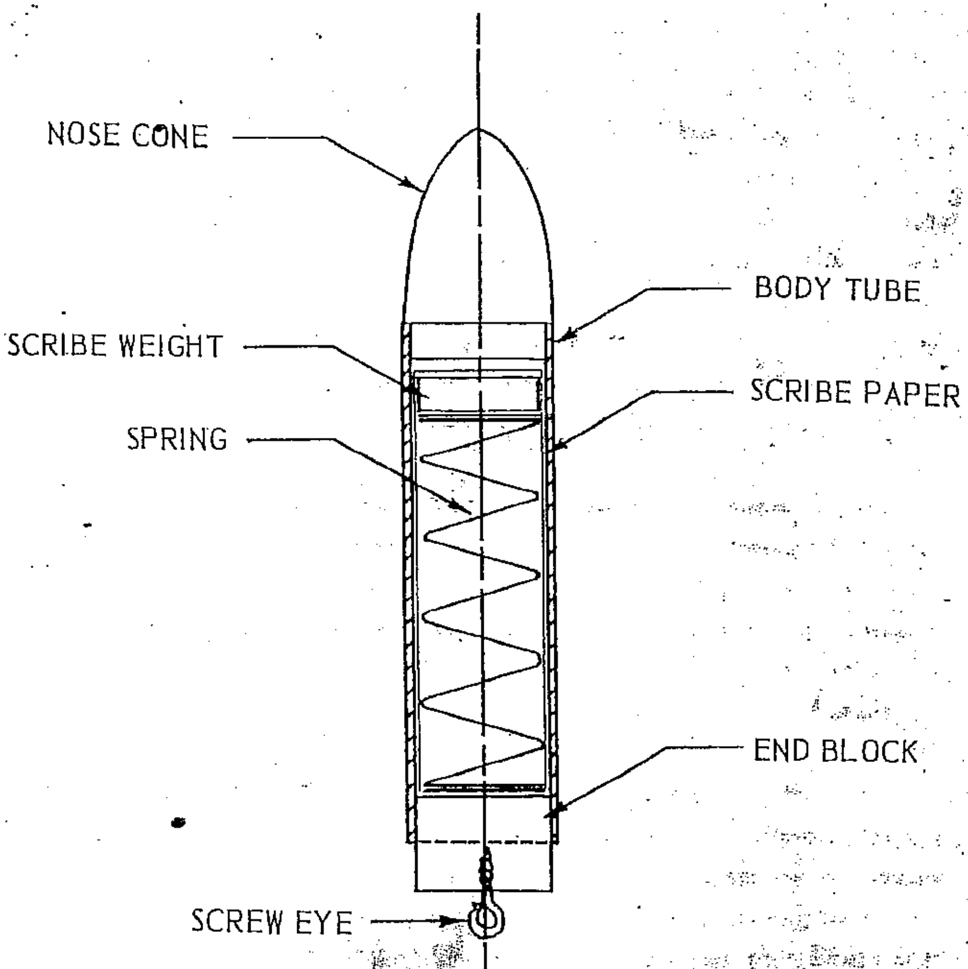
AMROCS ACCELEROMETER
OWNER'S TECHNICAL MANUAL

ACCELEROMETER DETAIL



ROCKET SUPPLY CO. • BOX 51 • TAPPAN, N. Y.

BASIC ACCELEROMETRY

Identify all parts of your instrument so that you may become familiar with their names before reading this technical report.

1. scribe weight- circular metal disk with three triangular scribes
2. spring- do not stretch!
3. meter tube- 2 3/4" body tube
4. spacer- cardboard cylinder
5. indicator paper- red and white wax paper
6. nose cone
7. shoulder- 1/2" long hardwood dowel

Glue the shoulder to one end of the tube by spreading glue on the inside of tube and inserting the shoulder so that about 3/8" protrudes from the tube. This protruding section will fit any AMROCS tube and is used as the adapter between the meter and its booster.

Your AMROCS accelerometer has been designed around a spring chosen for its accuracy and reproducibility; that is, the ability to give the same readings time after time when subjected to the same conditions. Best results may be obtained when friction between the scribe and indicator paper is reduced to a minimum; that may be done by adjusting the scribes (through sharpening or filing them down just slightly) or by reducing the inside diameter of the meter. Normally, placement of the indicator paper is accomplished by cutting off a piece 2 3/8" long, wrapping it around the included spacer, taping it along the seam and slipping it into the tube. It's easiest to slip the paper into the tube while it is still wrapped around the spacer; after you've slipped it in, simply slide out the spacer while holding the paper in the tube. The inside diameter may be reduced by wrapping the indicator paper around the spacer 2 or 3 time instead of once. This would require a piece of paper 4 3/4" or 7 1/8" long. The adjusting is necessary since the body tubes are not of exactly the same inside diameter. If you should accidently file down the scribe weight to a point where it's useless, don't worry; you can obtain a replacement weight from AMROCS. If you should run out of indicator paper, you can get more from AMROCS in 24" rolls. It's always best to have plenty on hand if you get curious and want to run a test immediately.

