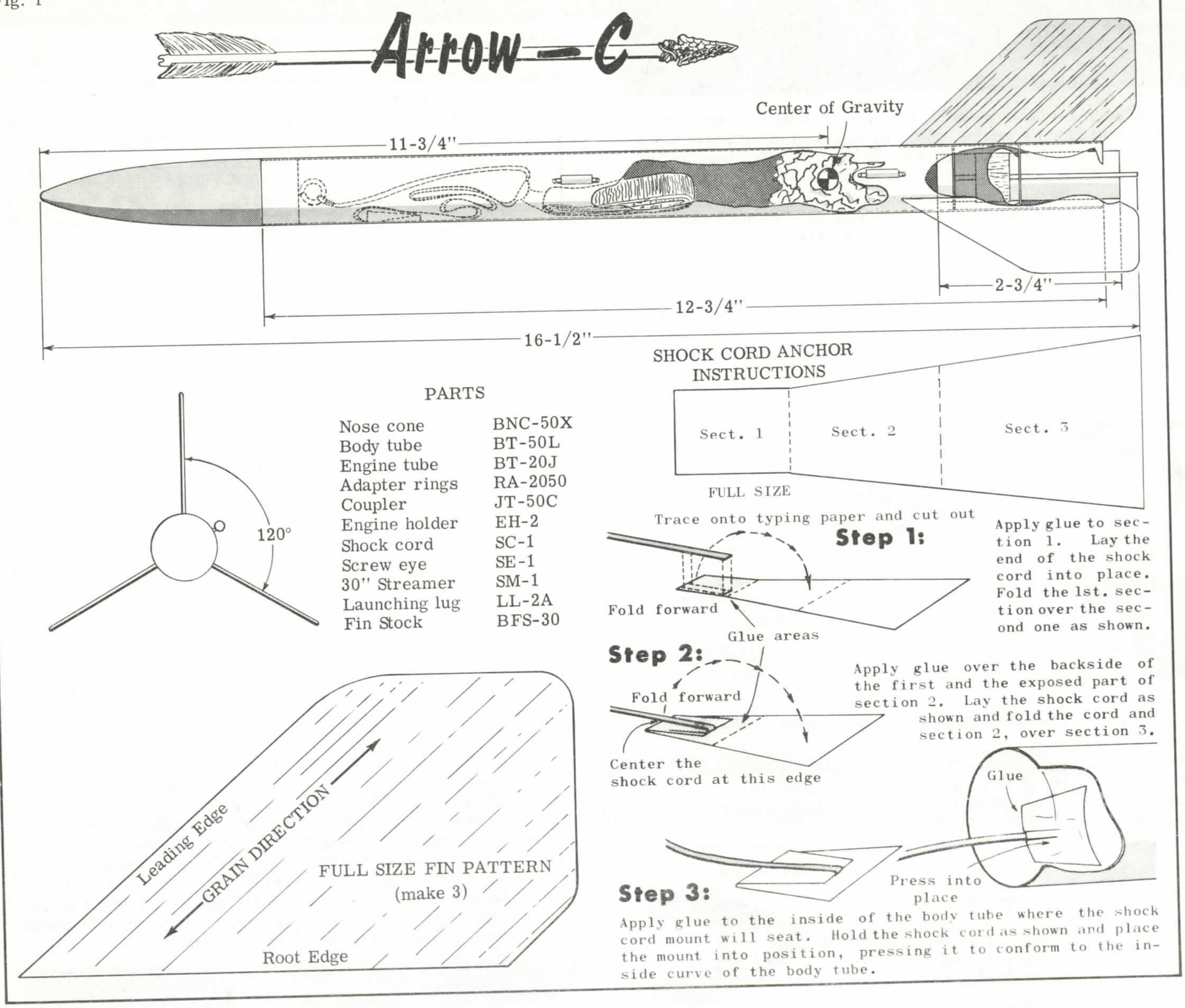
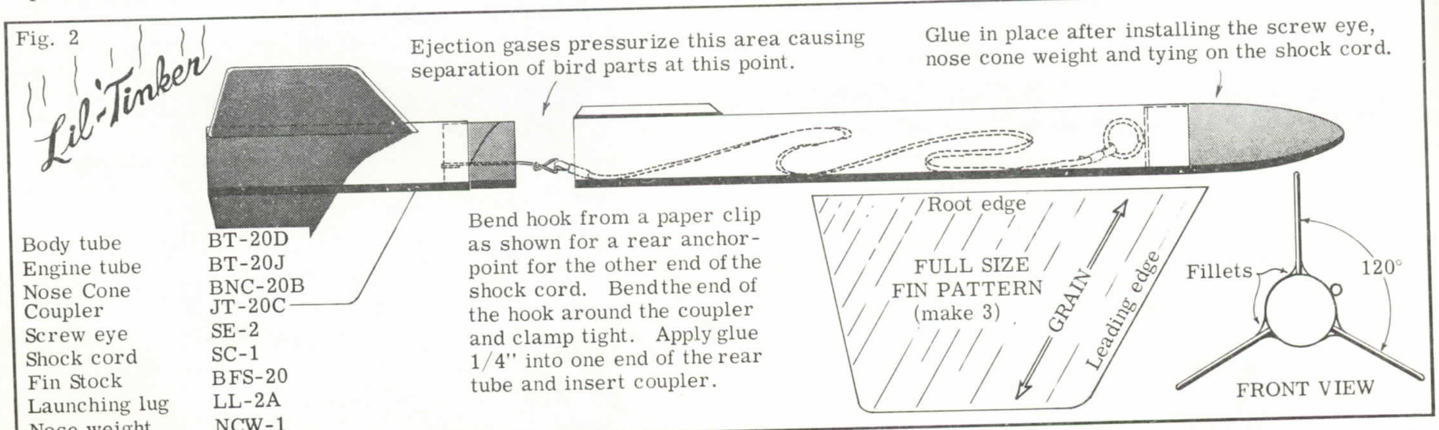


Fig. 1



Care should be taken in building the Arrow-C model rocket to be sure the balance point is at least as far forward as indicated in the plans. Additional weight may be added to the nose cone to bring the balance point forward if necessary. When flying the Arrow-C, the streamer must be protected from the hot ejection gases. Three or four squares of Estes flameproof wadding or enough flameproofed cotton to fill the tube for 1-1/2" should be used. While the Arrow-C was designed as a streamer recovery model, the streamer may be replaced by a 12 or 18 inch parachute for flying on calm days.

Fig. 2



The second type of recovery system, shown in Fig. 2. employs a removable tail section. The fins can either separate completely from the rocket body or the pieces may be held together by a shock cord. This type of design is quite popular in spot landing contests where it is desirable to land the rocket close to the launcher.

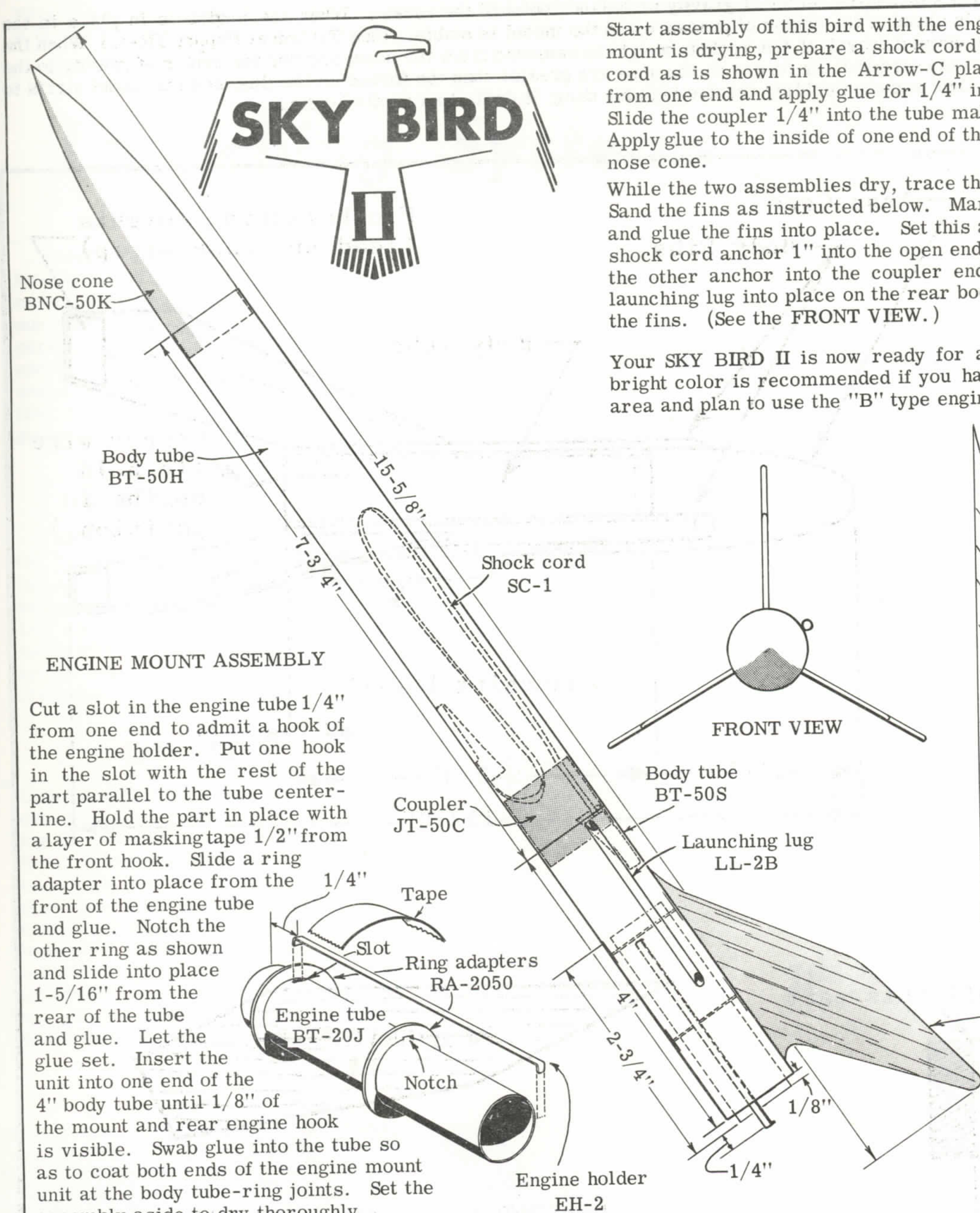
Since a model using break-up recovery lands harder than one using a parachute or streamer, it is especially important to have correct wood grain direction on the fins and to have all joints securely glued. Fin grain is correct when it is possible to follow an uninterrupted grain line from any point on the fin to the "root edge" of the fin (the edge that glues to the body). Generally this can be done if the grain is parallel to the front (or leading) edge of the fin.

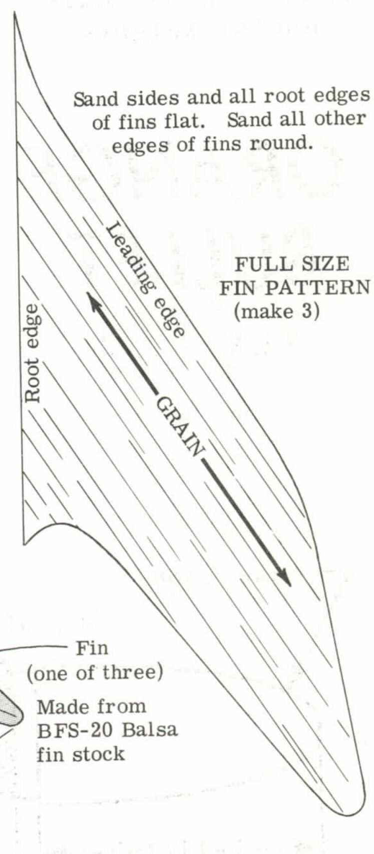
SKY BIRD II

Start assembly of this bird with the engine mount assembly. While the mount is drying, prepare a shock cord anchor for each end of the shock cord as is shown in the Arrow-C plans. Mark the tube coupler 1/4" from one end and apply glue for 1/4" into the front of the 4" body tube. Slide the coupler 1/4" into the tube making sure it is aligned correctly. Apply glue to the inside of one end of the 7-3/4" body tube and insert the nose cone.

While the two assemblies dry, trace the fin pattern and cut out 3 fins. Sand the fins as instructed below. Mark 3 fin guide lines on the 4" tube and glue the fins into place. Set this assembly aside to dry. Glue one shock cord anchor 1" into the open end of the 7-3/4" body tube. Glue the other anchor into the coupler end of the rear body tube. Glue the launching lug into place on the rear body tube locating it between two of the fins. (See the FRONT VIEW.)

Your SKY BIRD II is now ready for a paint finish of your choice. A bright color is recommended if you have a large launch and recovery area and plan to use the "B" type engines.

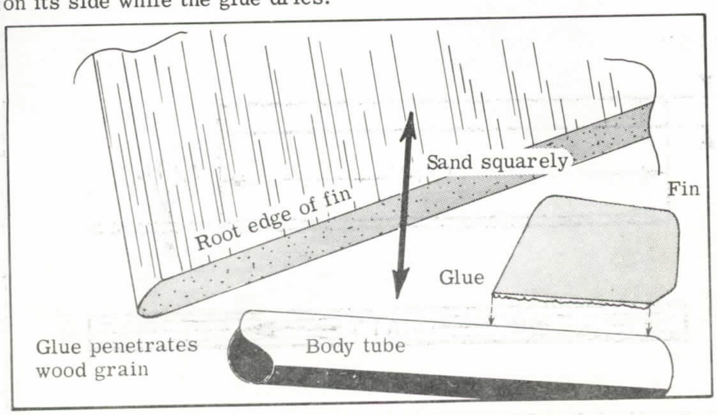


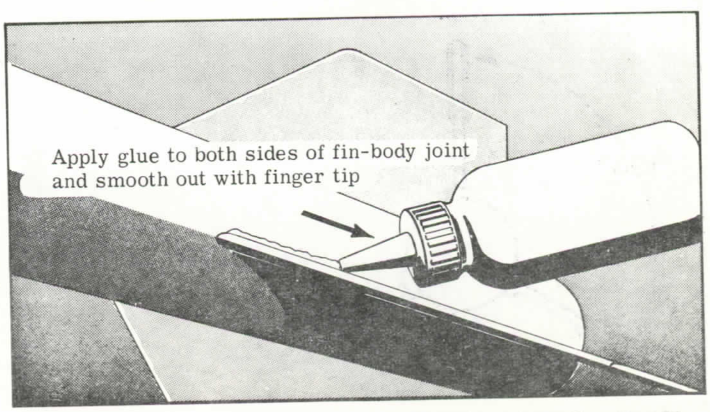


ENGINE MOUNT ASSEMBLY

Cut a slot in the engine tube 1/4" from one end to admit a hook of the engine holder. Put one hook in the slot with the rest of the part parallel to the tube center-line. Hold the part in place with a layer of masking tape 1/2" from the front hook. Slide a ring adapter into place from the front of the engine tube and glue. Notch the other ring as shown and slide into place 1-5/16" from the rear of the tube and glue. Let the glue set. Insert the unit into one end of the 4" body tube until 1/8" of the mount and rear engine hook is visible. Swab glue into the tube so as to coat both ends of the engine mount unit at the body tube-ring joints. Set the assembly aside to dry thoroughly.

To obtain a good glue joint, the fin root should be sanded square and covered completely with glue before it is pressed in place against the body tube. After this glue has dried, a glue filler (fillet) is applied to the joint as shown. The rocket should be supported on its side while the glue dries.



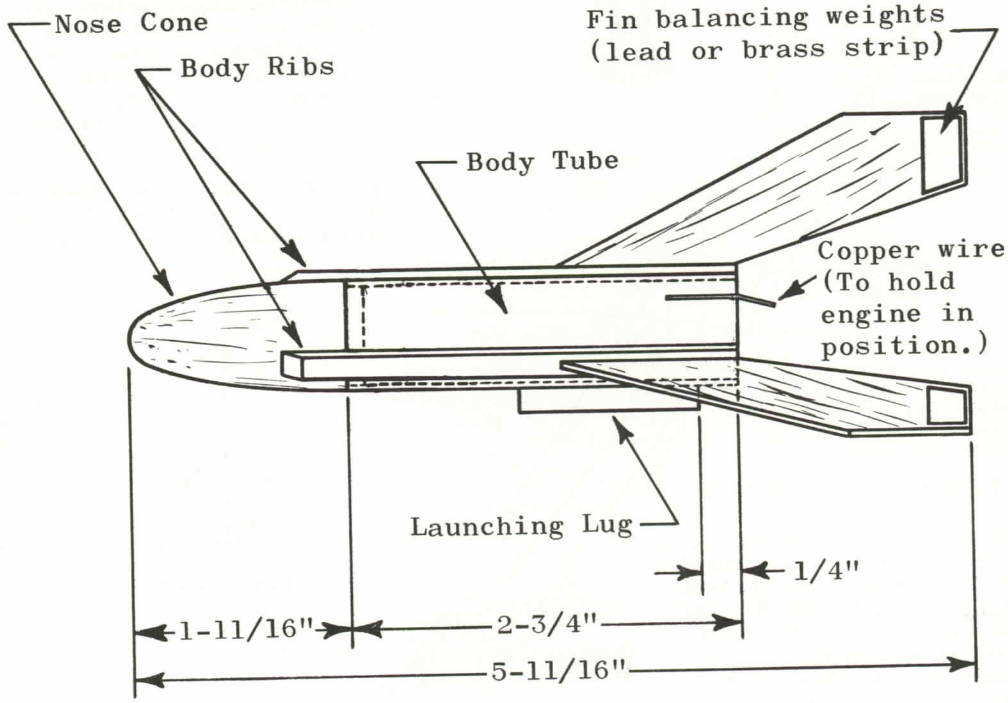


. . . or Shift the C/G

The third recovery method involves shifting the center of gravity or balance point of the rocket. When the engine is in place in the Orange Bullet, the center of gravity is ahead of the center of pressure and the model is stable. (See Technical Report TR-1.) When the engine is ejected at the end of the upward travel of the rocket, weight is removed from the nose, shifting the center of gravity to the rear. With the center of gravity moved rearward, air forces on the nose are greater than the forces on the fins, and the model starts to tumble. Because the model is very light and the tumbling creates high air drag, it drifts to a gentle landing.

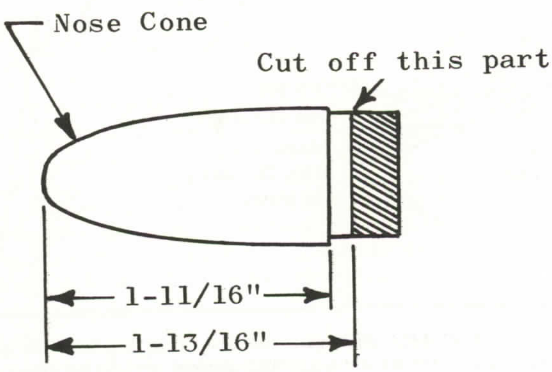
PARTS LIST

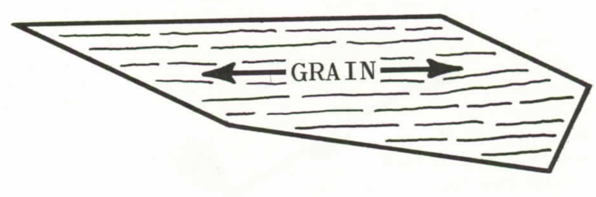
Nose Cone #BNC-20B
Body Tube #BT-20J
Fin Material #BFS-20
Launching Lug #LL-1A
Short copper wire
Lead or brass balancing weights



ORANGE BULLET

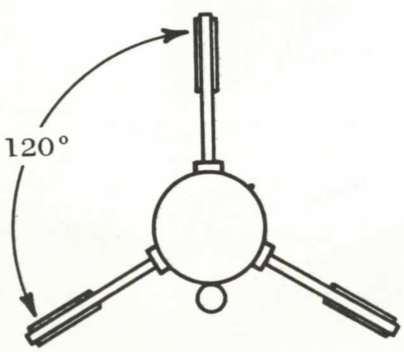
PLAN NO. 3

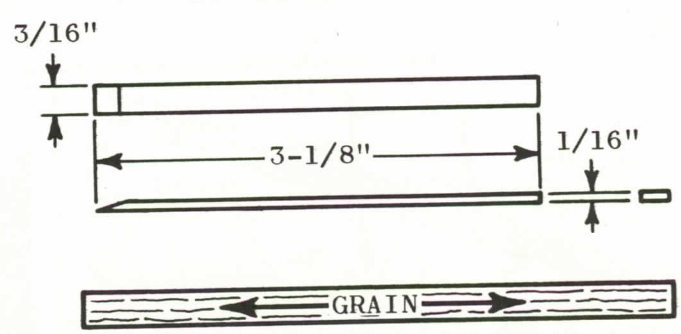




Use BFS-20 on fins and ribs

(Full size patterns)





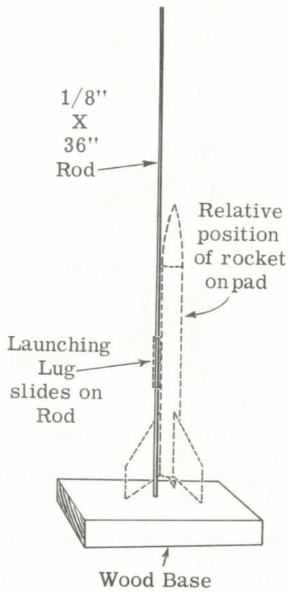
When the Orange Bullet is completed it should weigh about 1/4 ounce with the engine installed. Enough weight is added to the tips of the fins to barely make the rocket unstable for its return flight. The proper weighting can be determined by throwing the engine-less rocket into the air and noting the manner in which it falls. Add weight to the fins until the model does not fall nose first. If too much weight is added to the ends of the fins, however, the model will be unstable on its upward flight. The rocket is balanced correctly when it is just barely unstable without the engine.

Launching Systems

Model rockets are stabilized by air flow acting on their surface areas. To obtain this stabilizing effect, the rocket must be moving fast enough to provide adequate air flow. For this reason, the rocket must be guided during its initial accelerating period. Heavy models and those with small fins require guidance for several feet- -lighter ones and models with very large fins generally will need less guidance.

BUILD . . .

The most popular device is the launching rod. These vary in length from 20" to 5'. Most are made of a 36" long piece of 1/8" diameter welding rod or music wire, one end of which is set in a wood, plastic or concrete base as illustrated.

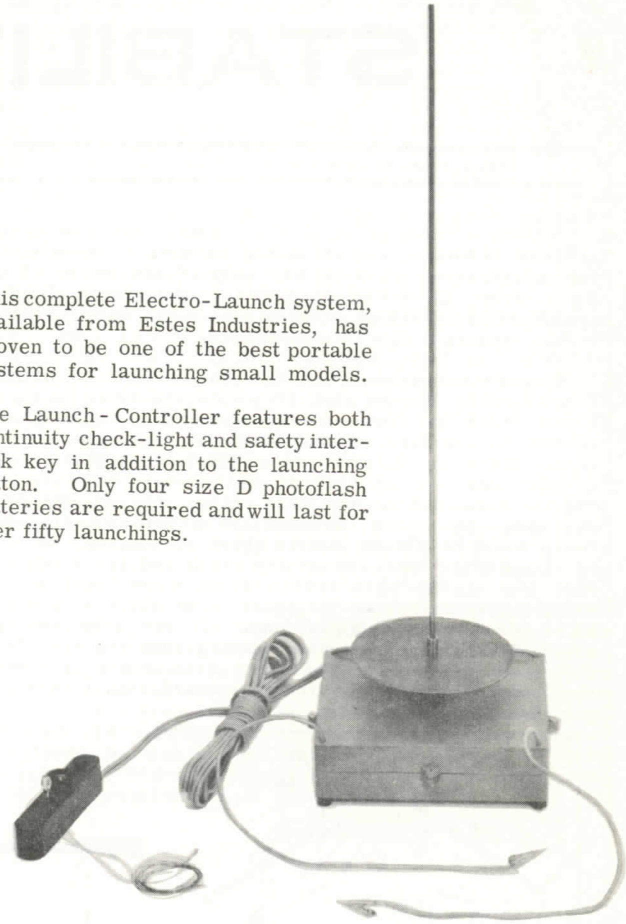


. . .OR BUY

Commercially produced launchers are also available, including the ELECTRO-LAUNCH by Estes Industries, a self contained unit which is used both to ignite the engine and guide the rocket initially. With any rod launcher it is necessary to glue a launching lug to the body of the rocket. On most rockets the launching lug is simply a 2" length of 5/32" soda straw which will fit loosely over the launching rod. The lug should be located at the balance point of the model.

