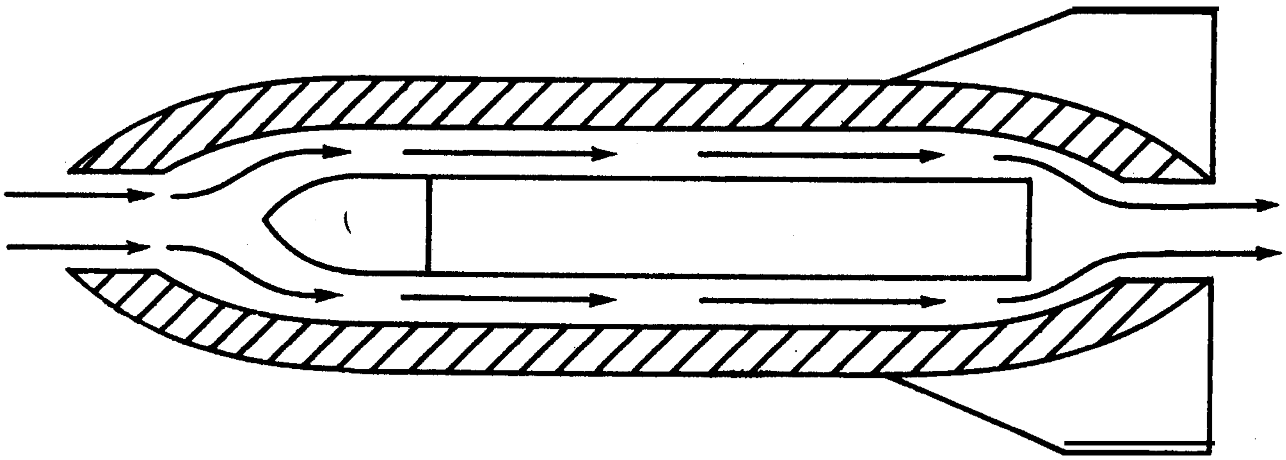
National Association of Rockety

TECHNICAL REVIEW

Volume 1



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NAR TECHNICAL REVIEW

Volume 1

The NAR Technical Review is a collection of Research and Development reports and technical papers oriented towards a wider distribution of recent and past works into various aspects of model rocketry. It is hoped that the Technical Review will act as a reference source for those persons interested in learning of recent research efforts, and will help prevent past works from being forgotten and needlessly duplicated.

This issue of the NAR Technical Review was published by the NAR Technical Services Committee (NARTS) with the assistance of the Leader Administrative Council (LAC). The editorial staff is composed of the following NAR members:

Special Thanks go to Bob Mullane, president of the Pascack Valley Section, without whom this issue would never have been printed.

THE KRUSHNIC EFFECT: ITS CAUSE AND CURE

By Lindsay Audin

One aspect of model rocketry that eventually confronts most rocketeers is the so-called " Krushnic effect", Usually the confrontation is quite accidental: a poorly emplaced engine block tears loose and the forces its way deep into the body tube. The rocketeer takes note of a distinct loss of thrust, a roaring sound and a billowing of the smoky exhaust: he has discovered the Krushnic effect, (He has more than likely also discovered the charred remains of a once-flyable rocket),

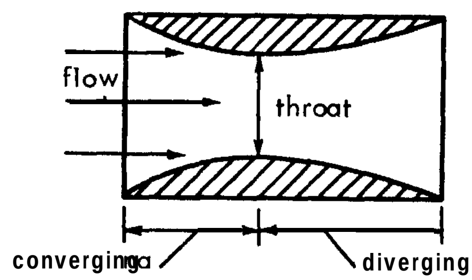
Named after the first known rocketter to study it, the Krushnic effect was originally ascribed to the formation of standing sonic waves set up by the exhaust in the body tube; that is, a system of stationary high and low pressure zones, as in an organ pipe. The compression and expansion of exhaust gases as they passed through these zones led to a loss of thrust, according to Krushnic in 1958. Unfortunately, the answer is not so simple,

The formation of standing waves occurs in fluids whose velocity is small compared to that of wave propagation; in this case, the speed of propagation is the speed of sound. The normal speed of a model rocket engine exhaust is far above that of sound. Thus, standing waves could not occur in this fluid.