Before wrapping the paper around the spacer, it is best to check for any stray marks that could be confused with the markings made by the scribe weight.

We suggest the following procedure for loading your meter:

1. wrap, cut and tape your paper around the spacer
2. slip it into the tube and remove the spacer
3. slip the spring into place
4. pull the rolled paper about 1/4" outside the tube and place the scribe weight inside the rolled paper
5. slip the rolled paper back into the tube until it touches "bottom", that is, the wooden shoulder which should be glued into place.
6. turn the scribe weight so that it makes a horizontal scratch on the paper at the level at which it is at rest; this scratch is a cause for error and must be done with care since it is the level at which all measurements are taken from the meter.
7. make a mark (using a sharpened pencil) at each of the 3 scribes so that the thin scratches may be easily found after the test
8. slip the proper nose cone on and be sure it is on tight; if not, you may lost most of your meter when the rocket starts its return fall
9. after recovering your meter, immediately remove the paper while being careful to make no further marks on the paper as you remove it
10. replace the scribe weight and spring so you will not lose them

Nover accept one reading as the correct answer. We've tried to make the meter as accurate as possible but to keep the cost down, we've had to compromise on accuracy. Thus we must impress upon you that you should take an average of at least 6 readings before coming up with any answers. This is standard scientific procedure and would be necessary even if our meters were twice as accurate.

THEORY

It is necessary to know the average acceleration of your rocket in order to calculate such pertinent facts as burnout velocity and maximum altitude. These facts can be calculated accurately through the use of the mass ratio and natural logarithms, but since these methods are out of the realm of the average rocketeer, we shall deal only with experimental date and approximate averages. The accelerometer's prime function is determining the maximum acceleration but through the use of physics we may learn a great deal more. Below is a quick summation of the equations used in finding drag free peak acceleration, velocity, and altitude.

The common relation for finding the acceleration is

(1)

$$\left(\frac{F}{W} - 1\right)g$$

F = thrust
W = weight
g = 32 ft/sec^2

In cases where there is a small but noticeable (not more than 10%) loss of weight due to the burning of propellant a fairly accurate estimate may be found by using

(2)

$$A_{av} = \left(\frac{T(W_1+W_2)}{2W_1W_2} - 1\right)g$$

A_{av} = average acceleration
W_1 = takeoff weight
W_2 = burnout weight
T = thrust (average)

The peak (burnout) velocity, V_b, is

(3)

$$(A_{av})\ (T_b)$$

T_b = Burning time

Maximum altitude is

(4)

$$H_t = \frac{V_b T_b}{2}\left(1 + \frac{A_{av}}{g}\right)$$

It should be clear that A_{av} is a most important fact. However, we have so far calculated only drag-free values; these values may be as much as 90% too great in the case of high performance rockets using long duration engines. In order to account for drag, we can follow either of two mathematical courses:

1. we can calculate the drag knowing the drag coefficient from wind tunnel tests using one of several formulae involving frontal area, velocity and an experimentally obtained constant

2. we can also determine drag directly from wind tunnel tests at varying velocities.

Unfortunately, such tests require extensive measuring equipment and a wind tunnel with variable speeds.

In place of such apparatus, it is possible to use the AMROCS accelerometer and obtain a close approximation. If the thrust time curve of the engine is available (as they are in most cases) then it is possible to find the acceleration at any time by noting the scale of the graph on the vertical axis and setting the maximum thrust to be the maximum acceleration. To obtain a more accurate graph, we must account for the change in weight of the rocket due to the ejection of the propellant during combustion. To make this account, we must know the mass flow rate of the propellant; that is, the weight of fuel used in a given time. This fact may be obtained from static tests, but for ease of calculation and simplicity we shall assume it to be constant. In order to marry the

thrust time curve with the mass flow rate and eventually transform the result into an acceleration versus time graph we must follow these basic steps:

1. obtain a thrust-time curve where thrust varies typically (obtainabl from manufacturer)

2. draw weight-time graph where weight varies linearly (see graph 2)

3. divide the graphs into segments .1 seconds apart (or shorter for accuracy)

4. calculate acceleration at each instant using equation (1) and plot the derived accelerations

5. adjust the peak acceleration to coincide with that given by the meter.

You may now make a velocity versus time graph showing the speed of your rocket at any given time by doing the following:

1. divide your acceleration versus time graph into .1 second intervals

2. find the area in each segment below the curve, adding each segment's area to the sum of the areas of the previous segments