This complete Electro-Launch system, available from Estes Industries, has proven to be one of the best portable systems for launching small models.

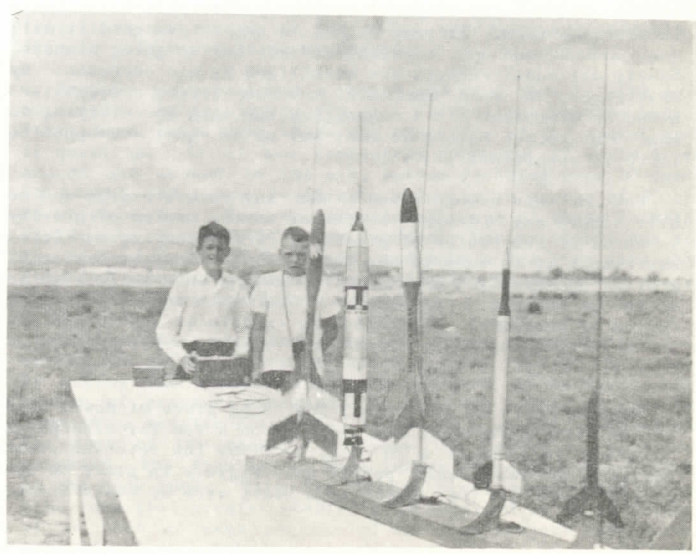
The Launch-Controller features both continuity check-light and safety interlock key in addition to the launching button. Only four size D photoflash batteries are required and will last for over fifty launchings.



THE ELECTRO-LAUNCH SYSTEM

e shapes and designs obtainable in model rockets are limited y by the scope of the imagination of the young rocketeer.

The range safety officer gives the all clear. A 10 second count down is given by the firing officer and with the press of a button the model streaks skyward.



Estes Industries Technical Report TR-1

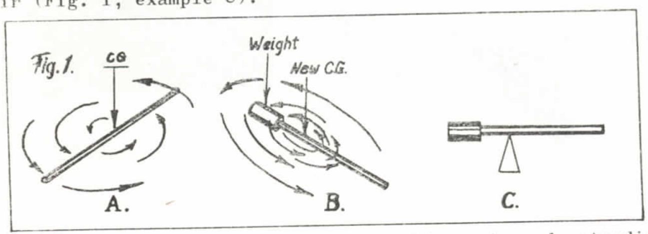
ROCKET STABILITY

by Vernon Estes

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 known 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).

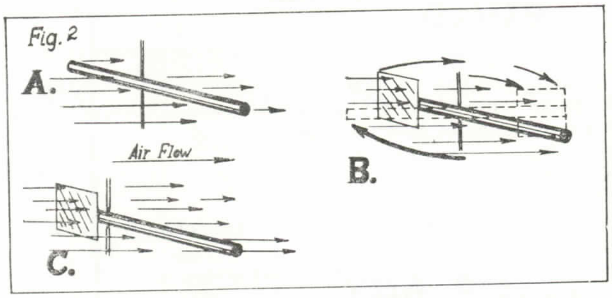


This simple explanation should aid you in understanding how a free body in space rotates around its center of gravity. A model rocket in flight is a free body in "space." If, for any reason, a force is applied to the flying rocket to cause it to rotate, it will always do so about its center of gravity.

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.

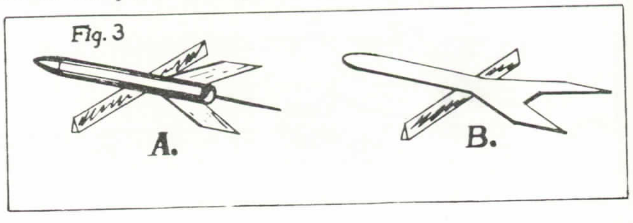
Suppose we take the same 2 foot long piece of dowel used in our first experiment and place it on a low friction pivot as shown in example A of Fig. 2. (The low friction pivot consists of two needle points held rigidly in place on opposite sides of the object by a heavy wire or board framework. The needle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



If, however, 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, the lateral center of pressure has to do only with the 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, and 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 effect 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.

Keeping 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.



This method will determine the lateral 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) behind 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.

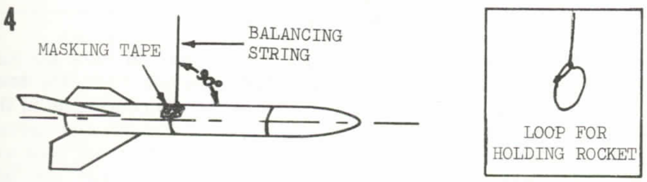
In flight, of course, the rocket will not be traveling sidewards, but with its nose pointed into the wind. With the model's nose pointed into the wind, the location of the effective center of pressure will be affected by the shape of the fins, the thickness of the fins, the shape of the nose cone, location 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 behind 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 ahead 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, light weight 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 how stable a rocket will be, any rocket, once constructed, 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.

4



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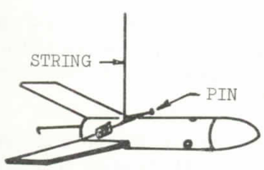
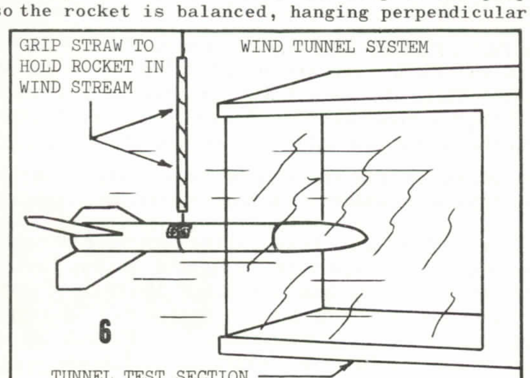


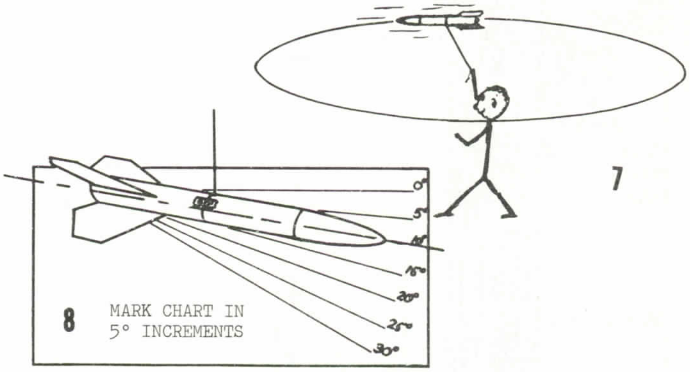
The rocket to be tested (with an engine in flight position: The center of gravity is always determined with an engine in place.) is suspended from a string as illustrated in Fig. 4. The string is attached around the rocket body using a loop as shown. Slide the loop to the proper position so the rocket is balanced, hanging perpendicular to the string. Apply a small piece of tape to hold the string in place. If the rocket's 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, and 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 below the tail with the rocket body at an angle of 10° 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° from the horizontal. Heavier rockets which accelerate at a lower rate require a similar margin of stability.



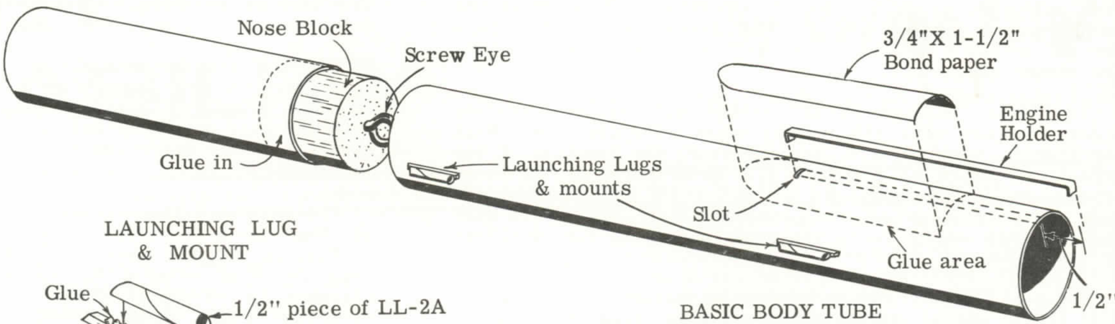
Caution should be exercised when swinging rockets overhead to avoid collision with objects or persons nearby. Velocities in excess of 100 miles per hour are possible. This is sufficient to cause injury.

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 the Astron Scout rocket and many other designs, greater stability is obtained by constructing it so that a large portion of the fins project beyond the rear of the rocket body.

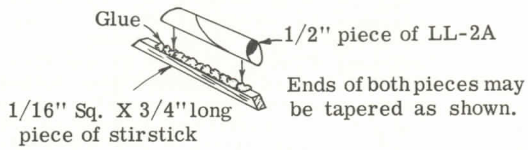
HI-G Payloader

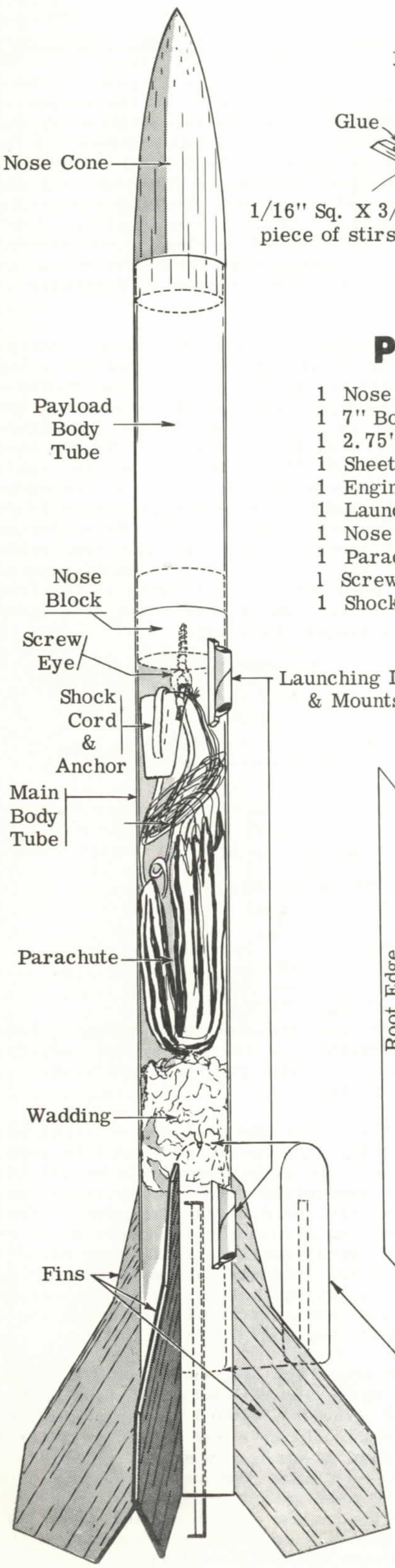
PARACHUTE - RECOVERED
HIGH PERFORMANCE BIRD
USE WITH EITHER SERIES I OR II ENGINES



BASIC BODY TUBE
AND PAYLOAD UNIT
CONSTRUCTION

LAUNCHING LUG
& MOUNT



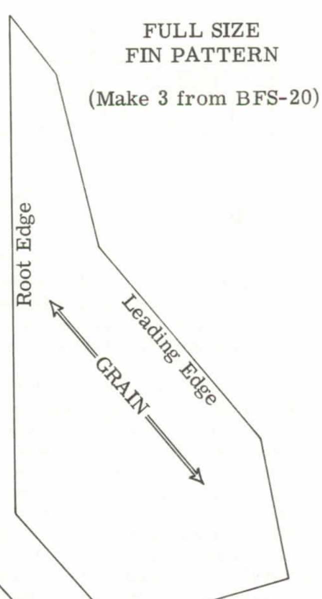


Parts List

1	Nose Cone	BNC-30M
1	7" Body Tube	BT-30F
1	2.75" Body Tube. . .	BT-30J
1	Sheet Balsa Stock . .	BFS-20
1	Engine Holder	EH-2
1	Launching Lug. . . .	LL-2A
1	Nose Block.	NB-30
1	Parachute Kit	PK-12
1	Screw Eye	SE-2
1	Shock Cord.	SE-2

FULL SIZE
FIN PATTERN

(Make 3 from BFS-20)



Rocket with a Purpose

Every commercial or military rocket is designed for a purpose--to carry a payload. The payload may be a camera, hydrogen bomb, mail sack, radio transmitter, animal or man. Regardless of the payload requirements, however, a rocket can be designed to do the job.

The Hi-G payload rocket has been designed to study the effects of acceleration on small objects, including biological specimens. Easy to build, the complete bird can be built from standard parts listed in our current catalog. White glue gives excellent bonding strength for all model rocket building.

Assembly

Measure 2-1/2" from one end of the 7" body tube and cut a slit just large enough to admit one hook of the engine holder. Put the hook in place as shown with the piece parallel to the centerline of the body tube. Cut a piece of bond paper 3/4" X 1-1/2" and spread glue on one side. Lay the paper in place over the front hook and part of the shaft. Smooth out the paper carefully and set this assembly aside to dry.

Mark the nose block 1/4" from one end. Spread glue 1/4" inside one end of the 2-3/4" body tube and insert the nose block to the 1/4" mark, making sure that it is perfectly aligned. Slide the nose cone into place in the open end of the tube.

Trace the fin pattern onto heavy paper or cardboard and cut out. Lay the fin template on the balsa with the main leading edge parallel to the grain of the wood and trace out 3 fins. Cut out the fins and sand the sides flat and sand all but the root edges round.

Mark the engine holder end of the 7" body tube for 3 fins (see the front view) using a drawer sill or other guide to draw the fin guide lines. Glue the fins in place and set this assembly aside to dry.

Assemble the parachute following the instructions in the kit. The shock cord and anchor are assembled as shown in the Arrow-C instructions. Place the anchor 3/4" into the front of the 7" body tube (far enough to clear the nose block of the payload section) and smooth out the anchor against the inside wall of the tube.

Insert the screw eye into the base of the nose block. Remove and squirt glue into the hole just made and replace the screw eye.

Tie the free end of the shock cord and the parachute shroud lines to the screw eye. Fold and pack the parachute, shroud lines and the shock cord into the body tube and insert the payload section into place, and your bird is ready for the paint finish of your choice. The brighter paints are recommended for recovery as the Hi-G flies extremely well with either Series I or II engines.

PARTS LIST

Qty	Part	No.	Qty	Part	No.
1	7.75" After-Body Tube	BT-50H	3	Sheets Balsa Fin Stock	BFS-20
1	4" Forward-Body Tube	BT-50S	1	Length of 1/4" Shock Cord	SC-2
1	2.75" Engine Holder Tube	BT-20J	1	Engine Block	EB 20A
1	Set Ring Adapters	RA-2050	1	Streamer Material 1"X36"	SM-1
1	Tube Coupler	JC-50C	1	Launching Lug 2-3/8"	LL-2B
1	Nose Cone	BNC-50Y			

PREDICTA-I

ASSEMBLY

☐ 1. Install the engine block flush with one end of the BT-20J. Glue one RA-2050 ring 1/4" in from each end of the engine tube. When positioned, apply a glue fillet to both sides of each ring and stand the assembly aside to dry.

☐ 2. Swab glue on the inside of the rear body tube at the depth shown. Push the engine tube (engine block end first) into place in one smooth easy motion, stopping with only 1/8" of the engine tube showing at the end of the body tube. Fill the space between the engine and body tube with a fillet of white glue. Eliminate all air bubbles, and stand the assembly to one side to dry.

☐ 3. Glue the tube coupler 3/8" into one end of the 4" piece of BT-50, leaving 5/8" of the coupler showing. Make sure the coupler is properly aligned by temporarily slipping the after body tube into place and rolling the whole thing on a flat surface. Carefully remove the after body-tube and stand the forward tube-coupler assembly out of the way to dry.

☐ 4. Trace the fin patterns onto stiff paper and carefully cut them out. Place these "templates" on the sheet balsa fin stock as shown and trace around them with a ball point pen. Make 3 fins of each size and sand as directed.

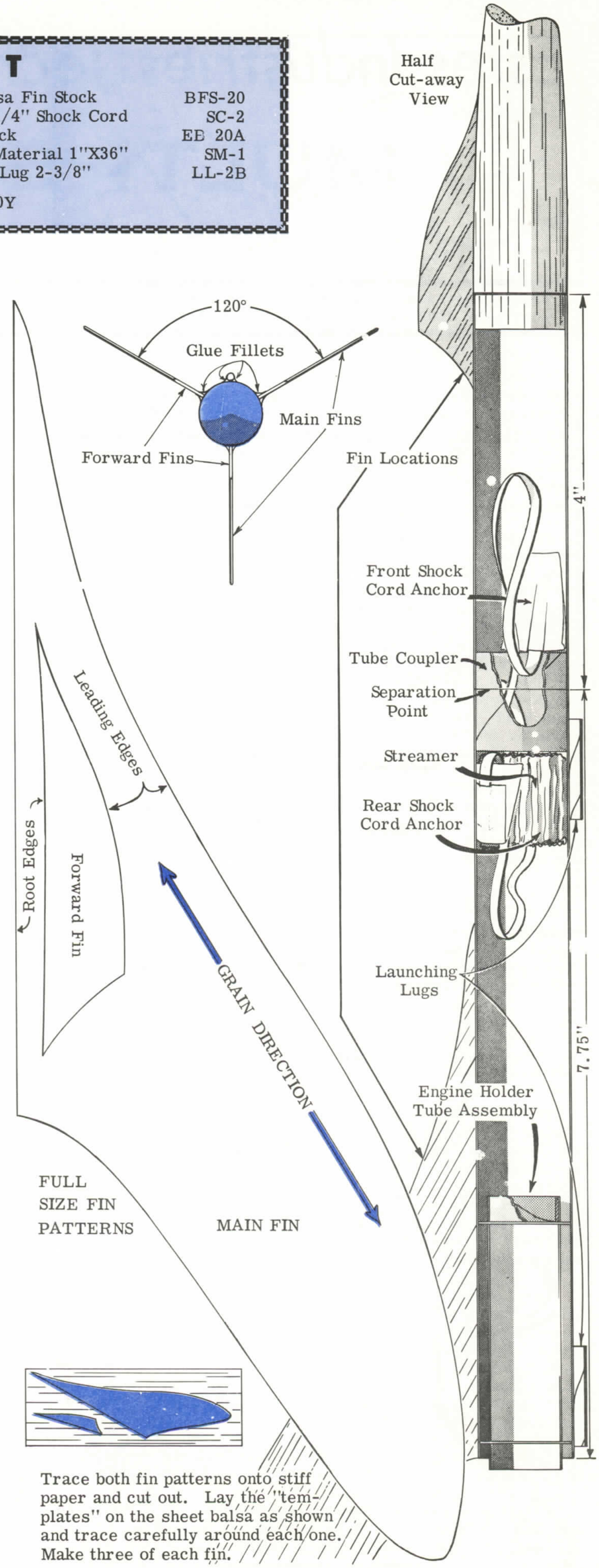
☐ 5. Apply glue around the inside edge of the forward body tube on the end opposite the coupler. Slide the nose cone into place and allow the glue to set. Apply a fill coat of glue around the joint and let this dry.

☐ 6. Cut, fold and attach a shock cord anchor (see Arrow-C instructions) to each end of the shock cord. Glue one anchor 3/4" into the front end of the after-body tube as shown, and glue the other anchor just flush with the inside end of the coupler in the forward tube. After the glue has set, coil the shock cord and stuff it into one tube, then fit the two tubes together. Cut 2 1" lengths of launching lug, and glue them in the positions shown.

☐ 7. Mark the body tube for 3 fins, and, using a drawer or door sill as a straightedge, draw the fin guide lines parallel to the model's centerline. Apply a line of glue on the root edge of a fin and place it on it s guide line on the body tube. Hold the fin in place until the glue sets. Apply all remaining fins in the same way. After the glue has dried, apply a fillet of glue to both sides of the fin-body joint of each fin, smooth out with a finger, and support the model horizontally until all the fillets are dry.

☐ 8. Cut two 36" lengths of 1" wide streamer material. Find the centers of these strips and attach them to the shock cord at half its length (cord at rest between the two sections of body tube). An easy way to secure the streamers is to tie one loop of a "granny" knot in the shock cord, center the streamers in this loop and pull the loop tight.

☐ 9. The original model was finished with four coats of sanding sealer (well sanded between coats) on all balsa surfaces, giving special attention to concealing the joint between the nose cone and forward body tube. Two coats of gloss white followed, then a coat of metallic gold base-color. The bird was thoroughly dry before masking for the final color application. The final color, four even coats of transparent blue, was applied--dried and unmasked after which the entire bird was covered evenly with a coat of crystal clear spray.



Trace both fin patterns onto stiff paper and cut out. Lay the "templates" on the sheet balsa as shown and trace carefully around each one. Make three of each fin.

Estes Industries Technical Report TR-2

MULTI-STAGING

by Vernon Estes

Multi-staging is one of the most prominent characteristics of modern rocketry. This 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.

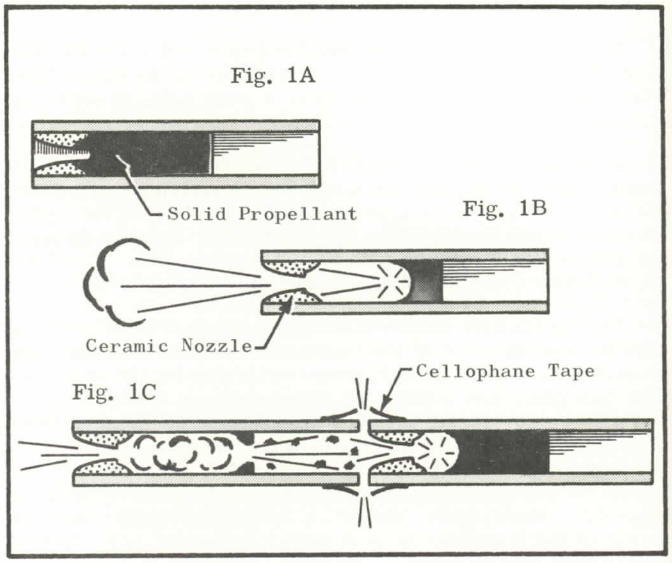
The principles of model rocketry and professional rocketry are identical although the model rocketeer uses somewhat different operating methods than the professional. The young rocketeer who masters the principles of multi-staging is gaining knowledge which he will find useful in his future career.