Experimentation confirmed this belief by showing that no measurable pressure zones existed along the length of the tube.

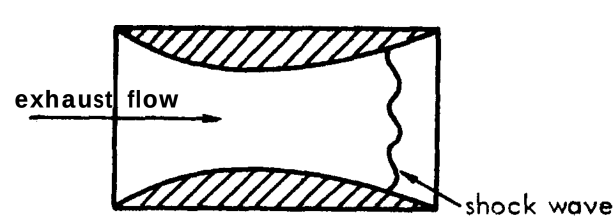
After additional tests, it was felt that the Krushnic effect was due primarily to the continued expansion of exhaust gases after they leave the nozzle of the engine.

To fully understand the reasoning behind this theory, one must understand the workings of the typical deLaval nozzle. Ideally, the nozzle is composed of two sections:



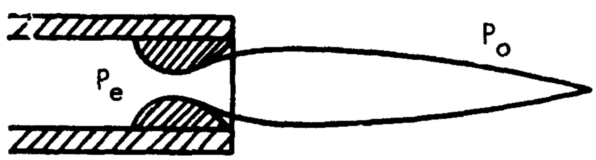
the converging section (whose cross-sectional area decreases to a minimum) and the diverging section (whose area increases from a minimum). The point of minimum area is called the throat. The purpose of the nozzle is to direct the gases and increase their speed. The speed in a well designed is subsonic (and increasing) in the converging section, sonic at the throat, and supersonic (and increasing) in the diverging section. Conversely, subsonic gases decelerate when area increases and supersonic decelerate when area decreases. The mathematics developed to explain a change in speed with a change in area are exceedingly complex and are a subject for another paper, Suffice it to say that the velocity will continue to increase in the diverging section until the gases leave the nozzle.

As they leave, the gases create shock waves (sudden transitions from supersonic to subsonic speeds). When the gas pressure is equal to atmospheric pressure, the shock waves are outside the nozzle. When the exhaust pressure drops below a certain point, however, the shock waves move into the nozzle, as in figure 2.

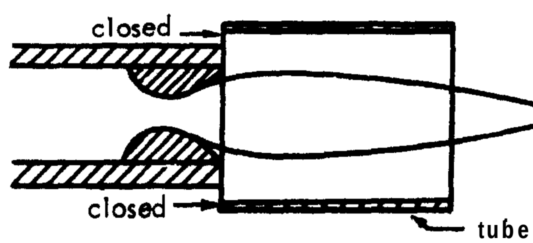


As explained previously, supersonic gases accelerate as nozzle area increases and subsonic gases slow down as area increases. When the shock wave moves into the nozzle, the supersonic gases cannot expand as far since the they do not reach the maximum exit area- the shock wave is "blocking" the way. Thus, the supersonic gases accelerate to a point, pass through the shock wave, become subsonic and are rapidly decelerated (since increases area now slo ws the subsonic gases). The gaes have not reached the speed normally attained when the supersonic gases are allowed to fully expand in the diverging section and, as a result, thrust is lowered. With this knowledge in mind, the Krushnic effect may be fully understood.

Imag ine a typical model rocket engine as Figure 3.



If P is close to P_o, mild shock waves will form at th e exit and can be ignored. If P_e is much less that P_o, the shock waves will move into the nozzle. This will occur if a tube of inner area greater than the exit area of the nozzle is placed behind the nozzle with no vening (i .e., air holes) in the tube. Figure 4. Through viscous effects, heat transfer, etc.



the shaded area develops a pressure below that of the atmosphere. The lower pressure causes the gases to "spread out" to fill this partial vacuum; as they spread out, they slow down. With the decrease in velocity comes an increase in pressure, The shock wave then moves into the nozzle and the supersonic gases don't reach as high a speed as under normal conditions, When the exhaust velocity drops, thrust drops. Thus - the Krushnic effect. Simple - isn't it?