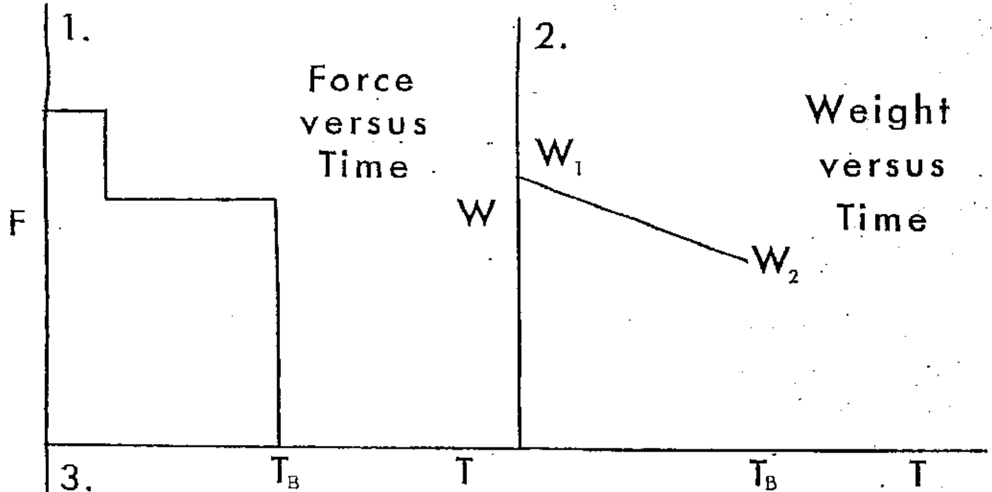
3. graph the area on a scale adjusted to the peak velocity (burnout velocity V_b) found by using equation (3).

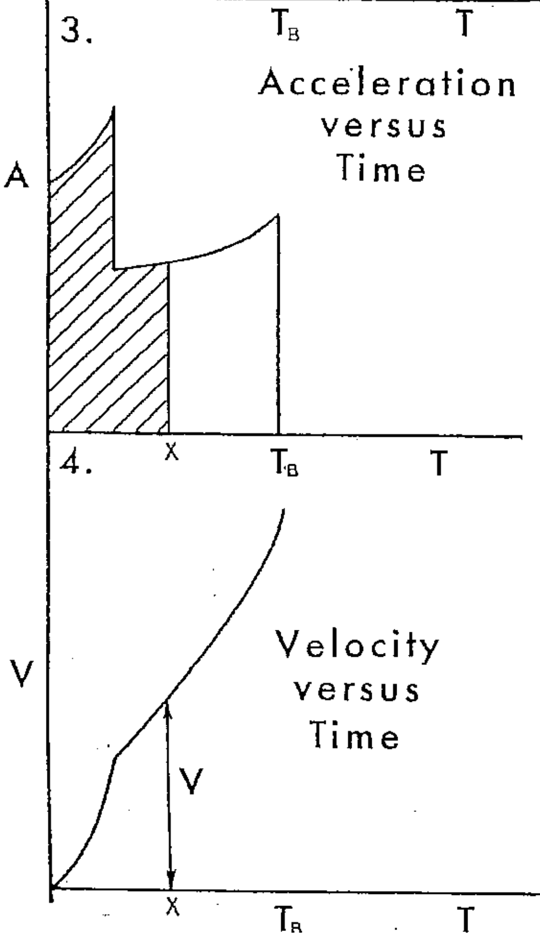
This process is still an approximation, because the drag is not at all constant. The actual source or error is our assumption that the drag is at a peak at the peak acceleration. Actually, drag is highest at the highest velocity and varies with the square of the velocity, making it difficult to take into account. (An example of the drag varying with the square of the velocity is as follows: if the velocity is doubled, then drag would become four times as great.)

Looking at a velocity versus time graph for a short duration engine (such as a ½A), it is apparent that this error due to air drag is not as great since the peak velocity is reached near the peak acceleration. Thus, greater error is incurred in the use of long duration engines and should be expected. In the case of larger, slower rockets however, the drag factor does not become as acute and the peak velocity error is not as great. Thus, one should look for the greatest error in the system with the highest velocity.

As a rough approximation of total distance travelled up to burnout (NOT total altitude), find the area under the velocity versus time curve. This estimate is most accurate for the short duration engines.

GRAPHIC ANALYSIS





GRAPH 1 IS A THRUST TIME CURVE THAT HAS BEEN IDEALIZED (THAT IS ALL CURVED LINES HAVE BEEN SUBSTITUTED BY APPROXIMATING STRAIGHT LINES) WHICH IS AVAILABLE FROM THE MANUFACTURER. GRAPH 2 SHOWS HOW THE TOTAL WEIGHT VARIES WITH TIME. THERE IS NO DIFFICULTY IN DRAWING IT SINCE THE LINE IS DRAWN BETWEEN THE TAKEOFF AND BURNOUT WEIGHTS (WHICH THE ROCKETEER MUST DETERMINE) AND THE TIME IS JUST THE BURNING TIME OF THE ENGINE. THE 3RD GRAPH IS DETERMINED BY NOTING EACH VALUE FROM GRAPHS 1 AND 2 AND PLUGGING THEM INTO EQUATION (1). SINCE IT IS IMPOSSIBLE TO DETERMINE THE ACCELERATION AT EVERY INSTANT, IT IS BEST TO DIVIDE THE TWO GRAPHS INTO .1 SECOND INTERVALS & DETERMINE ACCELERATION AT THESE TIMES; GRAPH THESE VALUES AND ADJUST THE SCALE SO THAT THE MAXIMUM ACCELERATION ON THE GRAPH AGREES WITH THE MAXIMUM ACCELERATION FROM THE ACCELEROMETER.