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 stage 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



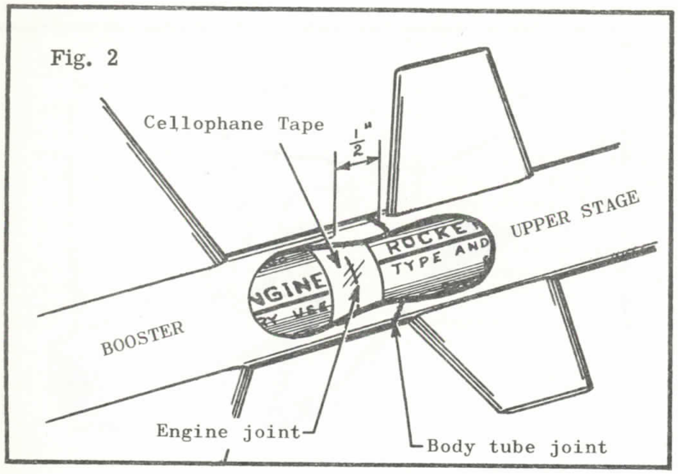
ahead of the booster engine so that the two can separate easily, ignition relaibility may fall as low as 40 percent, depending on the type of booster used (except when a Series II engine is used in the upper stage, in which case reliability will be about 80 percent). This unreliability in ignition is the result of several causes. First, when the forward propellant wall of the booster burns through, 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 (.009 square inches in a Series I engine), 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 reanalysed 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

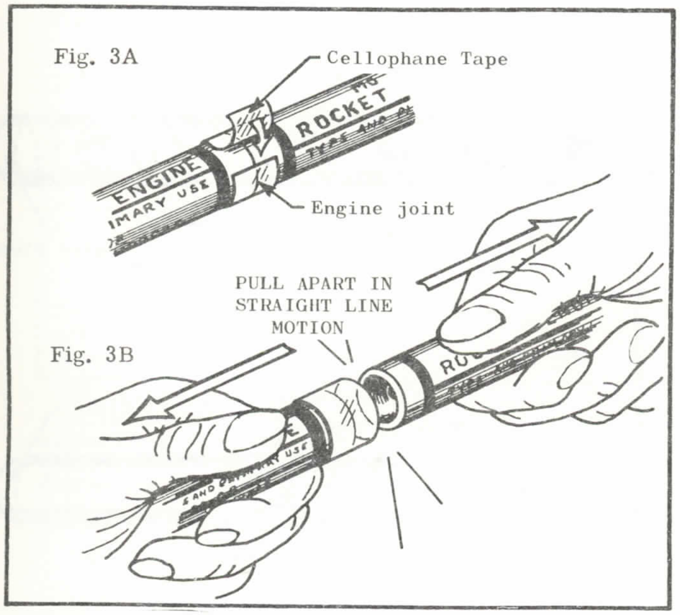


STAGE COUPLING

We have already seen that the stage coupling must be tight and must allow the stages to move apart only in a straight line directly 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 tightly 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

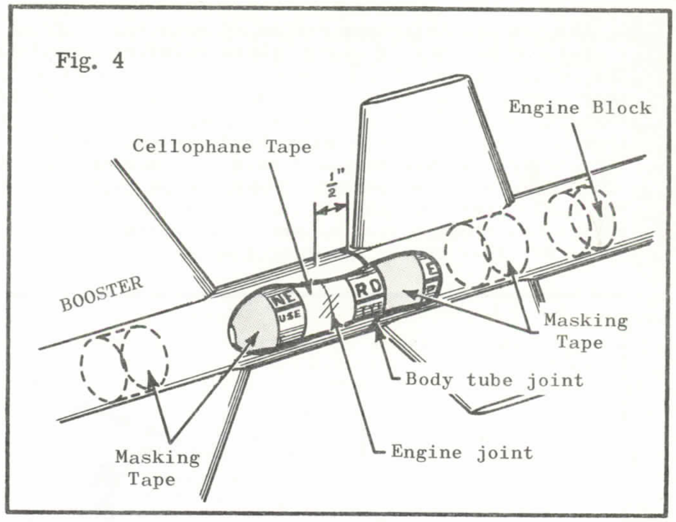
Fig. 3B



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, BT-30, and BT-40) 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 embarassing as well as damaging to the rocket.

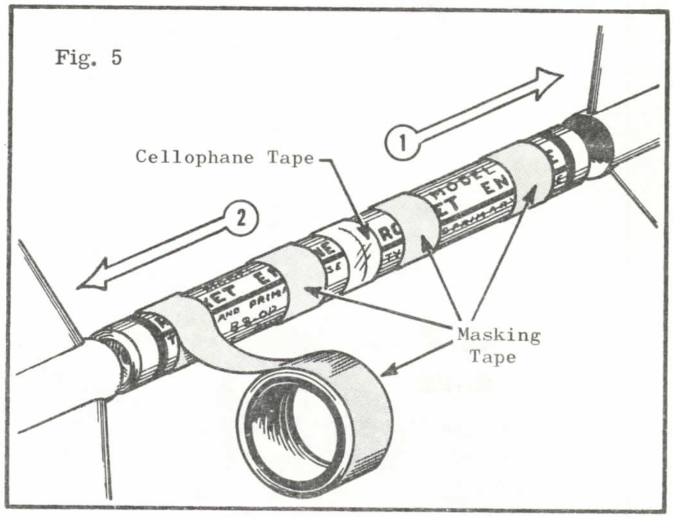
When the engines are taped together they can be inserted into the rocket. Wrap masking tape around the upper stage engine at the front and near the rear as in fig. 5 to give it a tight fit in the body and push it into place. Then wrap the booster engine and push the booster into position. Failure to get the upper stage engine in place tightly enough will result in the recovery system misfunctioning, while failure to get the booster on tightly can result in its dropping off under

Fig. 4



acceleration, leaving the entire engine unit dangling from the upper stage while the rocket loops around in the air.

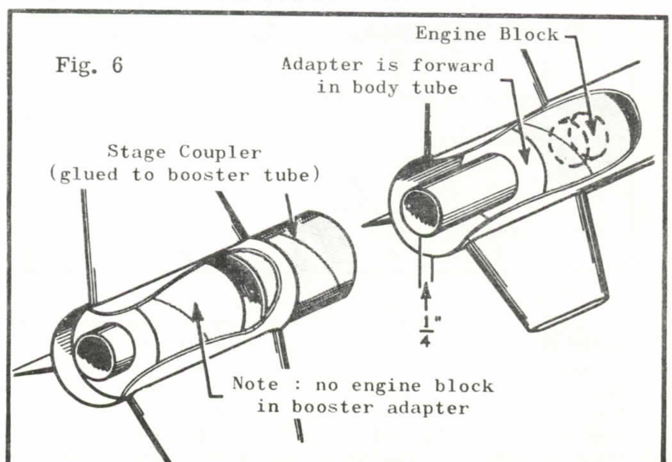
Fig. 5



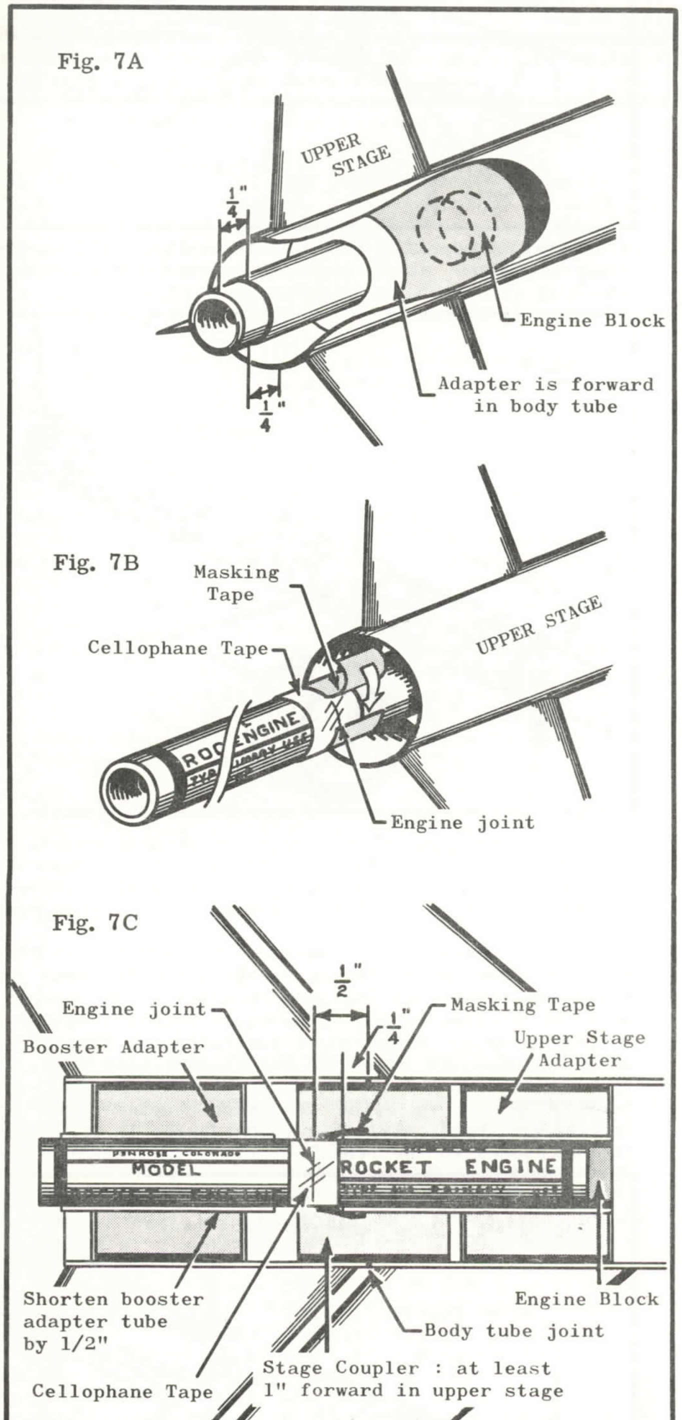
The procedures used for two stage rockets should also be used on rockets with more stages. It is important, however, to get considerable experience with two stage rockets before attempting to design a 3 or 4 stage model.

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.

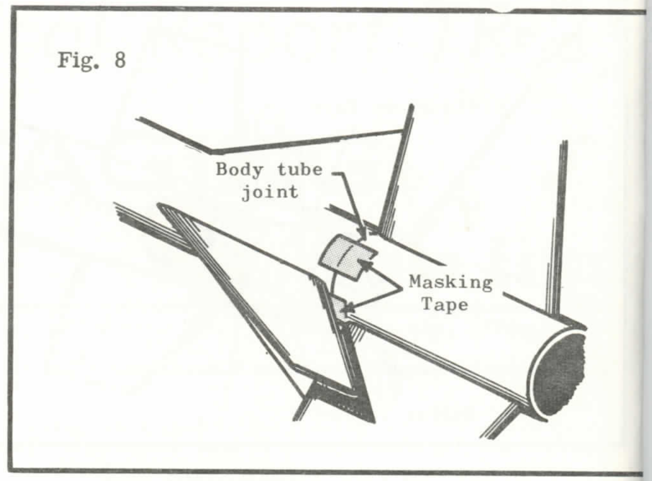
Fig. 6



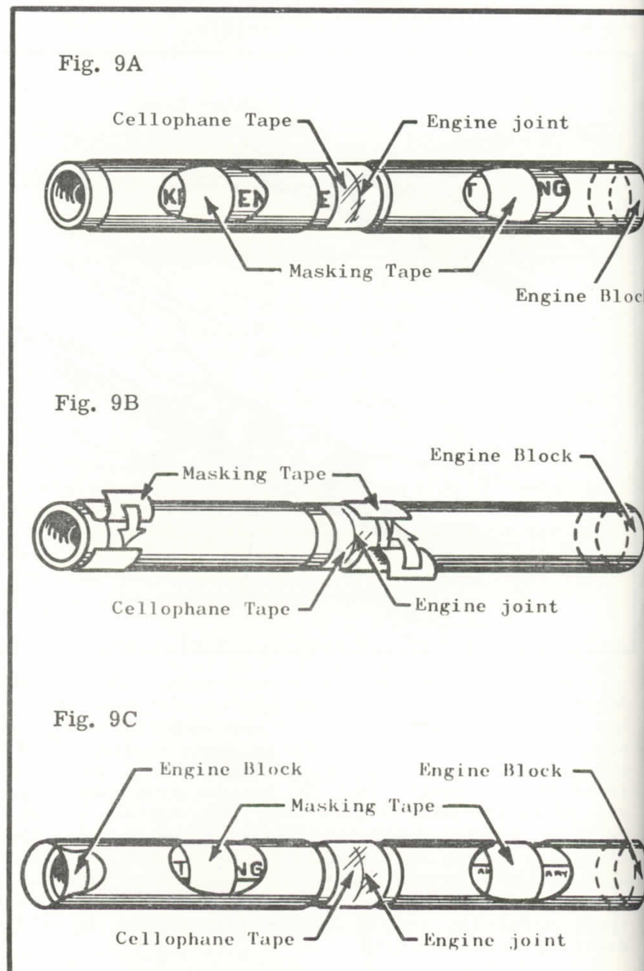
The most satisfactory method of mounting engines in rockets with large diameter tubes involves positioning the upper stage engine holder tube to project 1/4" rearward from the end of the main body and positioning the engine block so the engine projects 1/4" rearward from the end of the engine holder tube (see fig. 7). This allows the engine to be held in place in its mounting by wrapping a layer of masking tape tightly 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).



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.



With any coupling system, certain rules must be car fully followed. Engines must be held in their respecti stages securely. Engine blocks must be strongly glue Engines may be secured in their body tubes by (1) wra ping tape around the middle of the engine until it mak a very tight friction fit in the body as in fig. 9 (2) taping the end of the engine to the engine hold tube as in fig. 9B, or (3) by a combination of wrappi the engine with tape and properly positioning engi blocks as in fig. 9C.



When the forward wall of propellant in the boost ruptures and hot gases blow forward, the joint betwe the engines is pressurized. If the rocket has be constructed with proper care and the engines mount carefully, the tape that holds the stages together wi break, allowing the stages to separate, but not unt the upper stage has ignited. If proper care is n 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 engines in place.

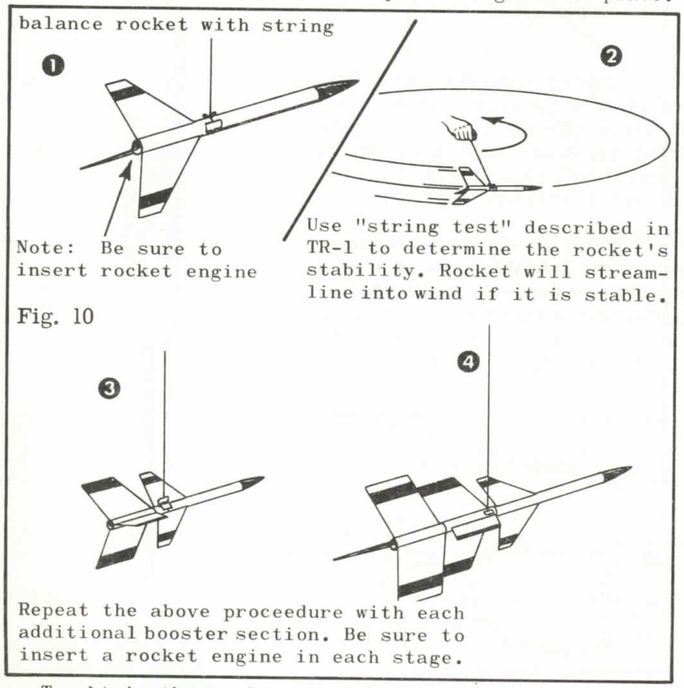


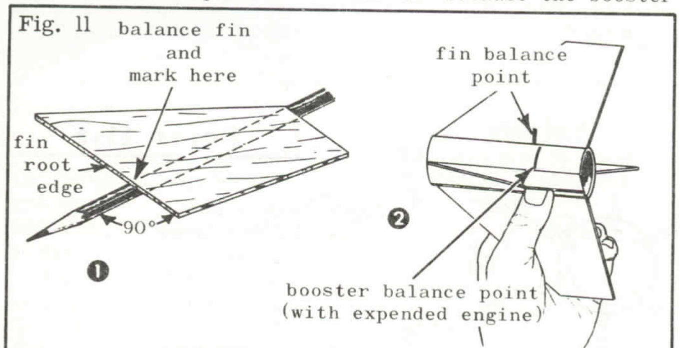
Fig. 10

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 air flow and causing turbulence.

BOOSTER RECOVERY

Most lower stages are designed so that they are unstable after separation. This is because the booster

Fig. 11



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.

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 which 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 A.8-0, B.8-0. 1/4A.8-0S, and B 3-0.

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 1/4A, 1/2A, or B 3 booster engines unless there is no wind blowing. Experience has shown that even a gentle breeze is enough to make these models weather-cock 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 B.8-6, A.8-4, B 3-5, etc.

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 launching 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 combustable 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.

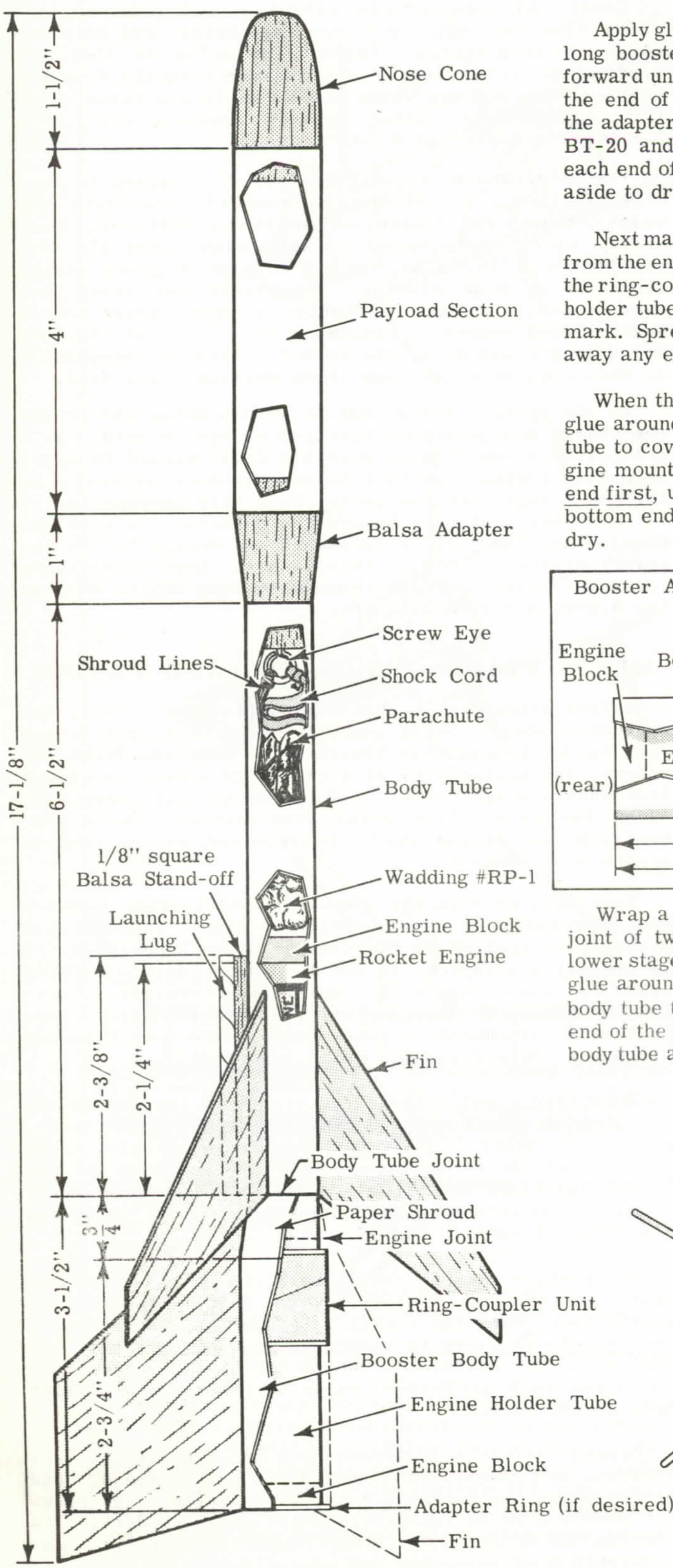
Estes Industries Rocket Plan No. 20

MINI-X

2-Stage Payload Rocket

Published as a service to its customers by Estes Industries, Inc., Box 227, Penrose, Colorado.

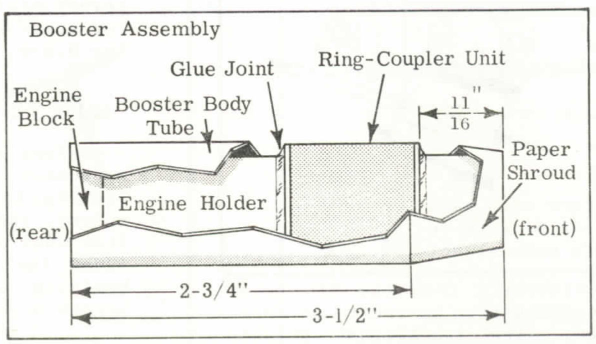
Assembly Instructions



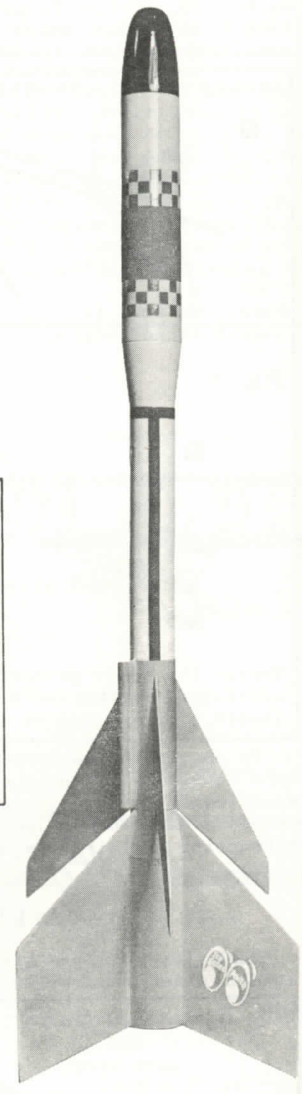
Apply glue to the last 1/4" of the inside of the 3-1/2" long booster tube. Insert an engine block and push it forward until the end of the engine block is even with the end of the tube. Select the two 20-50 rings from the adapter ring set (they should fit tightly around a BT-20 and tightly inside a BT-50). Glue one ring to each end of the JT-50C coupler. Set this assembly aside to dry.

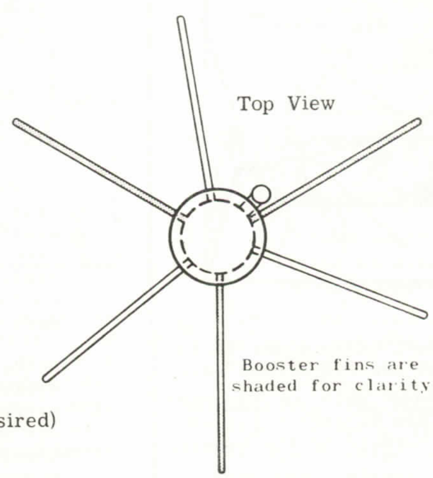
Next mark the 3-1/2" long engine holder tube 11/16" from the end that does not have the engine block. When the ring-coupler unit has dried slide it onto the engine holder tube. The front ring should be exactly on the mark. Spread glue around both ring-tube joints. Wipe away any excess glue with your finger.

When the engine mount has dried completely smear glue around the inside of the 2-3/4" long booster body tube to cover an area 1" from one end. Insert the engine mount unit into this end of the body, engine block end first, until the engine block end is even with the bottom end of the booster body tube. Set this aside to dry.