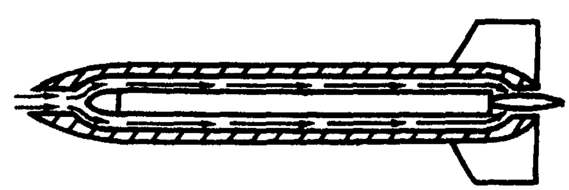
Now, no theory is very good without some proof to back it up. Tests were run in 1966 to determine the location of low pressure areas and means to crlleviate them. High speed photography proved that:

1. the area just behind the nozzle is lowest in pressure and pressure increases to match that of the atmosphere at or near the tube exit
2. the gases expand to fill in this low pressure area
3. by opening the closed end of the tuh (marked in Fig. 4) the partial vacuum was relieved by flow from the atmosphere and thrust drop was negligible, in agreement with theory.

Previous tests had shown that holes in the tube (along its length or around its circumference) served the same purpose i.e., allowing venting and filling of the partial vacuum by air flow from the atmosphere .

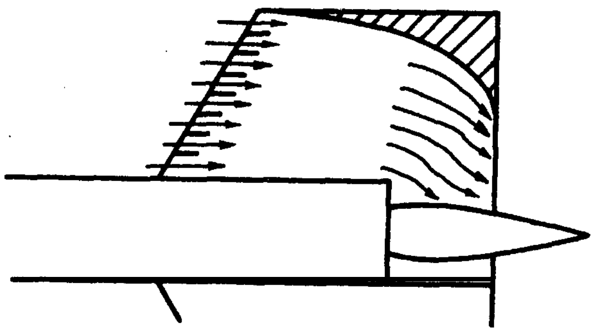
According to the theory, a tube of inner area equal to that of the nozzle exit area should not cause a severe reduction in thrust since the gases cannot overexpand as in previously discussed cases. Tests have shown this conclusion to be true to a point; thrust is still reduced, however, due to friction between gases and the wall and minor shocks reflected from the wall.

Seveml uses for this effect have been developed in past years. The most prominent are as follows:

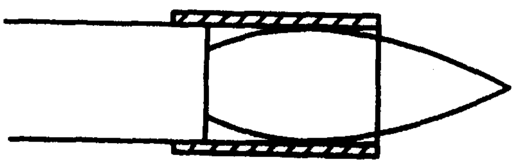


drag reduced by reduction of pressure difference between nose and tail; air is vented around core of rocket by suction

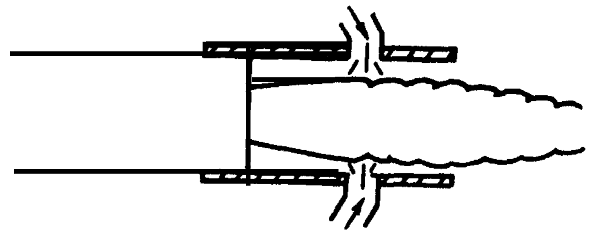
at base of engine due to Krushnic effect
(Essmun, 1963)



pressure drag reduced around fins by venting through hollow fins by using suction of area behind nozzle of engine (Lerner, 1964)



controlled thrust reduction by addition of tube - no air mixing (Penio, 1966)



thrust direction and control by water injection (Audin, 1967)

There is much nore to be done in the study of the Krushnic effect. Specifically, there is a marked lack of accurate data on the loss of thrust as a function of tube diameter and length. Some data has been collected (Jacobsen and Palmer, 1967) but the door to further research is wide open. Another aspect of the effect lending itself to study is the develpment of vortices in the tube near the engine nozzle. The major tools needed are an accurate test stand and a movie camera The projects may be as simple or complex as desired by the researching rocketeer; the field is only as narrow as his imagination and energy.

ON THE Metric SYSTEM IN MODEL ROCKETRY

By Patrick H. Stakem

The purpose of this article is to introduce you to the metric system and to thinking in metric. It's easy to say "That rocket weights about 5 ounces", or, "It went 1000 feet", but now that the metric system is in model rocketry to stay, we should be able to say, "That rocket weighs almost I30 grams", or, "It went 200 meters".