GRAPH 4 IS FOUND BY DIVIDING GRAPH 3 INTO .1 SECOND INTERVALS AND GRAPHING CONSECUTIVE SUMS; THAT IS, GRAPH THE SUMS OF THE AREAS IN EACH .1 SECOND SPACE. THUS THE AREA AT TIME X IN GRAPH 3 EQUALS THE VELOCITY, V, AT TIME X IN GRAPH 4.

APPLICATIONS

Your accelerometer has been engineered to be useful in many different experiments. We suggest that a single staged booster such as the Scorpion be used in the initial work with your initial work with your instrument so you may become proficient in analyzing data before attemp- anything of an advanced nature.

If you are considering a study of a live payload, we would suggest the use of a payload capsule, such as PC-1, of a size close to that of the meter. Thus, conditions for a system combining booster and meter will be identical to those combining the same booster with a different payload. It is then possible to safely assume that the acceleration readings obtained through the use of the meter apply to the payload capsule.

Higher forms of life, such as birds, mice, rats and hamsters react under light g-loads, usually in the 8 to 25 g range. Such animals could easily be killed or badly cripped by experiments in model rockets. The NAR policy statement on animal flights points out that any information gleaned from the flight of animals may be done more humanely in the laboratory using a device such as a centrifuge. Also, several modelers have been legally held from launching any such live payloads by several humane societies. Thus, it is in the best interests not to fly such vulnerable animals. If you still wish to launch biological payloads we suggest such substitutes as fish (a water sealed capsule must be used) or eggs of various types. It would be of interest to many science-minded rocketeers what such "g-stressed" creatures would be like after maturing. Other interesting subjects would be such non-mamalian creatures as salamanders, toads and turtles. Perhaps the easiest specimens are frog's and turtle's eggs since the mature animals are easy to keep and test.

Your accelerometer may also be used to test several aspects of drag. Among the most interesting are fin shape, nose cone shape and paint finish.

In all experiments involving varying designs, the following basic rules should be observed to avoid confusing relating causal factors:

1. whenever comparing results of several tests be sure that only one factor varies; that is, don't vary nose cone shape and fin thickness at the same time.

2. always take an average of <u>at least 6</u> readings (flights)before mak-

ing any conclusions

3. be sure weight of each rocket is exactly the same

4. be sure you use the exact same type of engine in each test; that is, don't mix a test using a B-.8-2 with a test using a B-.8-6

5. be sure your rocket fits very loosely on the launch rod and clean and wax the rod at the end of each flying day (if possible, use metal launch lugs)

6. use the same launch pad for each series of tests - <u>never</u> mix tests of rockets launched from towers with those launched from rods

7. discount data from any tests where the rocket deviated from a very straight and vertical flight and any haveing spin where not intended

8. check the symmetry of all test rockets; that is, be sure all fins are the same shape on each individual rocket and that all fins are on straight and are well aligned

9. use the same materials on each rocket; that is, do not mix hardwood fins with balsa fins (or other parts) on one rocket unless the same mixture is followed on all rockets of that series

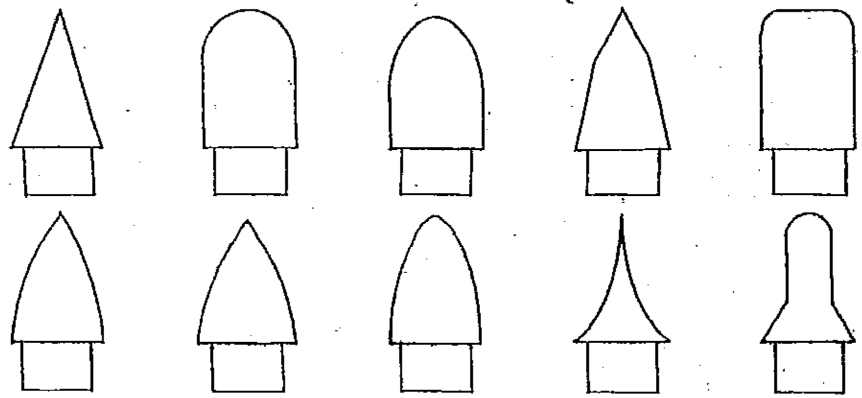
In order to obtain the greatest relative accuracy, it is necessary to use a short duration engine. Unfortunately, the speed at peak acceleration is rarely more than 50 feet per second and thus drag is so low that the meter will usually not measure any differences due to changes in design. In order to obtain accurate results over a significant range of variables, (fin shape, chord, etc.) it is best to use a two stage rocket. Thus, when the peak acceleration occurs (due to the thrust of the second stage engine) the rocket will already be travelling at a speed where drag is significant; when the peak acceleration occurs (due to the thrust of the second stage engine) the rocket will already be travelling at a speed where drag is significant; when the second stage ignites, the acceleration must always be greater (unless the first stage is multi-engined or uses a large model rocket engine) since total weight is one stage less. Thus, there is no interference from the g's due to the booster.