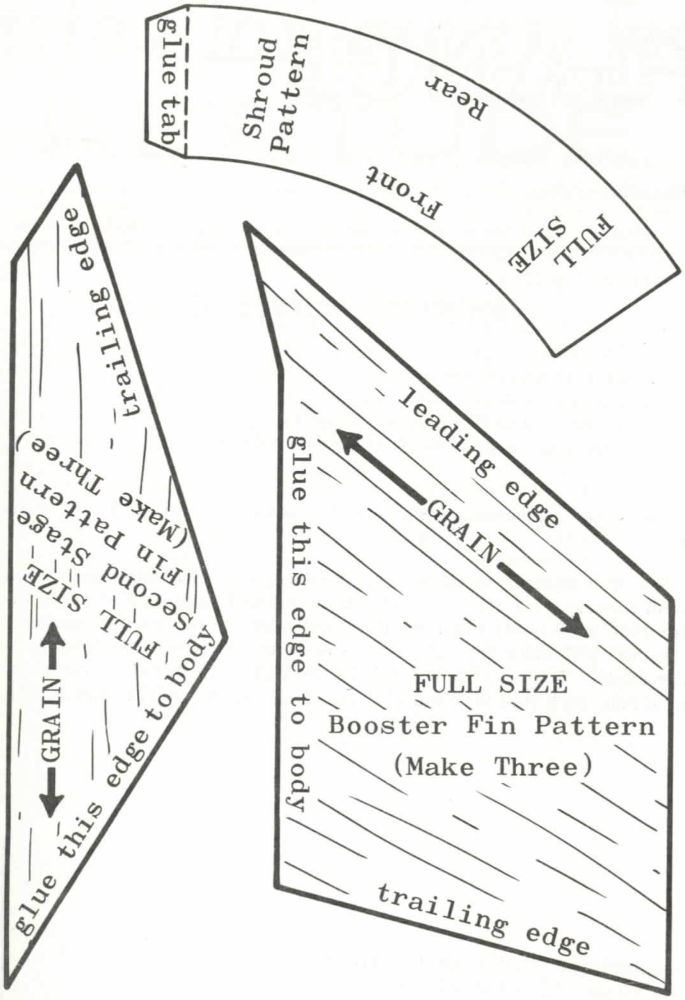
Wrap a layer of cellophane tape tightly around the joint of two rocket engines and slide them into the lower stage. Using your little finger or a brush, smear glue around the inside of the 6-1/2" long upper stage body tube to cover an area approximately 2" from one end of the body tube. Insert an engine block into the body tube and push it into place with the taped engines





Parts List

1	Nose Cone	#BNC-50J
1	Body Tube	#BT-50S
1	Balsa Adapter	#TA-2050A
1	Screw Eye	#SE-1
1	Shock Cord	#SC-1
1	Parachute	#PK-12
1	Body Tube	#BT-20D
2	Engine Blocks	#EB-20A
1	Launching Lug	#LL-1B
1	Body Tube	#BT-50J
1	Body Tube	#BT-20G
1	Stage Coupler	#JT-50C
1	Adapter Ring Set	#TA-1
	Balsa Fin Stock	#BFS-20

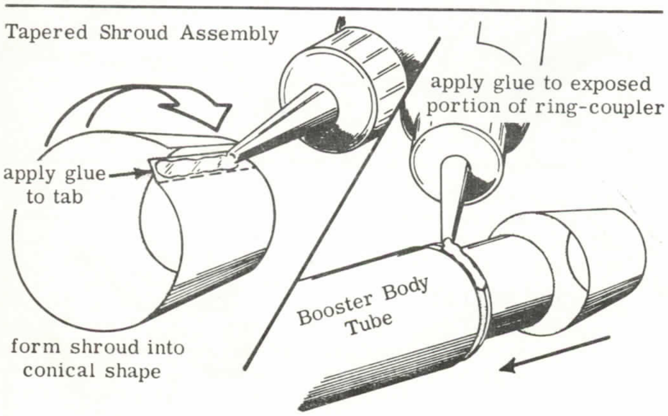


Trace fin patterns onto a separate sheet to preserve plans.

and the lower stage. Remove the engines immediately. (Another method of positioning the engine block is to mark an empty engine casing 2-1/4" from one end. Spread glue around the inside of the 6-1/2" body tube about 2" from one end. Insert an engine block and push it forward into the body tube with the engine casing until the mark on the casing is exactly even with the end of the body tube--and the engine block is 2-1/4" from the end of the body. Remove the engine casing immediately.)

Carefully trace the shroud pattern onto index paper or the heavy paper supplied in the adapter ring set. Cut out the shroud and form it to a conical shape. Apply glue to the tab and hold it in place with the joint exactly covering the tab area. When the glue has set slip the shroud onto the engine holder tube. Spread glue around the exposed part of the ring-coupler unit and slide the shroud up tightly against the booster body tube. Wipe away any excess glue.

Tapered Shroud Assembly



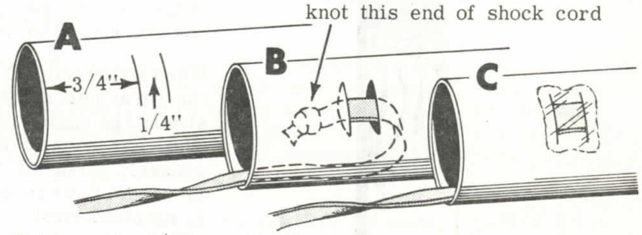
Glue the large end of the balsa adapter to one end of the payload section tube. The nose cone should fit tightly in the other end. If it is too loose wrap its shoulder with tape to increase the diameter.

Cut out three booster fins and glue them to the booster body tube. Match the grain on the balsa with the grain direction indicated on the fin pattern. Align each fin by sighting along the body and adjusting it until the fin is parallel to the body and projects straight away from it. When the glue has dried run a fillet of glue along each fin-body joint. Repeat this procedure with the three second stage fins.

Glue the launching lug to a 2-3/8" long piece of 1/8" square balsa. Glue the balsa to the second stage midway between two fins.

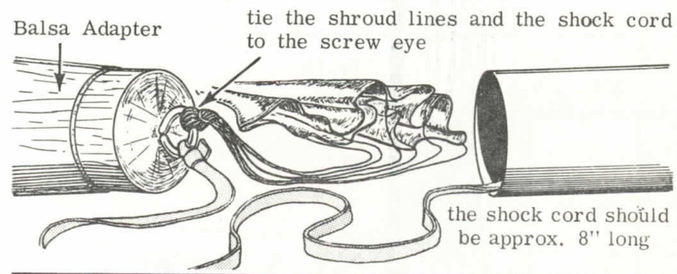
Attach the shock cord and recovery system as shown in the illustrations below.

Shock Cord Installation



A. Cut two slits 1/4" apart in the forward end of the upper stage body tube.
B. Press in the section between the slits and thread the shock cord through the opening.
C. Push the caved-in portion outward and seal with glue.

Attaching Recovery System



Paint the model and apply decals. Tape the upper and lower stage engines together with cellophane tape and secure tightly in the rocket as described in TR-2 (published in the Feb. '64 issue of the Model Rocket News). These procedures must be followed or the rocket will not fly correctly.

Recommended Engines

Upper Stage		Lower Stage	
1/4A. 8-4	1/2A. 8-4	1/4A. 8-0	1/2A. 8-0
A. 8-4	B. 8-6	A. 8-0	B. 8-0
		B. 3-0	C. 8-0

(Use 1/4A. engines for first flights.)

Use Series I and Series II engines only.

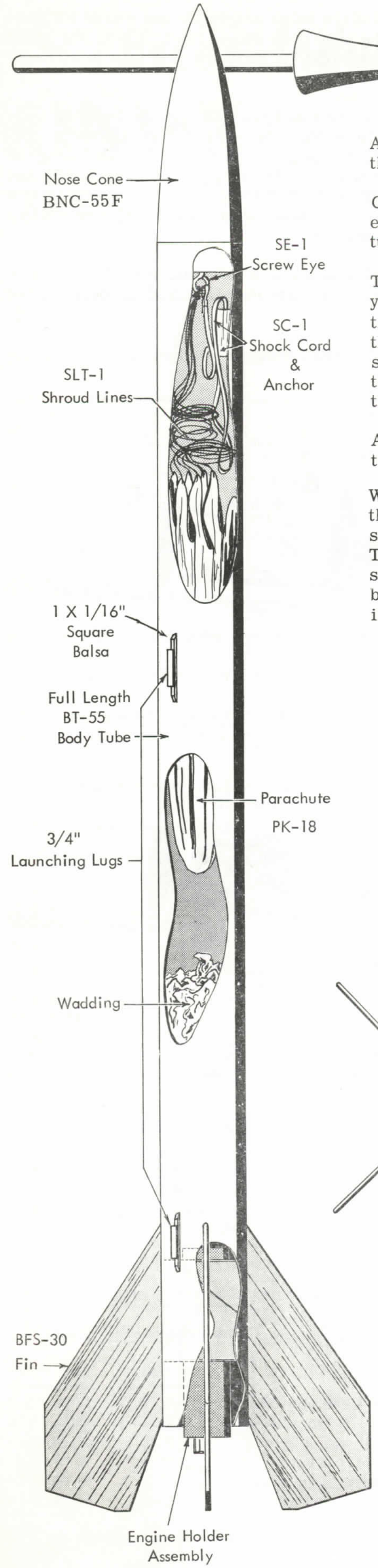
Suggested Engine Combinations

	1st Stage	2nd Stage
Medium Altitude with light payload	1/4A. 8-0	1/4A. 8-4
Medium Altitude with 1/2 oz. payload	1/2A. 8-0	1/2A. 8-4
Medium Altitude with 1 oz. payload	A. 8-0	A. 8-4
High Altitude with light payload	B. 8-0	B. 8-6
Extra High Altitude with light payload	C. 8-0	B. 8-6
High Altitude with 1 oz. payload	B. 3-0	B. 8-6

Other combinations of engines may be used to obtain desired flight performance.

(Maximum recommended payload weight is 1 oz.)

SKYLANCE



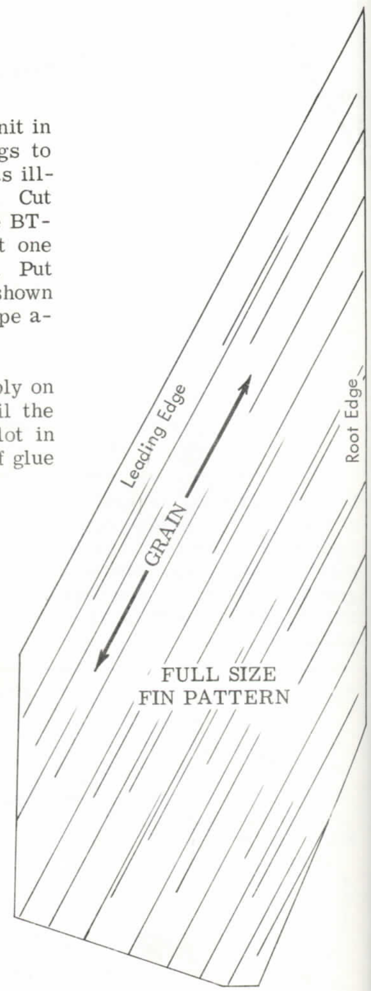
Assemble the engine holder unit as shown and glue it into the rocket body. 1/4" of the rear of the engine holder tube should be visible when viewed from the side.

Cut out the fins and sand them to shape. Sand the sides of the fins until smooth and sand all edges except the edge that is attached to the body (Root Edge) until smooth and round. Mark the tube and glue the fins in place. See the top view.

The method of anchoring the shock cord is detailed in the Model Rocket News, Vol. 5, No. 3. If you wish to use the old method cut two slits in the forward end of the body 1" and 1-1/2" from the front. Tie a knot in the end of the shock cord and thread the unknotted end of the cord thru the slit nearest the front from the inside of the tube, then on thru the second slit from the outside of the tube. Draw the shock cord on thru until the knot is seated against the inside edge of the first slit. Apply a coat of glue over the entire area of the cord exposed to the outside on the body tube.

Attach the screw eye to the nose cone. Assemble the parachute and tie it and the free end of the shock cord to the screw eye.

When flying the SKYLANCE pack 4 or 5 squares of flameproof wadding into the body, then pack the parachute and shroud lines in loosely over the wadding. The engine is secured in place by sliding the engine into the holder tube until seated against the front hook of the engine holder. The rear hook of the engine holder will snap into place at the rear of the engine holding it securely during all phases of the flight. Engines from the 1/2A .8-2 thru the B.8-6 units may be used. You can use an 18" parachute with this bird but if it is at all windy the 12" parachute is recommended.

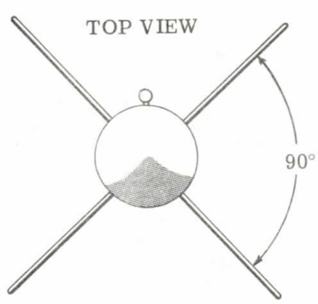


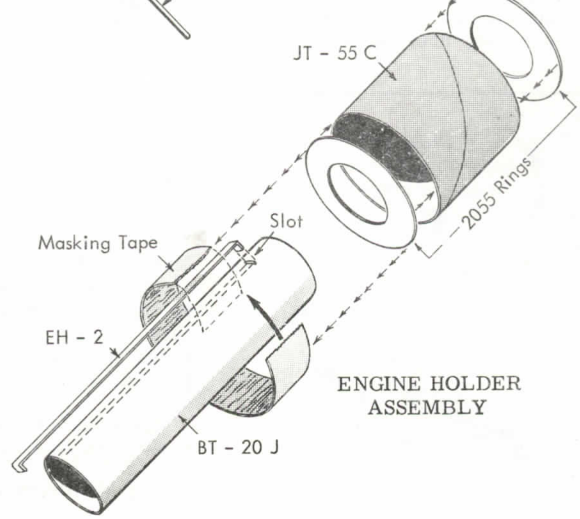
FULL SIZE
FIN PATTERN

Assemble the engine holder unit in two steps. Glue the 2055 rings to the ends of the JT-55 coupler as illustrated and set aside to dry. Cut a slot 1/4" from one end of the BT-20J just large enough to admit one hook of the engine holder EH-2. Put the engine holder in place as shown and apply a strip of masking tape around the tube and holder.

Slide the coupler-ring assembly on the tube-holder assembly until the front ring just reaches the slot in the tube. Apply a good fillet of glue around both tube-ring joints.

TOP VIEW





ENGINE HOLDER
ASSEMBLY

Estes Industries Technical Report TR-3

ALTITUDE TRACKING

Single Station Tracking

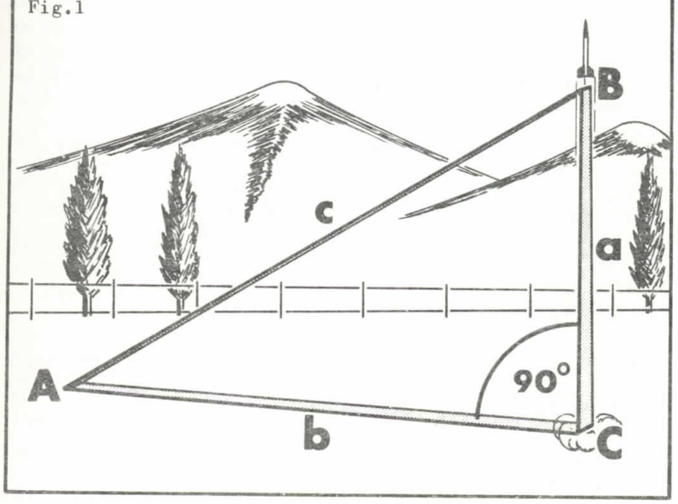
Every Rocketeer asks the question: "How high did it go?" However, previously few model rocketeers had the facilities to determine altitudes with any reasonable degree of accuracy. Some have attempted to find the altitude achieved by their rockets by the use of a stop watch, but this method is so highly 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, <u>including</u> one side are known. Now every triangle has six parts: three angles and three sides. So 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



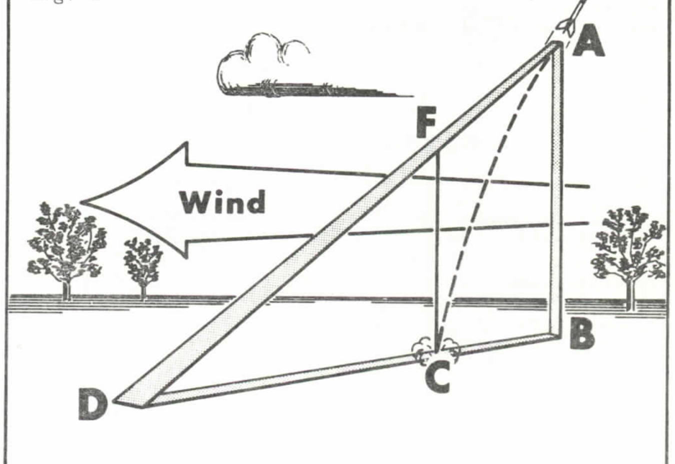
In the diagram above, point A represents the tracking station, B the rocket at its maximum altitude, and C a point on the ground directly below the rocket. The angle formed by the lines at C is then a right angle or 90°. Since there are 180° in the angles of a triangle, if we know angle A, we can find angle B, since B = 180° - (A + C), or B = 90° - 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 now 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.

Now 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. So 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.

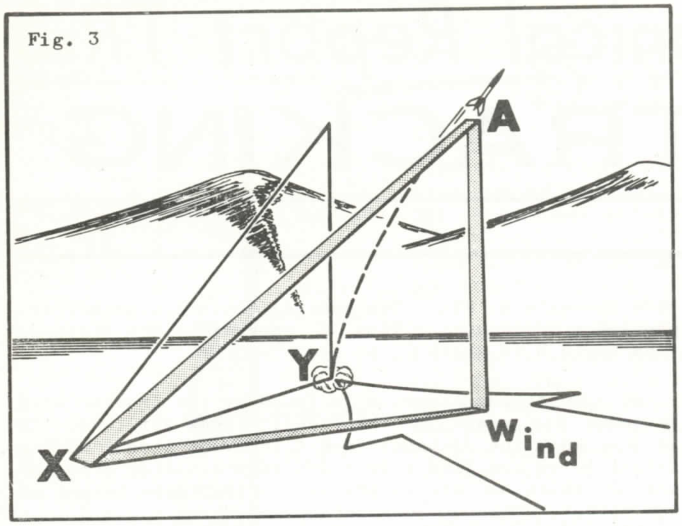


Fig. 3

So by observing the proper relation between wind direction and the position of the tracker, we can generally determine with 90% 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. Thus 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.

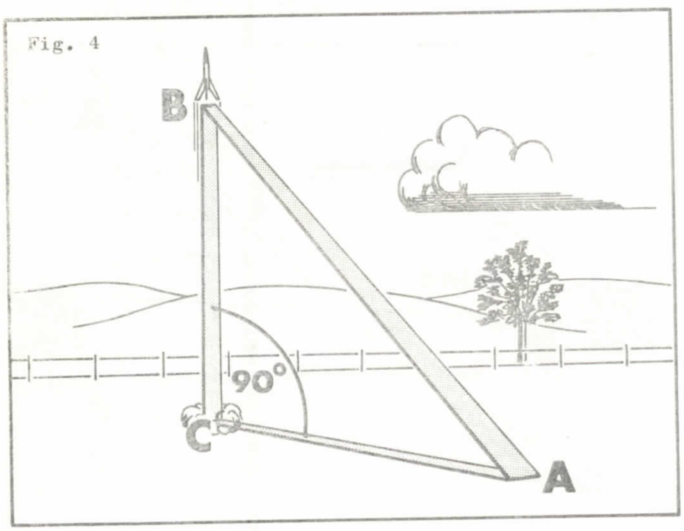


Fig. 4

If we assume that the rocket flight is vertical, we can call angle C a right angle (90°). In that case, B is equal to 90° - A (the sum of the angles in a triangle is 180°, half of this or 90° is taken by angle C). Then to find the distance from C to B or the height the rocket reached we take the <u>tangent of angle A</u> (abbreviated tan) <u>times the distance from the tracker to the launcher</u> (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°, we will look in the table of trigonometric functions and find the tangent of 62°. 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.

Kind souls of many years ago were nice enough to determine the tangents for all angles of right triangles, so we have a table which lists them. Since the tangent of the angle equals the opposite side divided by the adjacent side, or in the case of our first example, 470 divided by 250, by multiplying the quotient times the divisor we find the dividend. In our case, the quotient or tangent is 1.88, the divisor 250, and the dividend 470.

Summary

(1) In single station elevation tracking, we make sure that the line from the tracking station to the launcher is 90° 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 <u>in line with the wind</u>, 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 distances 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°, and station B calls in an elevation of 22°. The total of these two angles is 56°, so angle C, located at the peak of the rocket's flight, is equal to 180° - 56°, or 124 degrees. We now have 2 angles and one side to work with. Our first step will be to list the angles and their sines. Since the sin

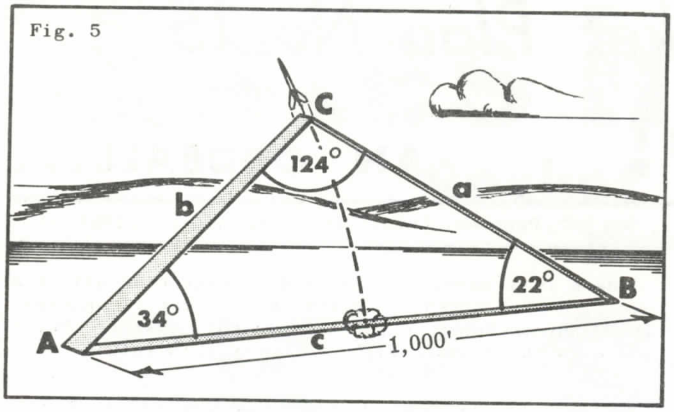


Fig. 5

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

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

The law of sines states that $\frac{c}{\text{SinC}} = \frac{b}{\text{SinB}} = \frac{a}{\text{SinA}}$ c = 1000', sinC = .8290 Therefore, $\frac{1000}{.8290} = \frac{b}{.3746} = \frac{a}{.5592}$ Pulling out the slide rule, we determine that $\frac{1000}{.8290} = 1205$. So 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 pulling out the slide rule again, we find that b = 451. The same process is repeated to find side a: $1205 = \frac{a}{.5592}$, a = 1205 x .5592, a = 674'. So we now have the three sides of the triangle.

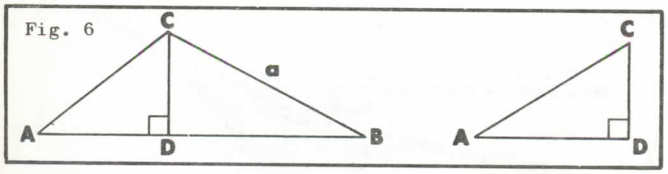


Fig. 6

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 $.5592 = \frac{a}{451}$, since $\text{SinA} = \frac{\text{opposite side}}{\text{hypotenuse}}$. .5592 x 451 = 252, hence CD = 252', and we now know the altitude reached by the rocket was 252'.

Fortunately, our computations to determine the altitude of the rocket can be simplified. To find the altitude we need only determine one of the unknown sides of the original triangle. So 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 $\frac{c}{\text{SinC}} = \frac{a}{\text{SinA}}$. Since we have found $\frac{c}{\text{SinC}}$ equal to 1205 when C = 124°, $\frac{a}{\text{SinA}} = 1205$. 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 on an angle is equal to its opposite side divided by the hypotenuse, so 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 $\frac{c}{\text{SinC}}$ 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 $\frac{c}{\text{SinC}}$ x SinA = A, so we can substitute the expression ($\frac{c}{\text{SinC}}$ x SinA) for a in the formula a x SinB = CD. Our formula then becomes $\frac{c}{\text{SinC}}$ 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, $\frac{10 \times 4}{5} = 8$, and $\frac{10}{5} \times 4 = 8$.

So we can change the expression $\frac{c}{\text{SinC}}$ x SinA x SinB = CD to read $\frac{c \times \text{SinA} \times \text{SinB}}{\text{SinC}}$ = CD. So by performing two multiplications and one division, we can find the altitude of the rocket. The division of SinC into the expression (c x SinA x SinB) can occur at any point, as $\frac{c \times \text{SinA}}{\text{SinC}}$ x SinB = CD, and c x $\frac{\text{SinA} \times \text{SinB}}{\text{SinC}}$ = 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 <u>in line with the wind</u>.

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

(4) The altitude is computed by the formula height = $\frac{c \times \text{SinA} \times \text{SinB}}{\text{SinC}}$, when A and B are the angles read by the trackers, c is the baseline distance, and C is the third angle formed by the meeting of the lines of sight of the two trackers.