To find the burnout velocity of the whole two stage rocket (which must be added to peak velocity of second stage in order to accomplish any analysis of the second stage) simply follow the instructions for finding peak velocities at the beginning of this manual. Keep in mind, however, that you should fly the two stage bird 6 times with a dummy upper stage of equal weight as that of the actual test stage. The average of these 6 values will determine the proper velocity to add to the upper stage velocity when it is flown later in actual tests.

In the study of subsonic air flow, it must be remembered that sharp edges and corners usually make more drag than rounded edges. Thus, the rocket with a pointed nose cone and sharp leading edges will suffer more drag than a missile with rounded edges. With this basic fact in mind, it is a challenge to the researching rocketeer which nose cone design will afford the least drag and thus contribute to a low drag coefficient, C_d. This coefficient is a dimensionless factor derived from the particular design of the rocket. It is usually found from wind tunnel tests. In figure 1, there are several of the more popular nose cone designs; you may wish to experiment and see which has the lowest C_d, and thus the least drag. You'll probably have to make most of them yourself as many are not presently sold. In figure 2 are several fin shapes: which do you think gives the least drag? See if you can find the perfect fin. Similarly, which of the fin cross sections in figure 3 offers the least drag? Or is the difference negligible?

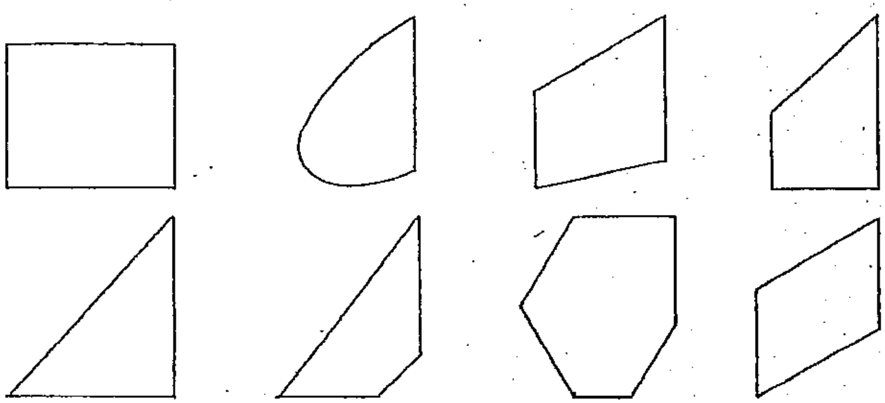
In this aspect of research, be sure all wood has the same maximum thickness and the fin airfoils are the same so results reflect only cross sectional changes, not changes in frontal area or surface area. Also, it would be wise to put a smooth finish on all fins to remove the variable of the wood grain.

After you have arrived at a design that pleases you, you may wish to look into the effects of a rough finish versus a smooth finish. A difference shows up with high velocity rockets since the drag is proportional to the square of the velocity; thus it is best to use a small, light rocket for conclusive results. We suggest, as a beginning, that you apply one coat of sanding sealer to the entire rocket and fly it several times before you sand it. Next, sand it smooth and fly it several more times and note the results. Add another coat and follow the same procedure, accounting for the increased weight as you add further coats. After the third coat, your rocket should be very smooth and slick. Apply (using a spray can for best results) an enamel or dope colored paint in thin coats. Your rocket should be very glossy and smooth. Fly it again and note the results.



NOSE CONES

figure 1

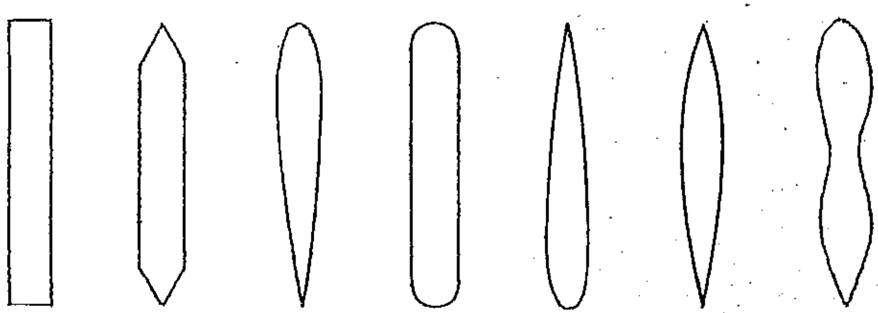


ALL FINS ARE SITUATED AS THOUGH ATTACHED TO A VERTICAL TUBE

FIN SHAPES

figure 2

ALL ROOT EDGES ARE ON THE RIGHT SIDE



FIN CROSS SECTIONS (AIR FOILS)

figure 3

After you've gotten the "feel" of model rocket drag research on nose cones and other parts you may wish to try to answer these questions: what effect does the launch lug have? its diameter? its length? What about fin joints to the body - do fillets really help? Is there anything detectable about factors?

If you are mathematically inclined, you can try to calculate the actual drag and the drag coefficient by using the following formulae:

(5) $D = F - NW$

(6) $D = .0028 C_d S V^2$ *

*derived from
Engineer's Handbook
by Thomas, 1958

F = average thrust (ounces)

D = drag (ounces)

S = frontal area (square in.)

V = ave. velocity (ft. per sec.)

N = g reading from meter

W = rocket wt. (oz.)

You will arrive at a rough approximation that should not be quoted as truth but only as a relative approximation.

Other interesting subjects for study include drag analysis of ring tail rockets and efficiency of the jet pump system.

Another intriguing experiment is to note the loss of velocity and acceleration due to spin. There is a definite relationship between spin and the total energy of the rocket and the distance travelled. We doubt very much if you'll find it since it involves higher mathematics and your results would probably not be accurate enough to discern the relation. Very little work of a definitive nature has been with spinning rockets and the field is wide open for inquisitive minds.

If you launch your rocket at an angle, you will have a slightly greater acceleration; or will you? You're not accelerating straight up so there's not as great a "gravity burden" to overcome but you're not rising as fast, either. Do the circumstances cancel or is the acceleration different? If you attempt this project, be sure to never launch your rockets at less than 60° from the horizontal as your rocket will fly too far away to be safe. Recall that if you fire your rocket at 60° it will land further away than it went up. So if you fired a rocket to an altitude of 800 feet, it would land more then 800 away from you. If you launched the same rocket at 45°, it would easily land more than one third of a mile away!

If you can't figure out how the acceleration changes with the angle, consult a trigonometry book and look up the definition of sine. If that doesn't help, get your math teacher working on the problem. While you're at it, explain model rocketry to him; he'd probably be interested in hearing about it.

There are other practical uses of your accelerometer; among them is the determination of the best way to ignite a cluster of engines. This problem is being studied by some of model rocketry's top brains, but as yet no one has come up with a completely satisfactory system. The accelerometer comes in by telling you if all engines fired at once by noting the peak acceleration. If the peak acceleration is low compared to the total thrust to weight ratio, then all engines did not fire simultaneously. This is an expensive experiment since it requires several engines for each test and should only be attempted by the rocketeer who has tried some of the previous experiments.

Another interesting test is the measure of the strength of the ejection charge of an engine. This may be done with the apparatus shown in figure 4. There are, however, several assumptions that must be made that will reduce the dependability of your estimate of the charge strength. They are:

1. air drag and resistance from the shoulder and lug are negligible
2. the burning time of the ejection charge is extremely small
3. the accelerometer will react instantaneously to the very short impulse of the ejection charge

In this experiment, all you're basically doing is launching your meter and measuring the driving force as you would in a normal rocket flight.

Be sure that the meter flies clearly off of the rod and does not land tail end down. If it does, you may get a reading from the shock of landing that will interfere with your ejection charge reading. To be sure of a correct reading, place your accelerometer no more than 18" below the top of the rod. To be sure of not burning your pad, place the engine section at least 4" above your pad.

To avoid error, take the following precautions:

1. make the shoulder connection very loose by sanding the shoulder or stretching the body by inverting a hard wood nose cone into the