Sines and Tangents

∠	sin	tan	∠	sin	tan	∠	sin	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 Industries Rocket Plan No. 15

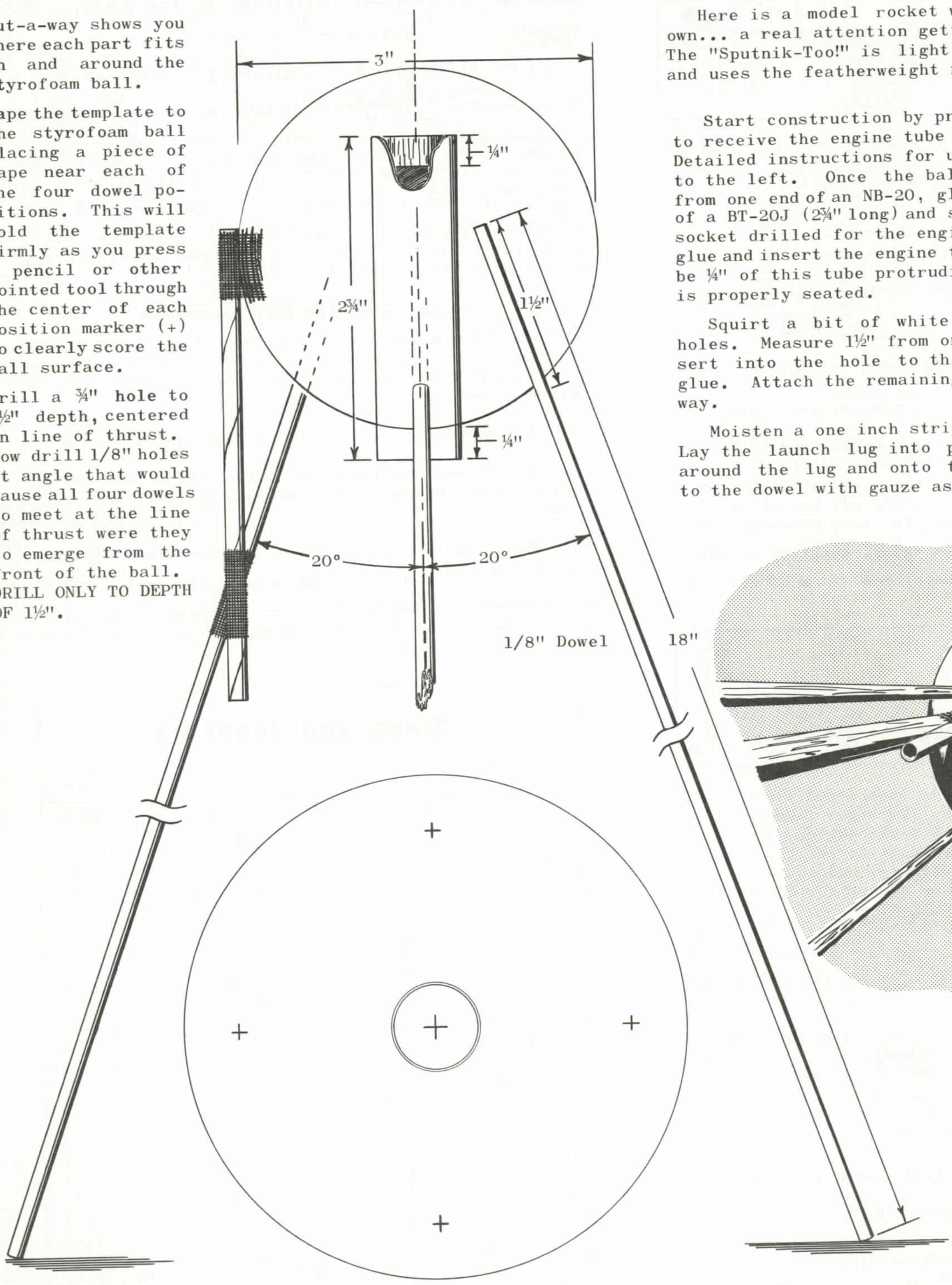
SPUTNIK – TOO! AN ODDBALL...

Published as a service to its customers by Estes Industries, Inc., Box 227, Penrose, Colo. ©Estes Industries, 1964

Cut-a-way shows you where each part fits in and around the styrofoam ball.

Tape the template to the styrofoam ball placing a piece of tape near each of the four dowel positions. This will hold the template firmly as you press a pencil or other pointed tool through the center of each position marker (+) to clearly score the ball surface.

Drill a ¾" hole to 2½" depth, centered on line of thrust. Now drill 1/8" holes at angle that would cause all four dowels to meet at the line of thrust were they to emerge from the front of the ball. DRILL ONLY TO DEPTH OF 1½".

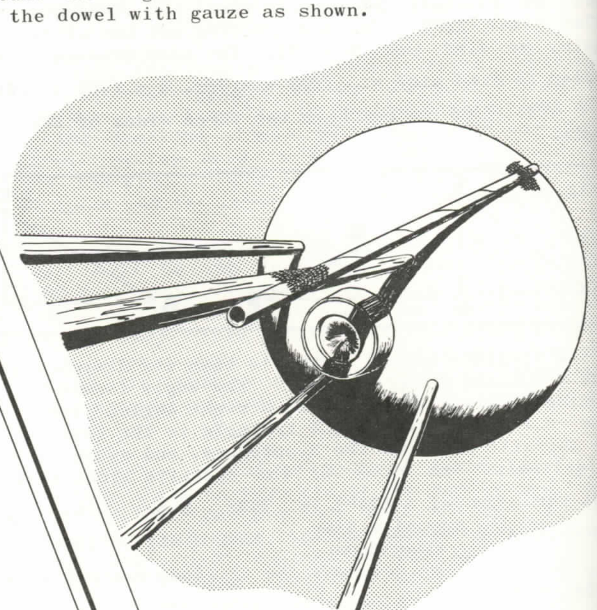


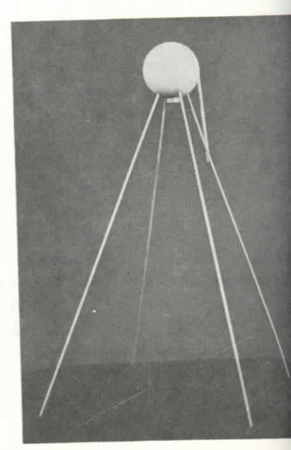
Here is a model rocket with a character all it's own... a real attention getter where ever it appears! The "Sputnik-Too!" is light in weight, easy to build and uses the featherweight recovery principle.

Start construction by preparing the styrofoam ball to receive the engine tube and dowel stabilizers. Detailed instructions for use of the template are seen to the left. Once the ball is ready, cut a ¼" slice from one end of an NB-20, glue this slice into one end of a BT-20J (2¾" long) and stand aside to dry. Smear socket drilled for the engine tube with a film of white glue and insert the engine tube assembly. There should be ¼" of this tube protruding from the ball when tube is properly seated.

Squirt a bit of white glue into one of the 1/8" holes. Measure 1½" from one end of the dowel and insert into the hole to this point. Wipe off excess glue. Attach the remaining three dowels in this same way.

Moisten a one inch strip of gauze with white glue. Lay the launch lug into position and form the gauze around the lug and onto the ball. Secure the other to the dowel with gauze as shown.





1	Styrofoam ball, 3" O.D.	Part #	SB-3
4	Dowel, 18" x 1/8" Dia.	" "	WD-1
1	Body tube 2¾" long	" "	BT-20J
1	Nose block piece	" "	NB-20
1	Launching Lug, 5" long	" "	LL-1C

NOTE: Rather than use the 5" launching lug, you may desire to mount a short lug on the ball and another lug on the dowel. If so, use another dowel to line them up.

Estes Industries

Rocket Plan No. 12

March, 1963

SKY SLASH II

Winning Design

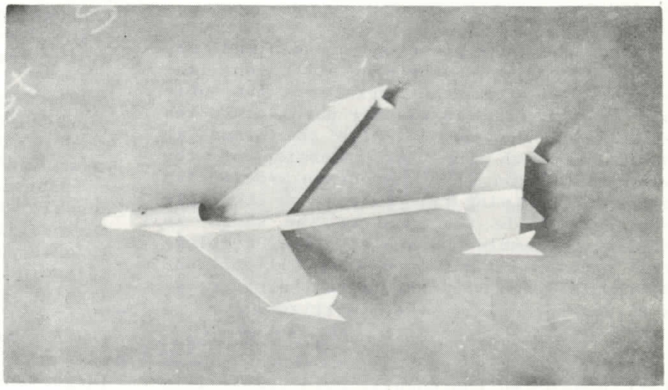
Estes Industries Boost-Glide Contest

by

Larry Renger

About the Designer

Larry Renger is a Senior in Aeronautical and Astronautical Engineering at Massachusetts Institute of Technology. A serious modeler for over seven years, he also holds three AMA indoor records, and combined his skills in model aeronautics and model rocketry to produce this design.

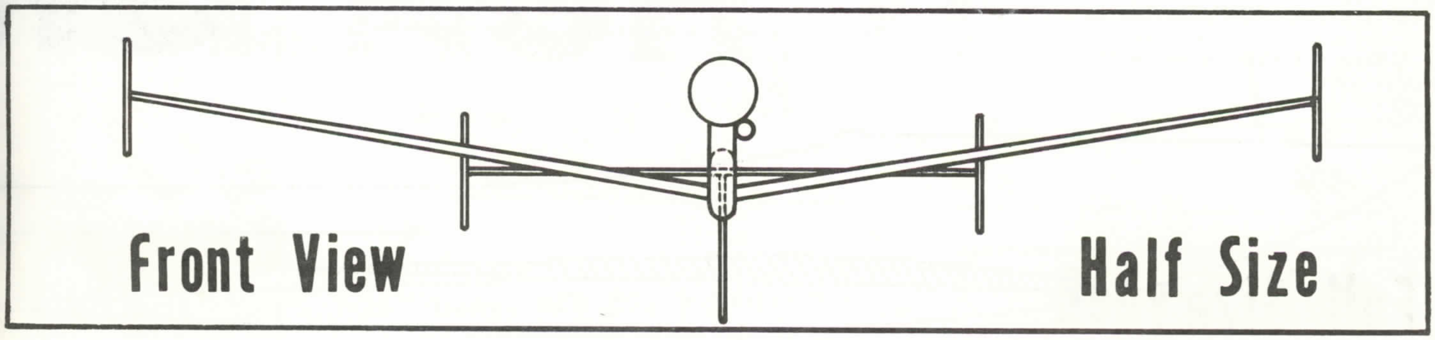


Parts List

1 Nose Cone BNC-20B
1 Sheet Balsa BFS-80
2 Sheets Balsa BFS-40
2 Sheets Balsa BFS-20
1 Body Tube BT-20
1 Launching Lug LL-1B
1 Nose Cone Weight NCW-1

Equipment Needed

1 Knife or Razor Blade
1 Bottle White Glue
1 Sheet Medium Sandpaper
2 Sheets Extra Fine Sandpaper
1 Pair Scissors
1 18" Straight Edge
1 Coping or Jig Saw



Assembly Instructions

This model is recommended only for the experienced modeler, as care and precision in the building are necessary for satisfactory results. The rocketeer who has previous experience with both boost-gliders and model airplanes is in the best position to build this glider.

Begin construction by tracing the patterns for the balsa parts onto the proper sized balsa sheets. Be sure that the balsa thickness is the same as that indicated on the plan sheet. Cut out the parts, being careful to run the wood grain in the direction required.

Sand the wings to the airfoil shown on the plans, and sand all other parts to achieve a smooth surface. Using a straight edge at least 18 inches long, mark the body for wing, stabilizer, and engine alignment. For this alignment, hold one end of the straight edge so that its edge is at the point on the rear of the body where the top of the stabilizer will come, run the other end of the straight edge to fall on the position for the bottom of the wing, and draw a line here for aligning the wing. Sand the 2 1/4" notch in the bottom of the rear of the body so that the notch's surface will run exactly on the line from the bottom of the wing to the rear of the body. Sand the upper forward part of the body so that the edge to which the engine holder tube is attached will be exactly parallel with the line from the wing to the stabilizer.

Turn the body piece upside-down and prop it in position so the wing attachment line is one inch from the surface of the table and so the line is exactly parallel to the surface of the table. Glue the wings in position, with the flat underside of the wing exactly on the line drawn previously, allowing the wing tips to rest on the table surface. While the glue on the wings is drying, assemble separately the complete tail section. Make sure that all portions of the tail are straight, with the rudder at a 90 degree angle to the stabilizer.

After the glue on both the wings and the tail has dried thoroughly, hold the tail in place against the body, and using the straight edge, check to be sure the wings and tail will fall exactly in line, and be sure that the forward upper surface where the engine holder tube will be attached is exactly parallel to the wing-tail line. Glue the assembled tail in place, checking to be sure that the alignment is still correct. If a wide, circular glide is desired, glue the tail assembly in place so that one tip is 1/8" higher than the other tip. After the glue holding the tail to the body has hardened, check the alignment again, then check to be sure the forward upper surface is still parallel to the wing-tail line. Glue the nose cone in the engine holder tube, glue the engine holder tube to the body, and glue the tip plates in position on the wings.

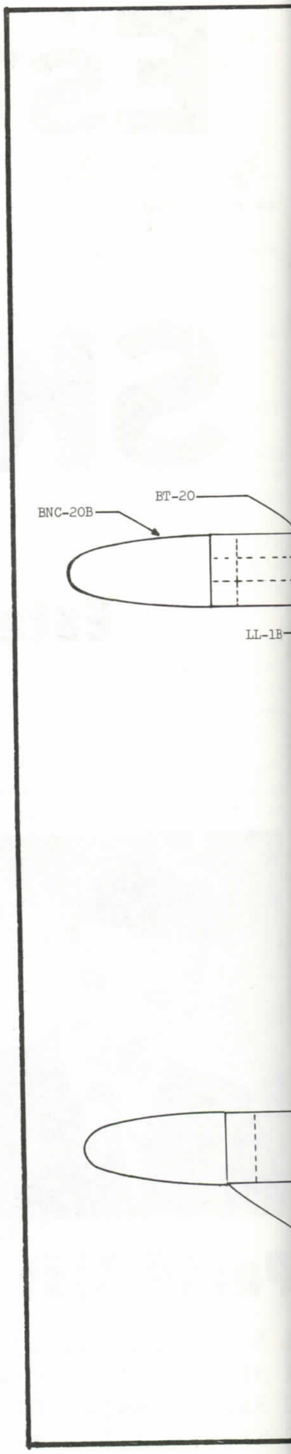
When all these glue joints have hardened, apply a glue fillet to all joints with the exception of the nose cone joint. Apply a light coating of white glue to the upper surface of the body for its entire length to protect the body from the exhaust gases. Glue the launching lug in place. A second fillet layer may be applied to the wing-body joint to give it additional strength.

Punch or cut one 3/16" diameter or several 1/16" diameter ejection pressure relief vent holes in the engine holder tube 1/8" back from the base of the nose cone. To check the positioning of the holes, place an engine casing in the holder tube, mark the casing where the rear of the holder comes, take the casing out, lay the casing against the tube with the mark next to the rear of the tube, mark the tube where the forward end of the casing touches it, and cut the hole 1/8" back of this point.

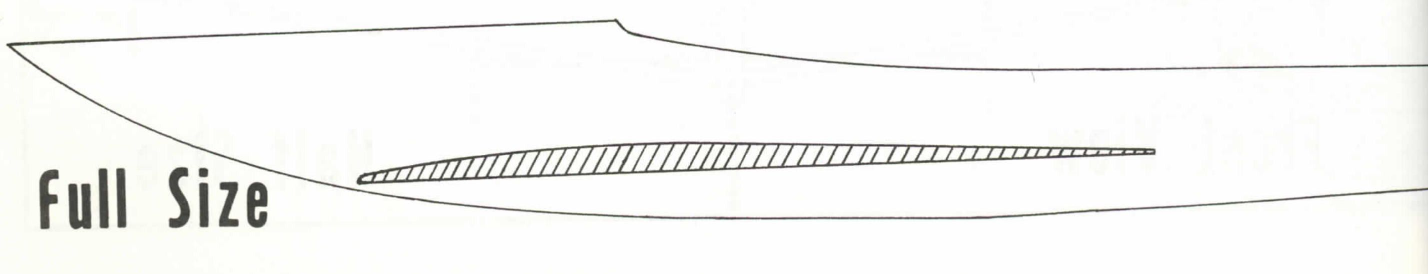
Before flying the Sky Slash II, balance it for glide by hand launching it and adding small amounts of weight (slivers of nose cone weight NCW-1) to the nose if the rocket stalls, or to the tail if the rocket comes in too fast. When the Sky Slash II is properly balanced, it should travel at least 20 feet forward for every foot of drop when hand launched lightly. Hand launched duration should average over four seconds for a well balanced model, although the maximum for a particular model will vary. The best way to get the best glide is to work on the balancing until the model feels right and appears to glide right, both of which are part of the modeler's skill gained only through practice. Generally the balance point for the glider will be in the region of the rear of the wing-body root joint.

The first flights on the Sky Slash II should be made with 1/4A.8-2 engines if the glider without engine weighs less than 20 grams (3/4 ounce, determined by weighing on a balance; the science department at your school should have one) or with 1/2A.8-2 engines if the rocket is heavier. Individual weights will vary with the amount of sanding, balancing weight, and paint. Generally, the lighter the glider, the longer the flight. For most sport flying, the 1/4A and 1/2A engines are recommended, as the Sky Slash II may well go out of sight on the glide with larger engines. For contest use, the B.8-2 engine is recommended.

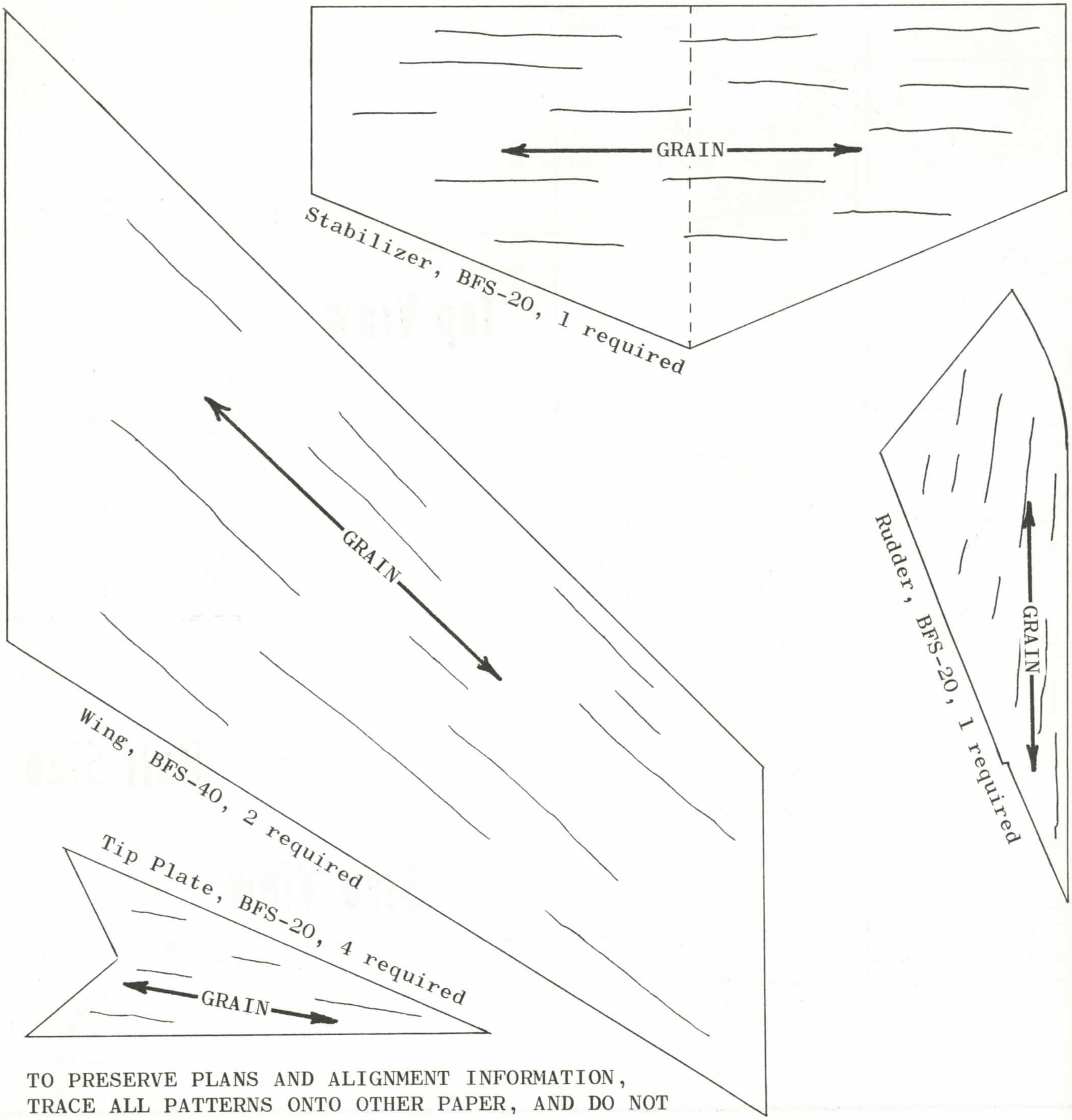
If the Sky Slash II fails to rise vertically on its initial flights, the alignment of the various parts should be checked carefully and corrections made if necessary. In addition, if one wing is heavier than the other, the glider may tend to turn in the direction of the heavier wing under power and in glide. If this is the case, the proper amount of weight added near the tip of the light wing will correct this. If there is much difference between the airfoils of the two wings, this may also cause a poor flight. As experience is gained in the use of this design, it will be possible to achieve better vertical flights and longer durations, as much of the performance of this rocket is dependent on the rocketeer's own skill.



SK



Full Size



TO PRESERVE PLANS AND ALIGNMENT INFORMATION, TRACE ALL PATTERNS ONTO OTHER PAPER, AND DO NOT CUT UP THIS SHEET.

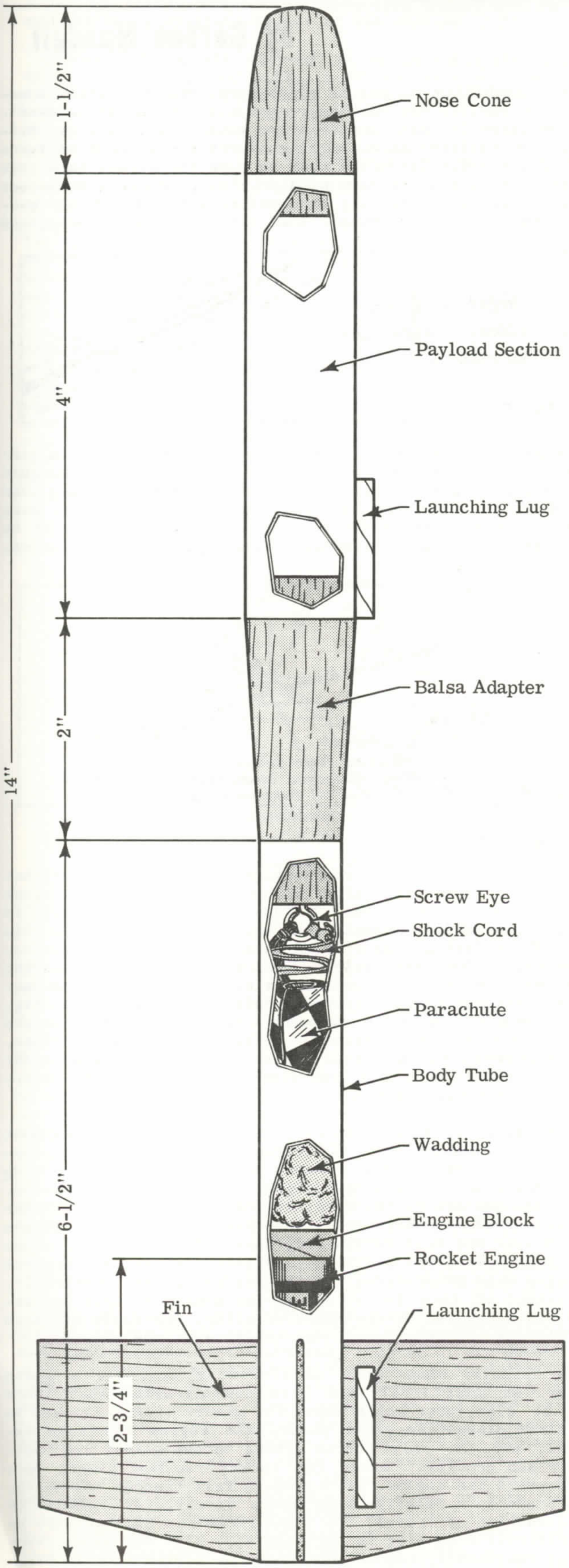
Launching Information

The Sky Slash II is launched vertically using an electric firing system. DO NOT launch the Sky Slash II at any angle greater than 30 degrees from the vertical, as this can result in the destruction of the model. Some launchers will require lengthening the leads to the micro-clips to allow attaching them to the ignitor. This can be done by cutting two 20 inch lengths of #18 wire, attaching micro-clips to one end of each, and gripping the other ends of the wires with the clips already on the launcher. Do not use Jetex wick with the Sky Slash II, as the exposed balsa is especially subject to damage by the flame of the wick.