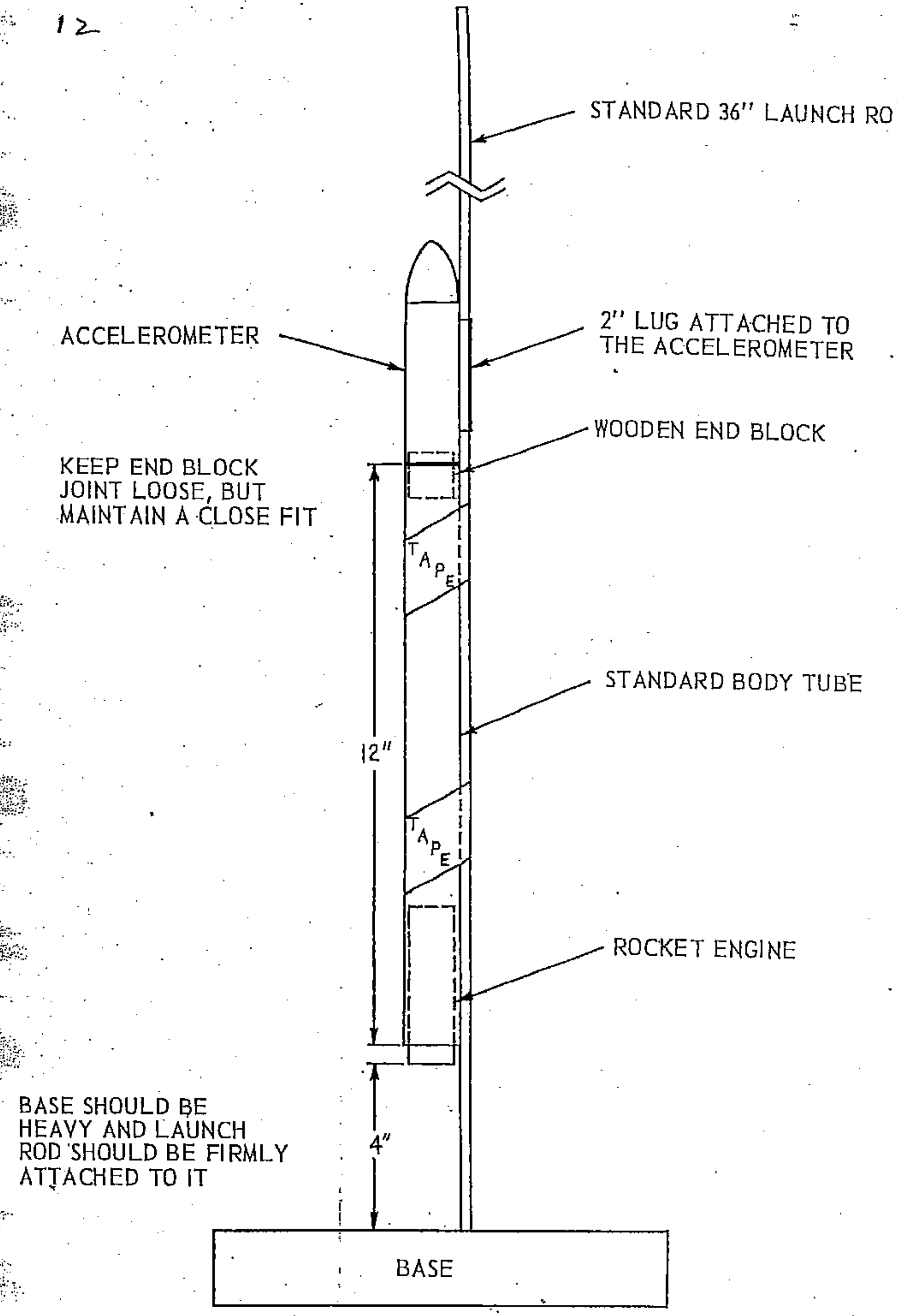


figure 4

tube and pressing it in until the shoulder fits loosely

2. tape the body tube tightly to the rod so that there will be no movement of the engine section

3. slide the launch lug over the rod before taping it to the meter so that it will not be flattened; check the fit of the lug over the rod - there should be as little friction as possible

Take at least 6 readings before calculating the average strength.

The formula to be used is derived simply from the acceleration formula. The approximate force of the ejection charge will be in the same units as your meter weight, be it dynes, ounces, etc.

Thus:

(7) $$F = wN$$

w = wt. of meter (about .3 oz.)

N = number of g's read from meter

We are sure that you would like to develop your own experiments and thus this manual is provided strictly to inspire further thought; the formulae are provided for the rocketeer who is not well versed in high school physics. We impress you that all work is approximate and all data should be analyzed in accordance with accepted numerical principles. Thus we include a simplified method for analyzing all sets of data that arise in model rocketry.

DATE ANALYSIS - I

In this section we present the theory of analysis and, in part II, we will provide an example to further clarify the method.

In order for your results to be worthwhile, they must be analyzed with the thought that all values are incorrect due to unavoidable errors such as the variability of the engine, density and viscosity of the air (including winds) and imbalances in the rocket itself. To account for such errors and the natural distribution of values around a central mean, we must calculate and use the <u>standard deviation</u> (s.d.) of our data.

First, let us define the "mean" of a set of data. If we add up all values and devide by the number of values (that is, take the average) we arrive at a number called the <u>mean</u> value of this set of values. To calculate the s.d., we:

1. find the difference between the individual values and the mean
2. square these differences
3. add them together

4. divide by the number of values
5. take the square root of the resulting number

The importance of the s.d. is that it may be used as a ruler to measure the maximum allowable error. If you have between 4 and 100 values, you should reject all values varying from the mean value by more than 3 s.d.

DATA ANALYSIS - II

As a further explanation, let us say we have arrived at the following 10 values from experimentation and we wish to analyze our findings.

(We suggest that you arrange your data tables in the same manner as set forth on the following page.)

ft/sec^2	difference from mean	(difference)^2
328	3	9
314	11	121
335	10	100
310	15	225
300	25	625
305	20	400
364	39	1521
332	7	49
340	15	225
322	3	9
3250 total		3284 sum

mean value equals $\frac{\text{total}}{\text{number}} = \frac{3250}{10} = 325$

s.d. equals $\left(\frac{\text{sum of diff.}^2}{\text{number}}\right)^{\frac{1}{2}} = \left(\frac{3284}{10}\right)^{\frac{1}{2}} = 18$

Note that the mean value need not be one of the given values.

All values are within 3 s.d. (that is, 3 times 18, or 54) but 365 just barely fits. When dealing with small sets (less than 20) it is often worthwhile to discard a value so close to 3 s.d. In this case, such a course is optional.