Estes Industries Rocket Plan No. 19

LOADLIFTER 1-A

Winning Design
Favorite Design Contest
by Merrell Lane



Assembly Instructions

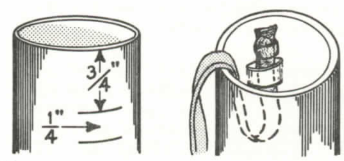
Spread glue around the inside of one end of the 6-1/2" long body tube as far in as you can reach with your little finger. Insert an engine block and push it forward into the body tube with an empty engine casing. Move the block forward until the end of the engine casing is even with the end of the body tube (and the engine block is 2-3/4" from the end of the body). Remove the engine casing immediately.

Cut out four fins and glue them to the body tube. Be sure to match the grain on the balsa with the grain direction indicated on the fin pattern. Align each fin by sighting along the body and adjusting it until the fin is parallel to the body and projects straight away from it. After the glue has dried run a fillet of glue along each of the fin-body joints.

Glue the launching lugs into place as shown in the drawing. Apply glue to the large end of the balsa adapter and insert it into one end of the payload section tube. The nose cone should fit tightly in the other end of the payload tube. If it is too loose wrap its shoulder with tape to increase the diameter.

Attach the shock cord and recovery system as shown in the illustration. Paint the model and apply decals.

Shock Cord Installation



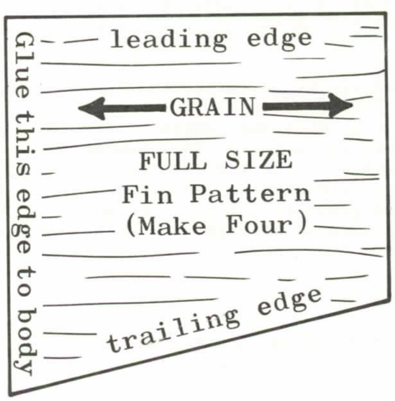
Cut two slits and push section inward. Thread cord through and knot. Restore body tube contour and seal with glue.

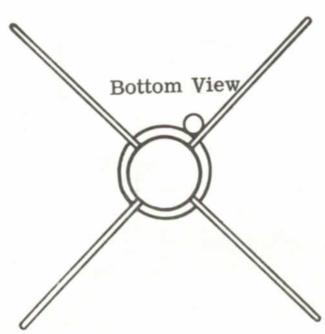
PARTS LIST

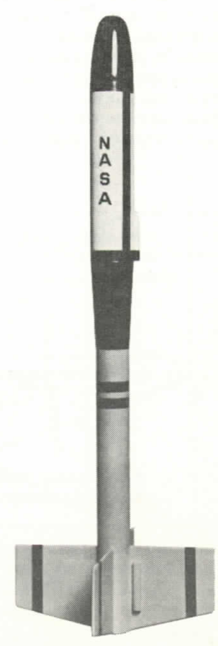
1	Nose Cone	#BNC-50J
1	Body Tube	#BT-50S
2	Launching Lugs	#LL-1A
1	Balsa Adapter	#TA-2050
1	Screw Eye	#SE-1
1	Shock Cord	#SC-1
1	Parachute	#PK-12
1	Body Tube	#BT-20D
1	Engine Block	#EB-20A
	Balsa Fin Stock	#BFS-20

Recommended Engines

1/4A.8-2 1/2A.8-2
A.8-3 B.8-4
B.3-5







Estes Industries Technical Report TR-4

Rear Engine Boost-Gliders

by Gordon Mandell

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, and to augment the findings library research in aerodynamics has been conducted. It must be borne in mind that these findings are of a mainly qualitative nature, with expected accuracy in most other cases (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, then, the design requirements for a vehicle of this type. The first thing we must bear in mind is that we are designing a rocket, which is

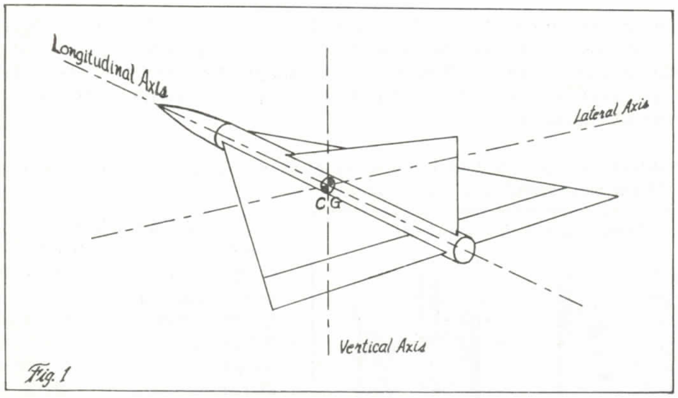


Fig. 1

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 the CP is called in physics a moment-arm, and the stabilizing force exerted by the surfaces, wing and rudder, multiplied by the length of 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 case of

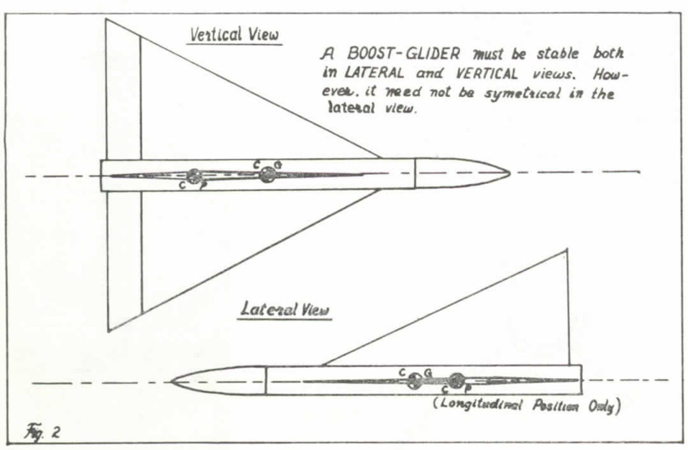


Fig. 2

rocket stability is one in which very little corrective moment is applied because the rocket flies with little oscillation directly into the relative wind. While the air hitting the surfaces at an angle produces a component of force acting perpendicular to the body to push the rocket back into parallel with the 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

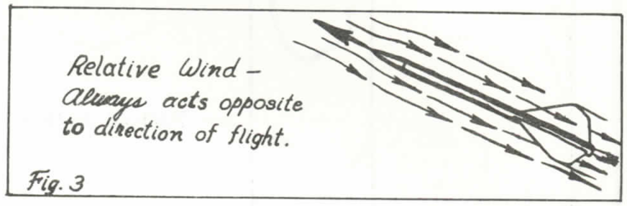


Fig. 3

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 that needed for most other rockets. Generally the center of pressure should be at least 3/4 the body diameter behind the center of pressure.

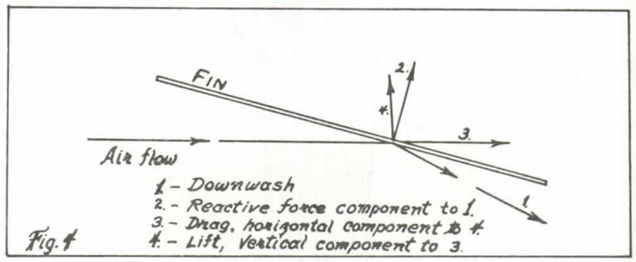


Fig. 4

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 wing 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 wing (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 expells 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 at the terminal velocity of glide.

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 posesses an engine located very far to the rear or excessive rocket stability.

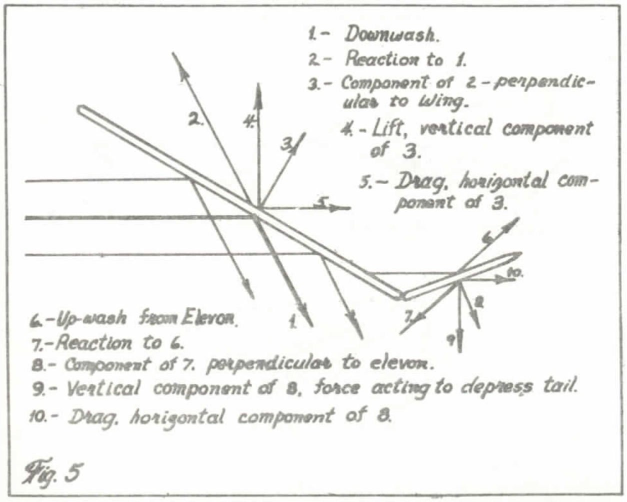


Fig. 5

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 for 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 than 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.

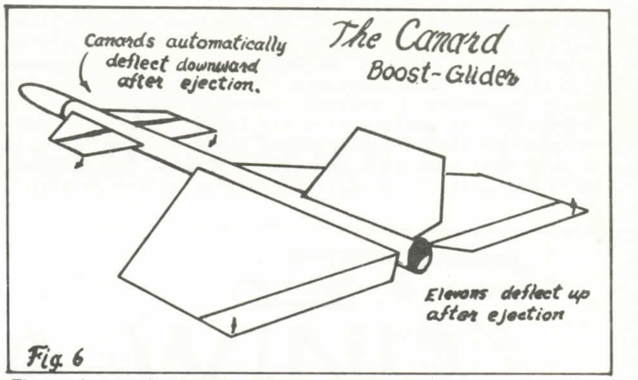


Fig. 6

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 sideslip 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 wing 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. Increases 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 is 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.

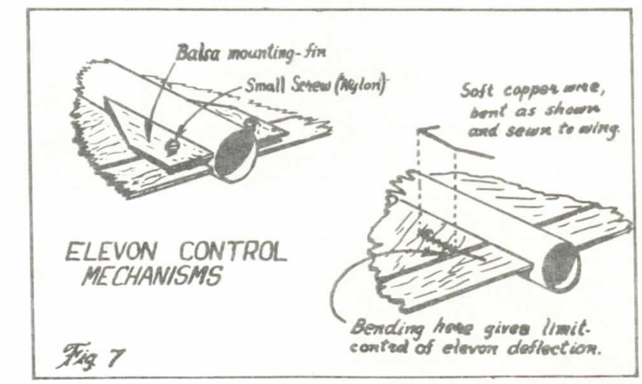


Fig 7

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.

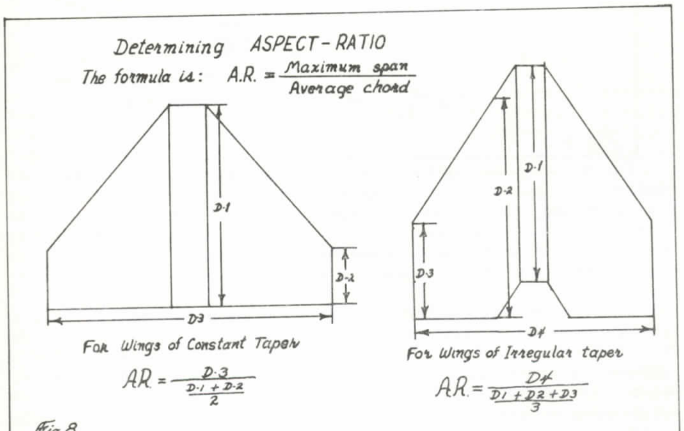


Fig. 8

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 grain of the wings. The wing-body joint may also be strengthened 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 elevcn 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 imparing the fit of the engine into its mountings. For applications involving the protection of elevons or rudders from exhaust gases, aluminum foil 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 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 eject charge activation.

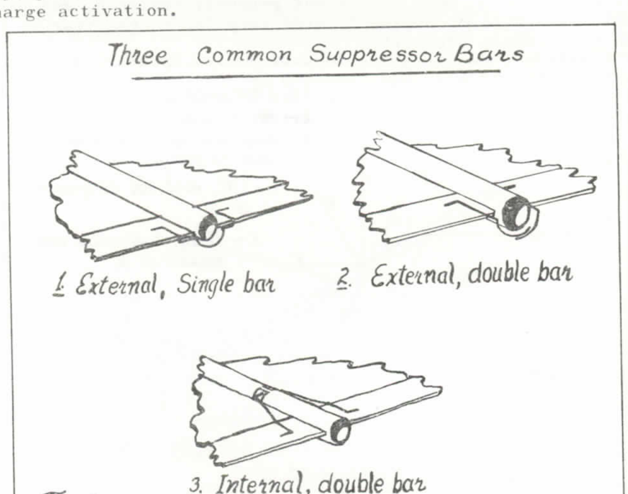


Fig. 9

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.

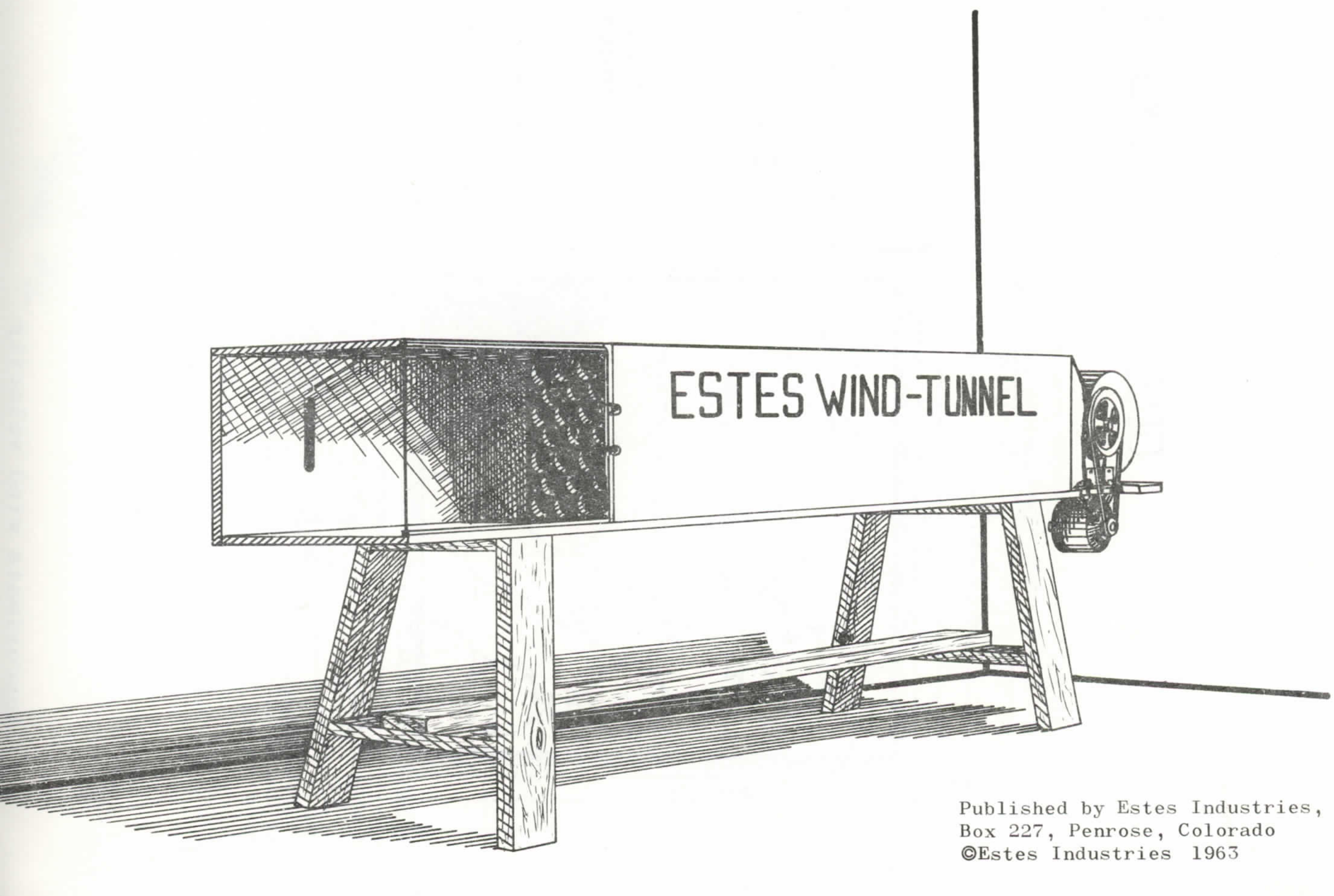
Research on cluster - engined boost - gliders has so far shown that they are not as practical to build and fly as single-engined gliders, due to the large concentration of weight at the rear of the body. This requires that rocket stability be increased by placing the wings very far to the rear, with 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 a greatly expanded knowledge of the physics of flight, but also in contributions to the entire art of model rocketry.

stes Industries Technical Report TR-5

BUILDING A WIND TUNNEL



Published by Estes Industries,
Box 227, Penrose, Colorado

Estes Industries Technical Report TR-5

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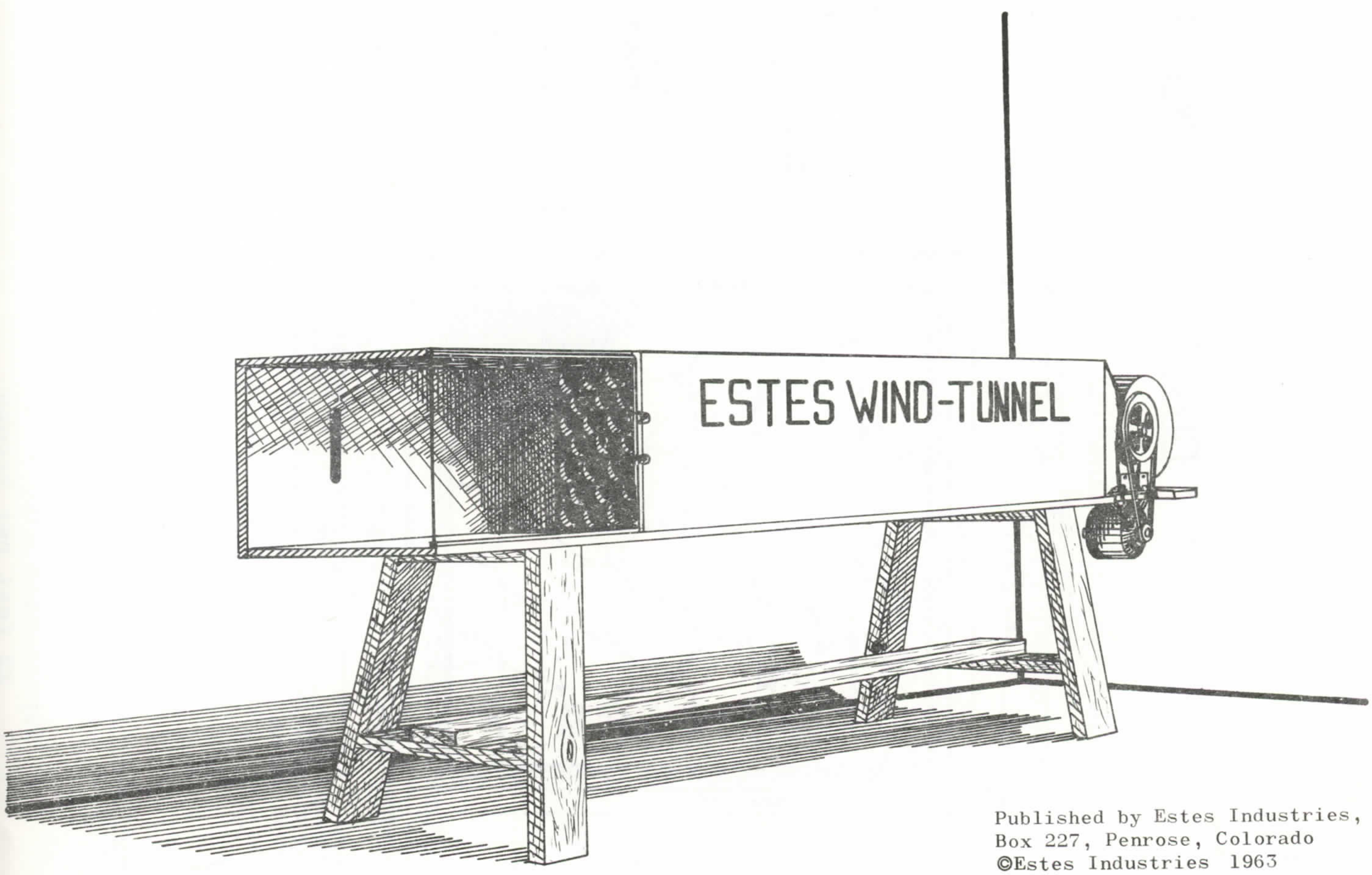

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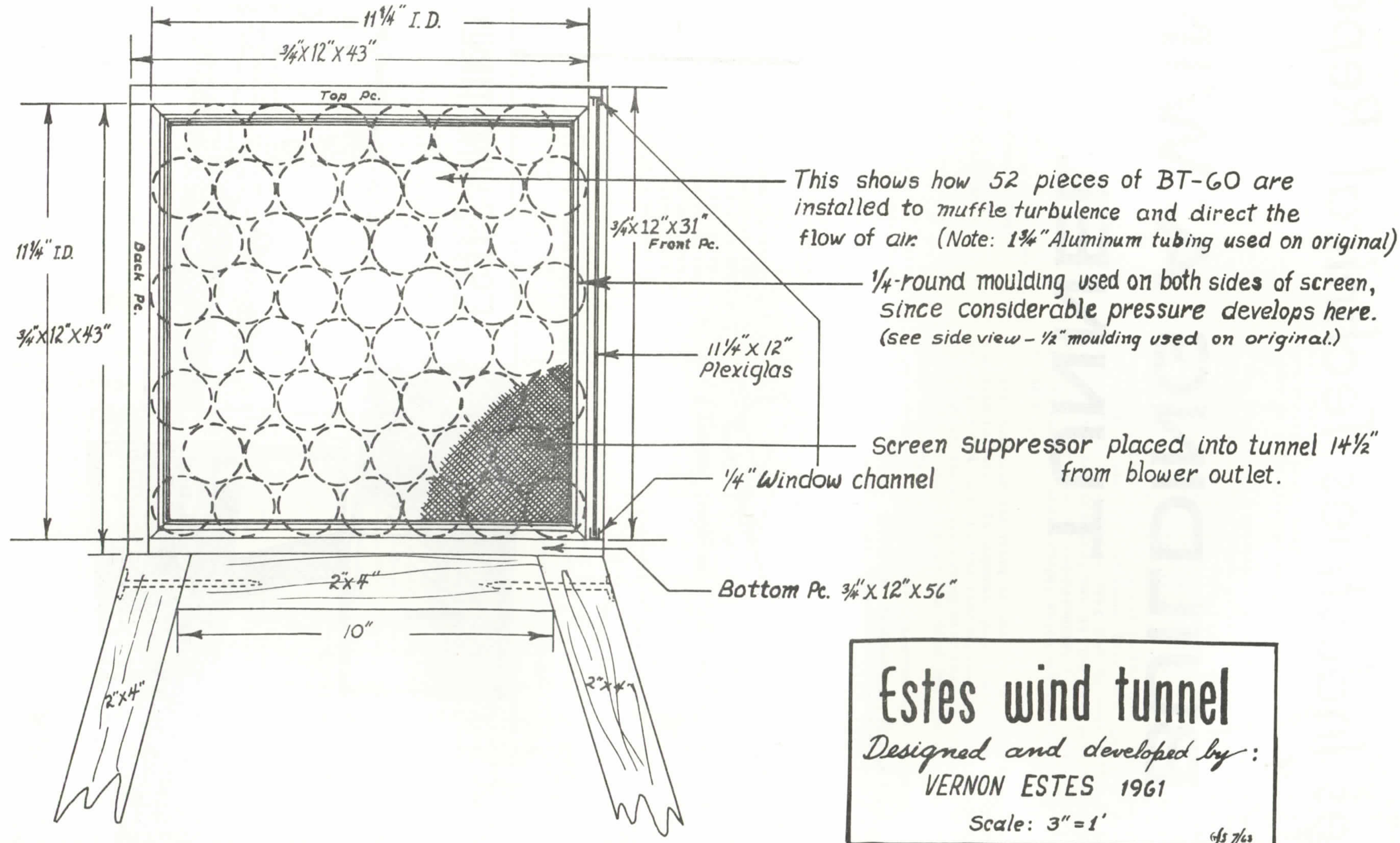
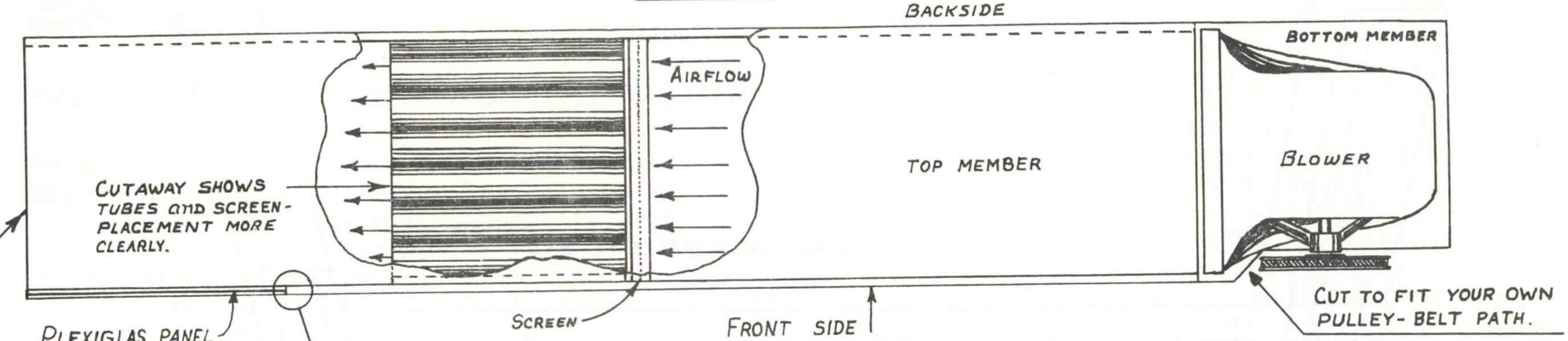
OBSERVATION - END VIEW

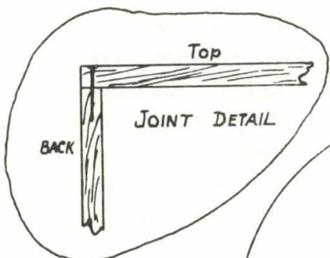


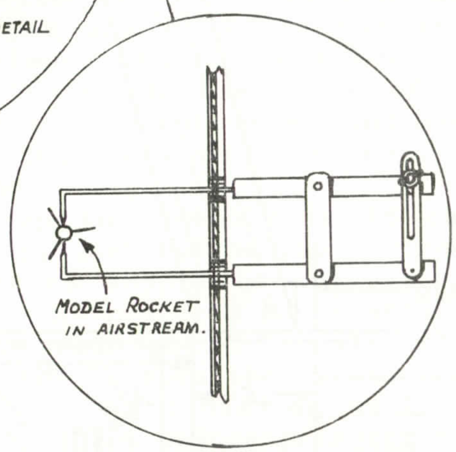
Approximate wind velocity
22 feet per second

Top View

Planview . . . . . Scale: 2" = 1'







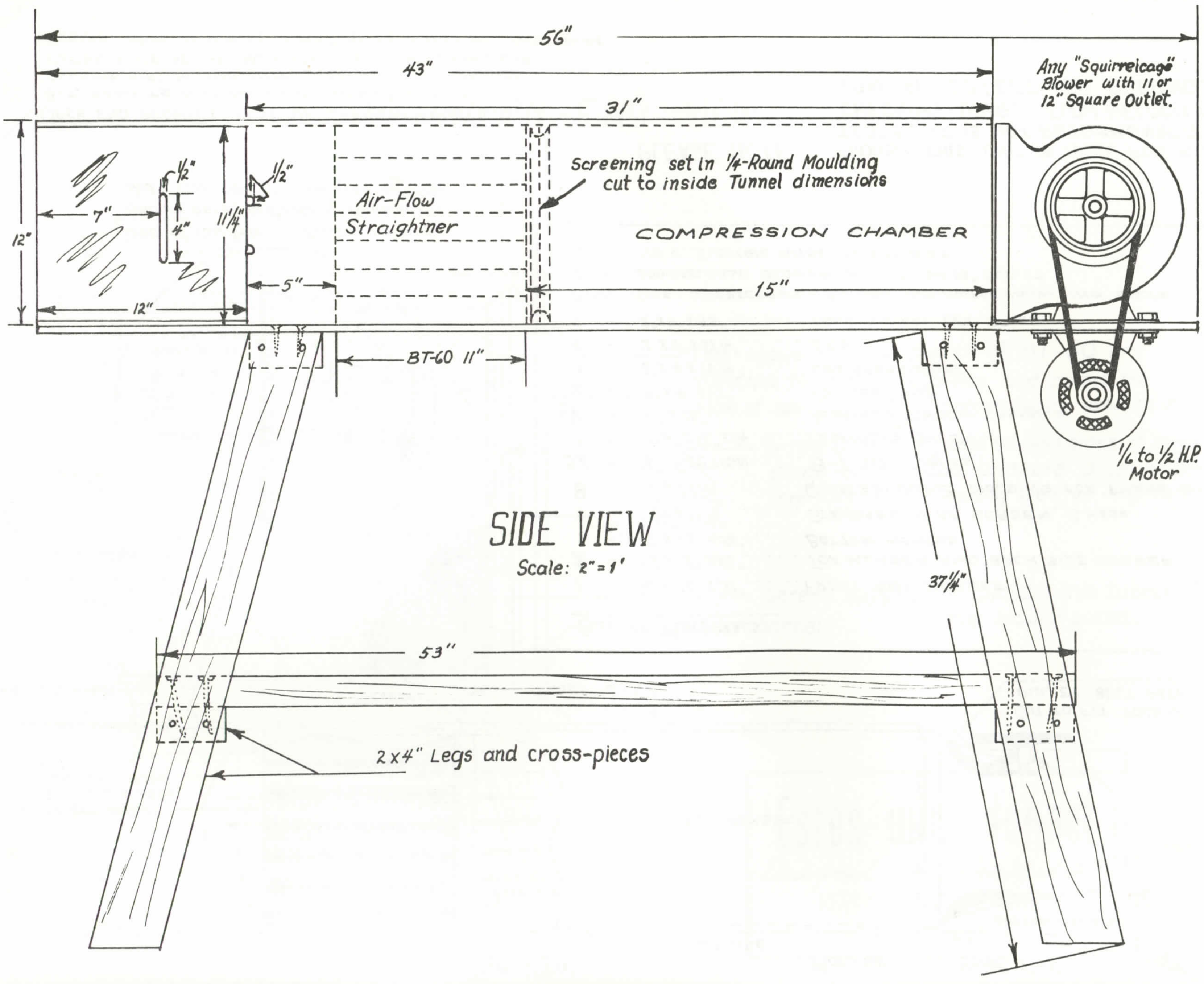
Use of low-friction Pivot-points is shown here, protruding through the slots adjacent to Plexiglas "window"

BILL OF MATERIALS:

1	-	3/4" X 12" X 31"	FRONT SIDE MEMBER.
2	-	3/4" X 12" X 43"	TOP MEMBER AND BACK SIDE MEMBER.
1	-	3/4" X 12" X 56"	BOTTOM MEMBER.
1	-	11 1/4" X 11 1/4"	STANDARD WIRE SCREEN, 8 MESH.
8	-	1/2" X 11 1/4"	QUARTER-ROUND MOLDING FOR FRAME ON SCREEN.
52	-	11" SECTION	B-T 60 TUBING.
1	-	11 1/4" X 12" X 1/4"	PLEXIGLAS SHEET.
2	-	1/4" X 12"	ALUMINUM WINDOW CHANNEL.
2	-	2" X 4" X 10"	TOP LEG-LAND.
2	-	2" X 4" X 19 3/4"	LEG CROSS-BRACE.
4	-	2" X 4" X 37 1/4"	LEG.
1	-	2" X 4" X 53"	LONGITUDINAL LEG-BRACE.
MISC.			NAILS - WOODSCREWS - BLOWER AND MOTOR-MOUNTING BOLTS.
1	-		SQUIRRELCAGE BLOWER WITH 11" OR 12" OUTLET.
1	-		110 V. ELECTRIC MOTOR, 1/6TH TO 1/2 H.P.

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.


56"
43"
31"
Any "Squirrelcage" Blower with 11 or 12" Square Outlet.
Screening set in 1/4-Round Moulding cut to inside Tunnel dimensions
Air-Flow Straightner
COMPRESSION CHAMBER
12"
1/2"
4"
7"
11 1/4"
1/2"
5"
15"
12"
BT-60 11"
1/6 to 1/2 H.P. Motor
SIDE VIEW
Scale: 2"=1'
37 1/4"
53"
2 x 4" Legs and cross-pieces

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

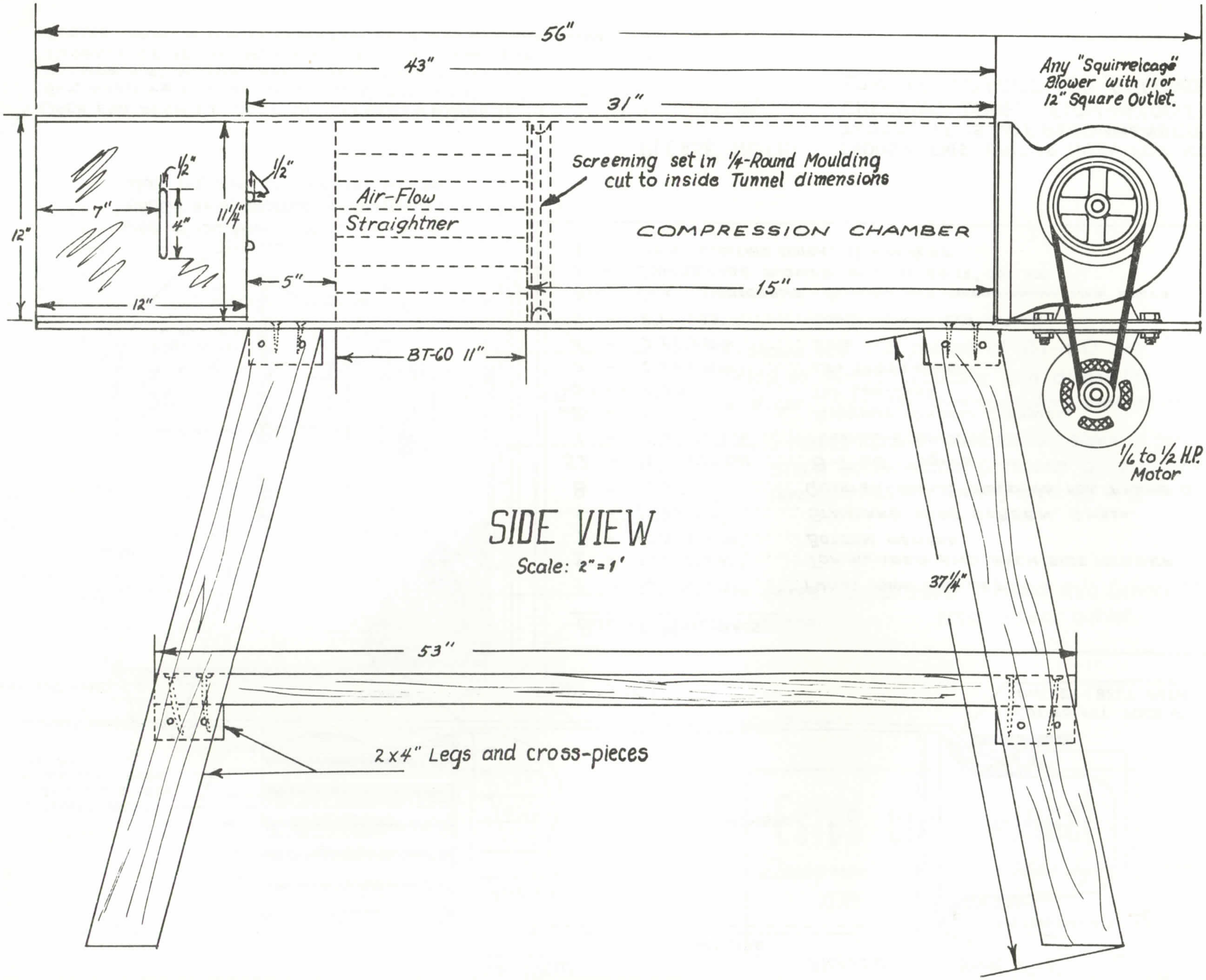
Cut and drill the bottom piece to match the mounting holes of the blower and the motor. Be sure that the holes are drilled to position the blower firmly against the rear of the tunnel. The blower should be adjusted so the flow is as even as possible.

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.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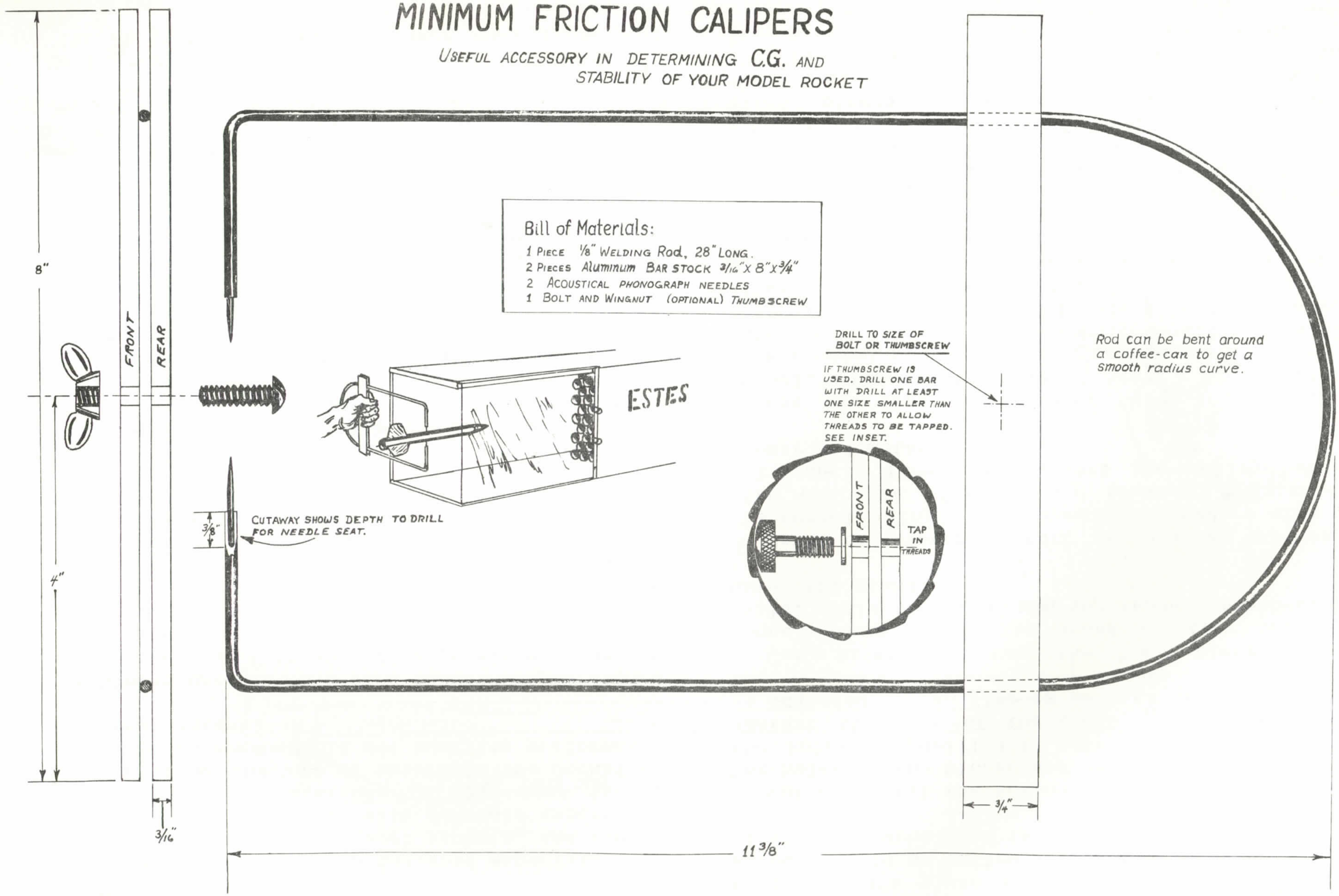
MINIMUM FRICTION CALIPERS

USEFUL ACCESSORY IN DETERMINING C.G. AND STABILITY OF YOUR MODEL ROCKET



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 <u>how</u> 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 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 wnat 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 <u>behind</u> 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 MULTISTAGE ROCKETS

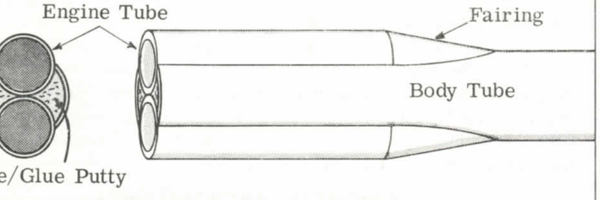
The procedures outlined above are also used in determining the stability of multistage rockets. However, some extra steps must be taken with such a model. A multistage rocket must be checked in all the shapes in which it will fly. Thus a two stage rocket is checked with both stages joined together and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

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

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

Fig. 5



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

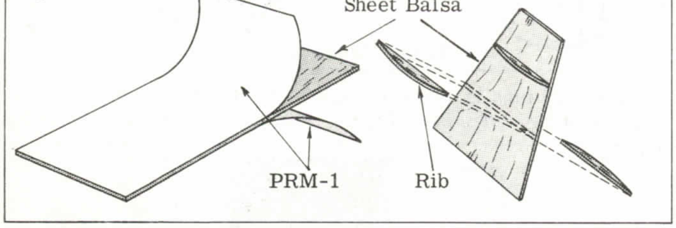
STABILITY

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

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

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

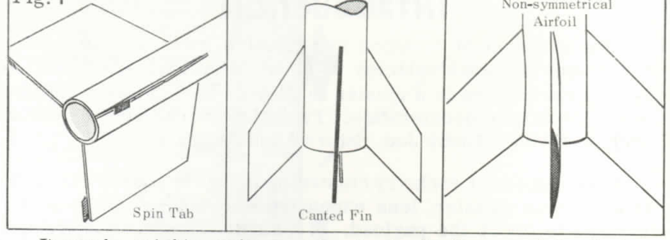
Fig. 6



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

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

Fig. 7



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

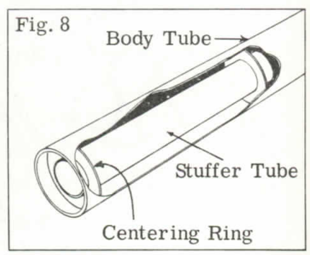
RECOVERY

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

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

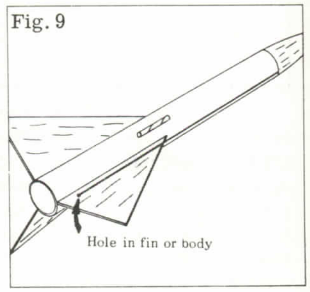
Additional steps can be taken to improve a cluster rocket's recovery system. A "stuffer" tube can be used in a long booster body to control the ejection gases and to keep the parachute from moving too far rearward in the body. The stuffer tube can be a section of either BT-20 or BT-50, centered and held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

Fig. 8



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

Fig. 9



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

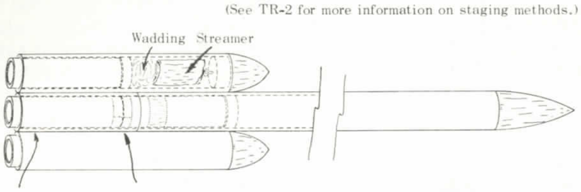
The best way to protect parachutes from the heat of ejection gases is to use an adequate amount of flameproof wadding. Use enough loosely packed wadding to fill the body for at least twice the diameter of the tube. Stuff the wadding into the tube just far enough to allow space for the parachutes, shroud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

MULTI-STAGING

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

As a result, the only successfully proven staged and clustered system uses a bottom stage which has one engine in the center and two or three engines alongside it. This center engine is coupled directly to the single engine of the next stage. The outside engines can be placed in pods with a streamer or parachute recovery system to return the booster gently. In this case the outside engines should have short delays (B . 8-2).

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



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

IGNITION

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

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

TYPES OF ENGINES

Since the usual purpose of clustering is to boost a payload to a greater altitude than would be possible with a single engine, it is usually necessary to use A or B class engines. A single engine rocket using a B 3-5 engine will normally lift a payload higher than a cluster rocket with four 1/2A . 8-2 engines. However, 1/2A or smaller engines can be useful for the first test flights of a lightweight cluster model.

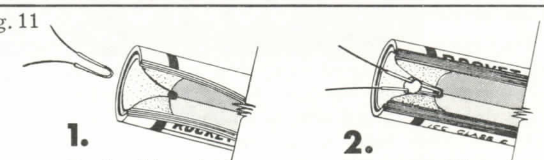
To decide which engines are best for a rocket, divide its total weight (including payload and engines) by the number of engines it uses. Compare the result with the "maximum rocket weight" listed in the engine selection chart in your catalog to find which engines can be used. For a more accurate choice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

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

INSTALLING THE IGNITERS

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

Fig. 11



Bend and insert. . . Tamp in wadding

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

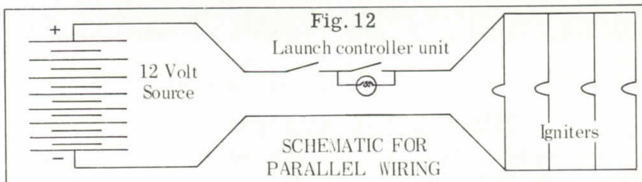
Finally, the wadding must be tamped in carefully and firmly. A small square (3/4" x 3/4") of flameproof wadding (Cat. #RP-1A) is rolled into a ball, dropped into the nozzle between the leads, and forced down further into the nozzle with a ball point pen or pencil point. When the wadding is installed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

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

CONNECTING THE IGNITERS

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

Fig. 12



SCHEMATIC FOR PARALLEL WIRING

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

Fig. 13

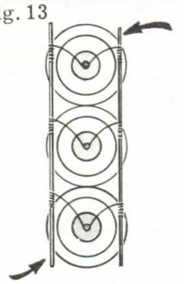


Fig. 14

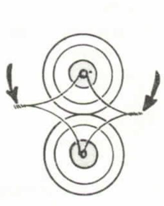
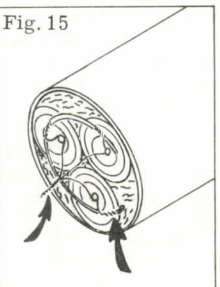


Fig. 15



Connect launcher micro-clips at points indicated by arrows.