Let us assume that this set of data applied to nose cone A and a second set corresponded to nose cone B. To arrive at a meaningful conclusion, we must compare only the mean values of the sets. Comparing s.d.'s can only give a slight indication of the accuracy and value of the experiment.

CONCLUSIONS

It may seem that the meter is just another gadget, but remember that it is how you use it and analyze the data that is important. All work you may do can be considered only an approximation and you may come to several erroneous conclusions because of data involving too great an error. In such a case, examine your assumptions since most errors will occur from false assumptions. Such false assumptions may be: thinking air drag may be discounted, that drag is relatively constant, that no spin exists, that all flights are straight and that no friction occurs from the launcher. A typical erroneous conclusion would be that drag is proportional to the cube of the velocity instead of the correct square of the velocity. The most important principle to keep in mind is that, with an instrument such as a simple accelerometer, data received is an indication of a relation even though the particular numbers derived may be wrong in every case. If you keep this in mind, you'll learn a great deal, and have a lot of fun doing it!

Please write us about your work with the accelerometer as we are always interested in new applications. Also, if you run into a particularly hard problem, write to us and we may be able to help. Good luck and good flying!

WE APOLOGIZE - We are truly sorry for the great delay in sending the accelerometer, but our insistence on giving a good product brought many delays. We hope that we may be of better service to you in the future. Thank you.

ACCELERATION DETERMINATION USING THE AMROCS ACCELEROMETER

In order to estimate maximum acceleration, the following procedure is recommended:

1. Accurately measure the length of all visible scribe traces and average the lengths.

2. Consult the graph along the distance axis (numbers indicate length of scratch in inches) and find the acceleration corresponding to this distance; for example, a length of 1" would mean a maximum acceleration of about 440 ft./sec.^{2} and an effective "force" of about 13.7 "g's". (Disregard weight scale.)

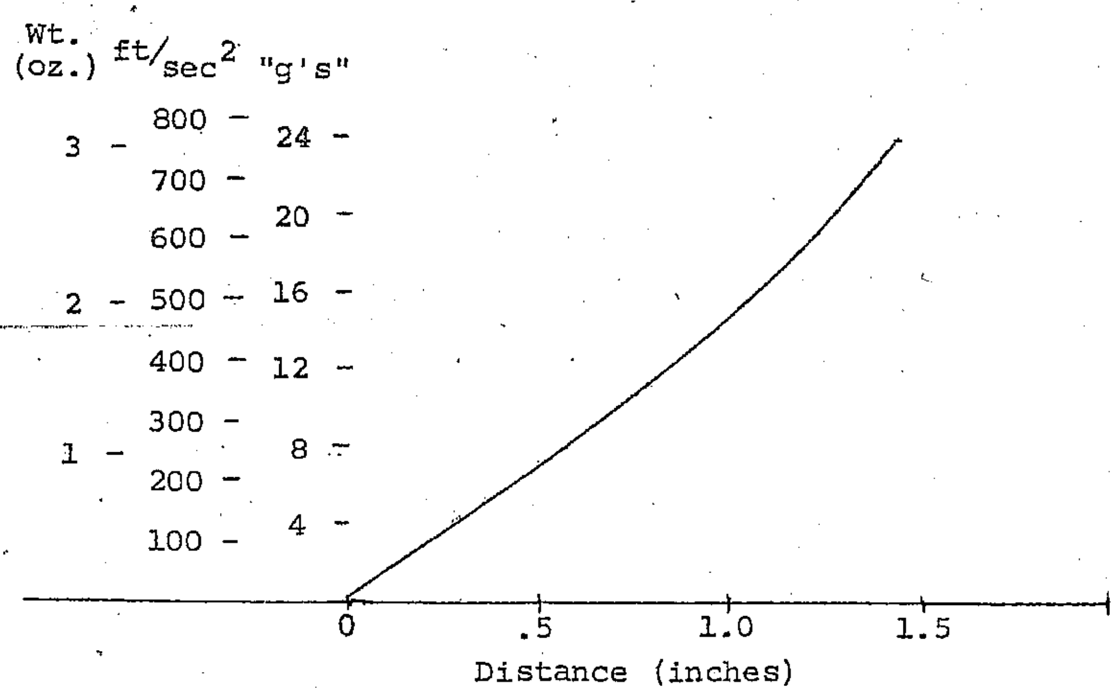
3. Run your test <u>at least 6 times</u> to derive a workable mean value as outlined in the manual.

EXTRA TIPS

To help in preparing your meter for flight we recommend the following hints:

1. Glue a thin piece of paper to one of the springs so that the weight cannot slip down into the spring. This paper should not hang over the edge of the spring since such overhang will cause friction and reduce the accuracy of the meter.

2. To maneuver the scribe weight so that it is flat on the spring, use the straightened end of a paper clip which has been bent slightly at the end. Be careful not to make any stray marks on the scribe paper when maneuvering the weight.



WEIGHT DETERMINATION USING THE AMROCS SCALE

In order to estimate weight of a small model rocket or part of a larger one, simply measure the change in height of the platform and find the weight corresponding to this distance on the graph. See instructions. (Disregard other scales.)