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

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

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

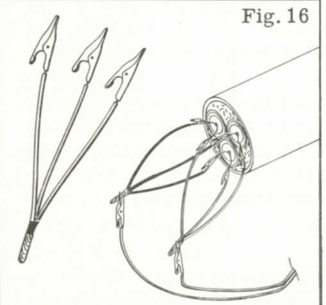


Fig. 16

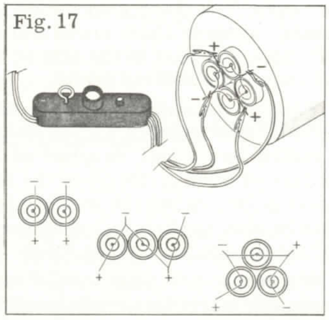


Fig. 17

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

THE POWER SYSTEM

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

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

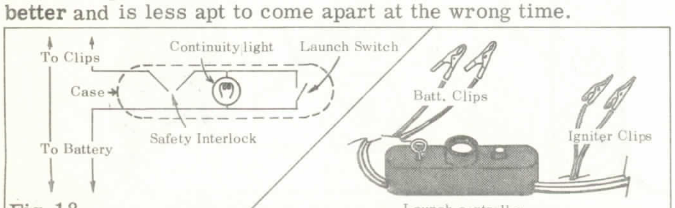
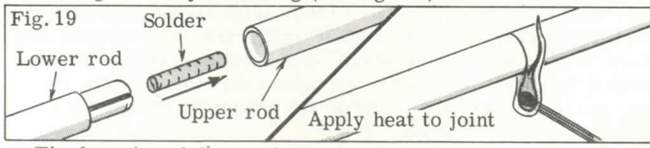


Fig. 18

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

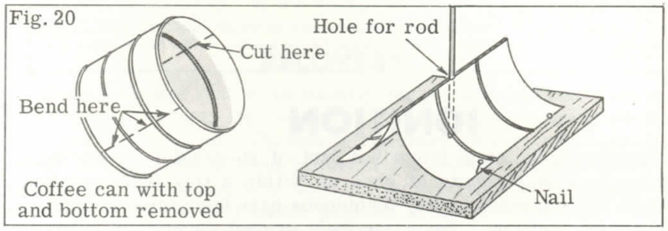
LAUNCHERS

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

Fig. 19


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

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

Fig. 20


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!

Estes Industries

Guide for Rocket Clubs

Published as a service to their customers by Estes Industries, Inc., Box 227, Penrose, Colorado.

Why Form a Club?

Formation of a model rocket club offers several potential advantages to the members. A club provides the best opportunity to share ideas and to engage in projects beyond the resources or abilities of a single person. In a club the skills of individuals in such areas as electronics, mathematics, rocket design, writing, and physics are available to others so that the group can have activities a single rocketeer would not have the knowledge to carry out. The club offers an opportunity to pool resources to build and operate launching sites and advanced equipment, and to obtain a club laboratory or shop.

The club which has a responsible adult advisor or sponsor can obtain community approval and support much more readily. This is especially valuable in communities where model rocketry is still new to the greater part of the population. By organizing a club, it becomes much easier to gain publicity necessary for community recognition and support.

Organization of a club provides an unexcelled chance to participate in many different activities. Among other things, the club can conduct contests, develop research programs, obtain and show films, sponsor educational activities, and give demonstrations. By organizing, of course, the club can compete with other clubs in the areas of altitude, duration, and similar contests, as well as in special research programs to develop and apply scientific devices.

Organizing the Club

The first step in organizing a club is to get several individuals interested in model rocketry. The informal activities of a few persons can serve as a basis for getting more persons interested in model rocketry. Try to find an adult sponsor or advisor who is interested in rocketry. The sponsor can be either an individual or a group. The best bet for a sponsor or advisor is the father of one of the members of the club. If several of the fathers can be interested, it will be even better, since model rocketry is an activity which can be enjoyed by adults as well as young people, and several adults can usually accomplish more in working with the club and the community than one alone. (The adult members don't need to be scientists or rocket experts, either.)

If it is impossible to obtain the father of one of the members for an advisor, there are undoubtedly several civic organizations in the area which will quite possibly be interested. Such groups as the Lyons Club, city recreational committee, Rotary Club, Optimists Club, lodge, and grange, as well as school science teachers, church groups, and aero-space firms, if approached properly, will often be quite willing to help the club form, support it, and provide the needed adult help in its regular activities.

When approaching an adult group for support, the best thing to do is to explain what model rocketry is, the difference between the model rocketeer, the "Basement Bomber," and the amateur rocketeer, the educational and recreational possibilities of model rocketry, the "safety first" attitude in model rocketry, the safety record now established, why the group is organizing, and why the support of an adult group is desired. If the approach is made in a diplomatic manner, the chances are that the club will receive the enthusiastic support of the adult group. Even in the first group approached does not feel that it is possible for it to help the club, persistance in contacting other groups should pay off quite well. If a direct approach to the various civic organizations in the community doesn't get results, try an appeal through the local newspapers.

The neighborhood group can be a good start in organizing the club. Imagination is important here.

The most important single item in forming a model rocket club is to develop a sound system of organization. The accompanying constitution is only a suggested form, and the individual circumstances of the group should be carried foremost in mind when adopting a club constitution. The organization of the group should provide for a democratic system of government, orderly meetings, reasonable membership policies, sound finances, and interesting activities.

The first step in organizing the club is to bring together as many interested persons as possible for a meeting. A temporary chairman and secretary should be chosen, and someone should explain the reasons for the formation of the group immediately. A count should be taken to determine if enough people are actually interested in participating in the club to make formation practical. In order to have an actual club, there should be at least six members, although an organization of fewer persons is possible. For a really active group, ten or more members is a desirable figure for which to aim. The larger the group, the more activities can be held. Those interested should then be signed up as members, and the meeting can proceed to the adoption of a constitution or a set of by-laws. So that this can proceed smoothly and rapidly, a suggested constitution should be prepared ahead of time, and presented to the meeting for adoption or alteration and adoption. The group should elect a first set of officers at the first meeting. A secretary and a president are the two most important officers for the club during the these requirements, he is then ready to contribute to the activities of the group. The same standards hold true for the scientific organization as for the individual.

Constitution of the West Podunk Rocket Research Society

ARTICLE I: NAME

The name of this organization shall be the MODEL ROCKET RESEARCH SOCIETY of West Podunk, Colorado.

ARTICLE II: PURPOSE

It shall be the purpose of this organization to develop the art of model rocketry through the pursuit of such research programs as the members shall feel useful, and to implement these research programs through the holding of regular contests between society members, through the creation and maintenance of a society library, and through the operation of a society research laboratory. It shall further be the purpose of this organization to aid the cause of rocket safety through educational programs designed to acquaint the public with the high degree of safety gained through following the Model Rocket Safety Code, in contrast with other, non-model, forms of rocketry.

ARTICLE III: MEMBERSHIP

The membership of this organization shall consist of **all** interested persons, regardless of age, who express a desire to join, pledge to follow the Model Rocket Safety Code, and who pay promptly all dues monies as assessed by the society at its regular meetings.

ARTICLE IV: MEETINGS

Meetings of the Model Rocket Research Society of West Podunk shall be held at least 26 times per year and at such times and places as the membership shall approve by a two-thirds majority vote. Operation of the society rocket range shall not be considered a meeting. A quorum of one half the membership shall be necessary for the transaction of any business, and all meetings shall be conducted according to Robert's Rules of Order, Revised. Consistent failure to attend society meetings without proper reasons shall be considered cause for the dismissal of a member from the society, subject to review by the society Executive Board.

ARTICLE V: OFFICERS

The officers of this organization shall consist of a President, Vice President, Secretary, and Treasurer. The Executive Board of the society shall consist of the four above officers, an adult member who shall be appointed as society advisor, and one elected member-at-large for every twelve members or major part thereof. Officers and Executive Board members may be removed from office by a two-thirds vote of the entire membership.

ARTICLE VI: ELECTIONS

The election of officers and Executive Board members shall take place at the first meeting of the calendar year. Nominations shall be submitted by the members in the meeting, and voting shall be by secret ballot. A candidate must receive at least one half of the votes cast to be elected. All officers and Executive Board members shall serve terms of one year. Vacancies in offices shall be filled by the nomination and election of a society member to fill the vacant office for the remainder of the term, and such nomination and election shall take place at the society meeting at which the vacancy is announced.

ARTICLE VII: DUTIES OF OFFICERS

1. President:

   It shall be the duty of the President to preside at all society meetings, to serve as an ex-officio member of all committees, and to represent the society at public affairs.

2. Vice President:

   It shall be the duty of the Vice President to preside at society meetings in the absence of the President, to serve as chairman of the Range Operations Committee, and to serve as director of the Library Committee.

3. Secretary:

   It shall be the duty of the Secretary to take minutes at all meetings, to handle all society correspondence, to serve as chairman of the publicity committee, and to keep a file of all minutes and correspondence.

4. Treasurer:

   It shall be the duty of the Treasurer to collect all society dues, to keep records of all income and expenditures, to keep all society funds safe, and to manage the purchase of equipment, etc., for the society upon authorization by its members.

ARTICLE VIII: COMMITTEES

There shall be four Standing Committees of the society, and such additional committees as the society Executive Board may from time to time consider necessary. The Standing Committees shall be:

1. Range Operations Committee:

   The Range Operations Committee shall be in charge of the building, operation, and maintenance of a society firing range and the equipment necessary for it. Members of this committee shall be responsible for the enforcement of safe conduct on the firing range.

2. Laboratory Committee:

   The Laboratory Committee shall be in charge of the research work of the society, including the obtaining of equipment, the procuring and maintaining of the laboratory building or room, the assignment of research duties, the recommendation of projects to the society, the enforcement of safe procedures, the compiling and publishing of research results, and the education of society members in the correct approach to research in the scientific method.

3. Library Committee:

   The Library Committee shall be in charge of the procurement of all necessary reference material for a complete library, the establishment of lending policies for the society library, the collection of money, if any, assessed for the use of the library, the cataloging of all books and materials according to a suitable system, the care and maintenance of the books and materials connected with the library, and the collection and preservation of published materials dealing with the activities of the society.

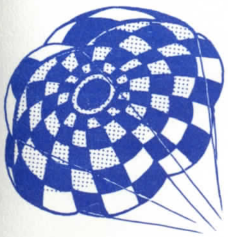
4. Publicity Committee:

   The Publicity Committee shall be in charge of notifying the public of any society activities which may be of general interest or value, the editing and publishing of a regular society newspaper or magazine, and the arranging of all society demonstrations and educational programs for the public.

ARTICLE IX: AMENDMENTS

This constitution may be amended by a two-thirds majority of the members of the Model Rocket Research Society of West Podunk, Colorado, present and voting at any meeting of the society, provided that such proposed amendments were distributed in written form to all society members at least seven days in advance of the meeting. The society Executive Board may veto any amendment, but if, at the next regular meeting of the society, the veto is announced and a simple majority of those present vote to override the veto, the amendment shall go into effect. The amendment shall also go into effect if the Executive Board shall fail to announce its veto at the first regular meeting following the original vote on the amendment.

Parachute Recovery



The parachute offers one of the simplest, most effective recovery methods available to the model rocketeer. At the same time it is often misunderstood, misapplied and mistreated. Experience has shown that the principles and methods described here are reliable with both single and multi-stage rockets provided the model itself is built correctly.

Parachute Materials

While practically everything from bed sheets to balsa has been tried for making parachutes, three materials, paper, silk and plastic, dominate the field. Paper is inexpensive but not durable, so it is of limited value for model rocketry. Paper parachutes rip easily when hit by high velocity air and do not unfurl as rapidly or reliably as plastic or silk when packed in small diameter body tubes.

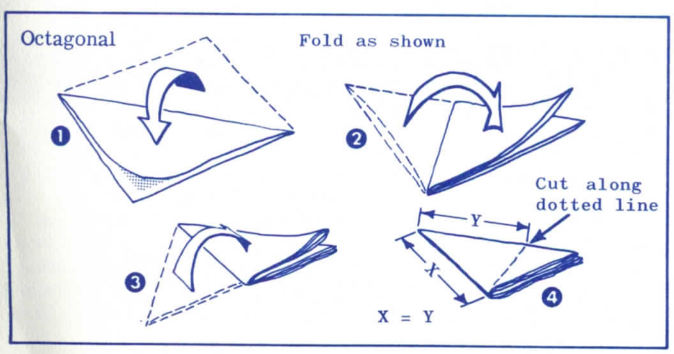
Silk is an excellent material for model rocket parachutes, but combines disadvantages with its good points. While it is light, will not take a "set" easily and is extremely strong, it is also expensive and a difficult material to handle in construction. Loose silk threads have a habit of tangling and preventing the parachute from opening, so it is necessary to sew all edges of the fabric into tight seams to get proper operation. Shroud lines should be sewed directly to the silk.

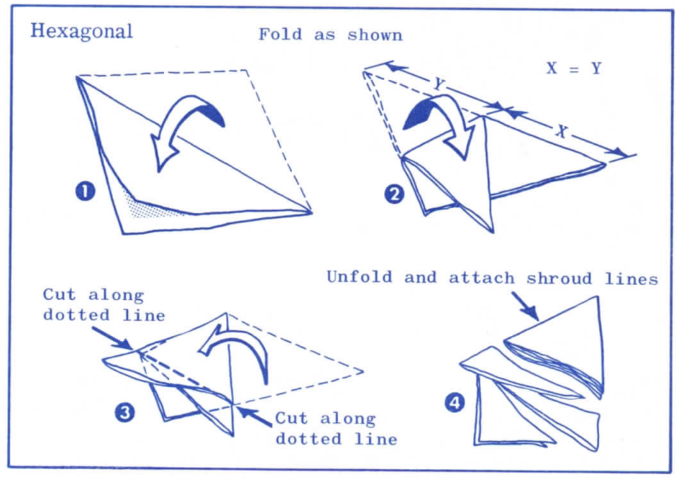
The most widely used parachute material for model rockets is plastic. Combining the virtues of low cost, durability and versatility, it is available in an almost unlimited range of colors, thicknesses and sizes. The types of plastic used for parachutes are for the most part those sold especially for model rocket use and the plastic bags used by cleaners to protect clothing. Plastic thickness generally ranges from .0015" to .0005". For normal use .00075" is the minimum recommended thickness. The main disadvantage of plastic is its sensitivity to heat. The parachute must be well protected from the ejection charge.

Shroud lines are important to the operation of any parachute. Experience has shown that smooth, hard surface material such as carpet thread is best. Shroud line length should be sufficient to allow the parachute to open fully. Generally the proper length will be between 3/4 and 1 parachute diameter (for example, between 9 and 12 inches for a 12 inch diameter parachute).

Parachute Shape

The most common parachute shapes are square, round, hexagonal and octagonal. While square parachutes are the easiest to make, they are not very efficient and allow a considerable amount of sway during descent. Round parachutes are fairly stable in descent, but are more difficult to make. The hexagonal and octagonal parachutes are highly stable, reasonably easy to make and generally give the best appearance. The accompanying drawings illustrate methods for making these shapes.





Parachute Size

For best results a parachute should have at least 38 square inches of area for each ounce of rocket weight. Thus the maximum weight for a 12 inch parachute will be about 3 ounces. Less area may be used on very light rockets, since they will gain less momentum than larger models. On the other hand the upper limit on parachute area can be determined only by considering desired duration, landing softness, weather conditions and opening reliability.

For small, lightweight rockets extra-small parachutes are often advisable since these models can reach extreme altitudes and drift considerable distances even in gentle breezes. The 38 square inches per ounce formula can be used to determine the parachute's size, but experience will be a better guide.

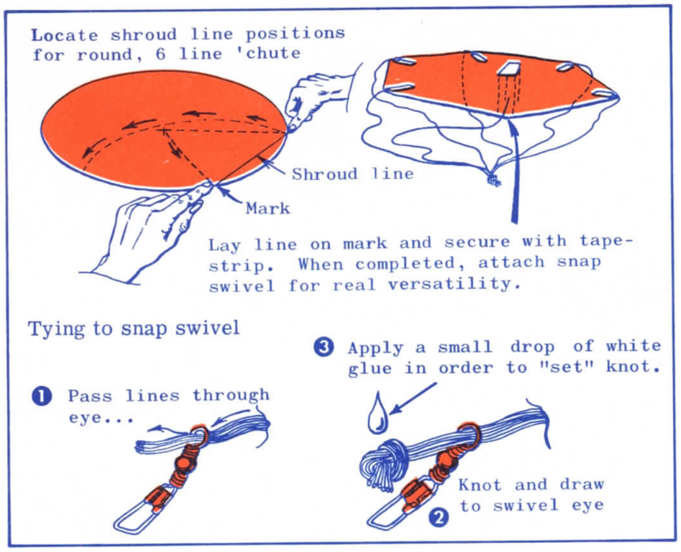
The effective area of a standard commercial parachute can be reduced in several ways. The shroud lines may be shortened or two lines taped together at the top to keep the parachute from opening completely. The center of the parachute may be cut out or the two color printed parachutes (PK series) may be cut on any of the inside circles to form smaller parachutes.

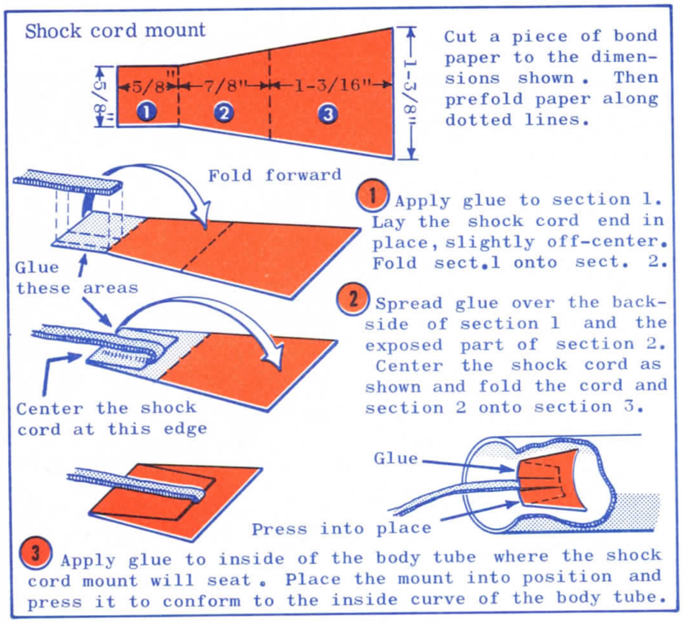
The opposite extreme in parachute size becomes important in duration contests. In such a contest a large, lightweight parachute is important to obtain the lowest possible descent rate. The area to weight ratio must be very high. Competitive duration models have ratios of from 300 to 500 square inches per ounce for calm weather. Models equipped like this can turn in times of 10 to 20 minutes.

Parachute Assembly

After cutting the parachute to shape as in the preceding section shroud lines are attached either by tying or by using tape discs or strips. Tape strips are generally the most satisfactory since they are easy to use, light and strong. When shroud lines have been attached to the parachute and cut to the proper length they can either be attached directly to the rocket or attached to a snap swivel. (The use of a snap swivel offers a definite advantage since different parachutes may be selected for various flying conditions or the same parachute may be used in several different rockets.)

The parachute is ejected from the rocket body in flight with considerable force and generally opens quite suddenly. This shock must be absorbed so shroud lines, etc. are not broken. A length of shock cord (model airplane contest rubber) is connected between the parachute and the main part of the rocket.

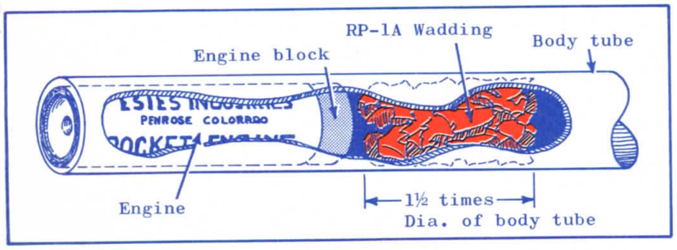




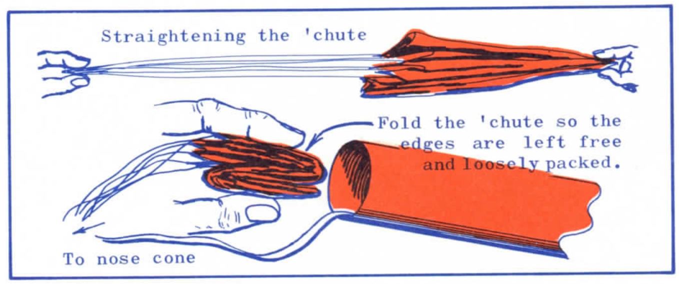
The free end of the shock cord is then attached to a screw eye in the base of the nose cone. The parachute can then be attached directly to the nose cone if the cone weighs less than 1/2 ounce. If the nose cone weighs more than 1/2 ounce there should also be a length of shock cord between it and the parachute.

Parachute Packing

When preparing a rocket for flight it is extremely important to protect the parachute from the heat of the ejection charge. The most reliable and effective way of doing this is by filling the body tube for a distance equal to 1-1/2 times its diameter with flameproof tissue, cotton or recovery wadding. The wadding serves as an insulating layer between the parachute and the engine and as a gas seal and piston to insure that the ejection charge works evenly against the parachute and nose cone.



When the wadding has been placed in the tube, dust the parachute lightly with talcum powder to keep it from sticking to itself when packed in the rocket body. Next form the parachute into a spike shape as shown, fold once or twice to make it fit the space available in the body tube and insert it into the tube. Pack the shroud lines and shock cord in over the parachute and push the nose cone or payload section into place.



It is interesting to note that elaborate, precise and exacting methods for folding model rocket parachutes have been proposed and used, but the most reliable recovery comes with the somewhat sloppy system described above. Current theory holds that this reliability is the result of the tendency of the material to spring back somewhat when crumpled and the ability of loose corners, edges and folds to catch the breeze.

For parachute duration contests special attention to packing, secure shroud line attachment, etc. is important. The rocket's body tube should be large enough to hold the parachute and wadding without squeezing and yet small enough to keep the rocket's weight as low as possible. B4-2 and C6-5 engines are generally recommended for use in duration events.

The Time Factor

The period the parachute spends packed in the rocket while awaiting flight has a considerable effect on reliability. Plastic has a special tendency to take a "set," especially when cold. As a general rule the parachute should remain packed no longer than 1 hour in warm weather, 1/2 hour when the temperature is between 40° and 60°, and no more than 5 minutes when the temperature is 32° or less. In cold weather it is a good idea to prepare the rocket in a heated area and keep it warm until just before launching. If the parachute is in the rocket longer than the period recommended it should be removed from the rocket body, opened up, refolded and repacked before flight.

If these steps are followed carefully, parachute recovery can be highly reliable, spectacular and useful. It will prove its value again and again in demonstrations, payload launchings, contests and sport flying, and will provide an excellent basis for further experiments into rearward ejection, side ejection, booster recovery and many other special systems.

Engine Mounting

Ejection gases must pressurize the parachute compartment of a model if the parachute is to be ejected. If the engine is loose in the body it will be expelled rather than the parachute. If there are any holes the gas can leak through, it will, and the rocket will streamline in.

Use plenty of masking tape to hold engines in place. Wrap the engine with tape even if a wire engine holder is used to retain the engine, since an air-tight seal is needed. It is practically impossible to have the engine held in place too tightly.

Wind

Never fly rockets in high winds, since aerodynamically stabilized vehicles fly into the wind and will present a hazard if they take paths parallel to the ground. In addition, a parachute recovered rocket will drift for a considerable distance at the same speed as the wind. Thus in a 20 mile-an-hour breeze the model will drift at 20 mph--considerably faster than a normal person can run. In more moderate winds it is still important to use caution, but rockets can be flown without great difficulty if parachute size is kept within reasonable limits set by the weather conditions and rocket performance.