The metric system is the best and most consistent system of units for scientific calculation yet devised. It is decimal based; i.e., each unit is exactly ten times the magnitude of the next smaller unit, This allows 'calculations to be carried out quickly and accurately, even in one's head. Compare 10 millimeters equals 1 centimeter, and 100 centimeters equals 1 meter with 12 inches equals 1 feet, 3 feet equals 1 yord, etc.-

The main difficulty that you will meet is the often confusing concept of weight and mass. In the English system, we are faced with pounds, slugs, and poundals, and I, for one, get confused However, in the metric system, wieghts, masses, and forces come out naturally and easily. Before I discuss conversion I'll try to clear up the ideas of weight and mass, because unless you understand these, the conversions will be useless.

The measurement of mass, length, and time is basic and does not vary, regardless of the gravitational environment in which they are measured. All common measurements can be expressed in terms of mass, length, and time; velocity is length/time, acceleration is $length/time^2$, and force is defined as mass timer acceleration (F ma). "Weight" is a name for the force of attraction between two bodies - in OUF case, some objects and the earth. Near the earth's surface, this force can be defined by the mass of the object and the acceleration of gravity; that is,

$$W=m\ g$$

where W is the weight of the object, m is the mass of the object and g is the accel eration of gravity. (32.2 ft $/sec^2$ or 9.8 m/sec^2). We are commonly associated with weighing an object on a scale, and since differs from mass by only a constant when near the earth we can determine the mass of an object by dividing its weight by "g"(m W g). In the English system, the similarity between mass and weight leads to confusion as the same name is applied to both; i.e., the pound. To clear up this confusion, the terms pound-mass and pound-force (one pound-force equals the force measured by a scale which is weighing an object of one pound-mass) were devised. Such a similarity still leads to confusion in calculations since

$$\frac{1\ lbf}{1\ lbm} = 32.2\ ft/sec^2 = g$$

In the metric system, however, the unit of force is not related to the gavitational constant. The force unit, the newton, is defined as one kilogram times one meter/second^2. Thus,

$$1\ nt = 1\ m/sec^2$$

[redacted]

and "g" never enters the picture, Since the newton is a unit of force, it can be used as a unit In such a case, the weight of one kilogram on the earth's surface is

$$F = m\ a = m\ g = W$$
$$= 1\ kg\ (9.8\ m/sec^2)$$
$$= 9.8.\ nt$$

On a satellite where g=0,

$$W = m\ g$$
$$= 1\ kg\ (0)$$
$$= 0$$

On the moon where g= 1.65 m/sec^2

$$W = m\ g$$
$$= 1\ kg\ (1\ .65\ m/sec^2)$$
$$= 1.65\ nt$$

The appendix at the end of this article contains a list of the major English-metric conversion factors that anyone in model rocketry should need. The conversion method is simple. for example, since .3048 meters equals 1 foot,

$$\frac{.3048\ meters}{1\ foot} = 1$$

Now, we know that we can multiply any quantity by 1 and get that same quantity;

$$4\ feet \times 1 = 4\ feet$$

so this is how we convert:

$$4\ feet \times \frac{.3048\ meters}{1\ foot} = 1.219\ meters.$$

The following worked examples should help to clarify matters.

A rocket weighs 2.5 ounces. Convert to metric system.

$$2.5\ oz \times \frac{28.35\ grams}{1\ oz} = 70.875\ grams$$

We usually speak of something weighing so many grams. The gram, however, is a unit of mass, not a unit of force or weight. We can loosely speak of a weight of so many grams if we remember that any equations involving forces must contain units of force to come out right. Keep in mind the direct correspondence between mass and weight: it is "g", the local gravitational constant. Thus, it is "legal" to say, "My rocket weighs 50 grams". For formula, work, we must remember that 50 grams is equivalent to

$$50\ grams \times \frac{1\ kg}{1000\ grams} \times \frac{9.8\ m}{sec^2} = .49\ nt$$

Just be careful of your units.

A rocket is travelling 150 meters/second. What is this in miles per hour?

$$\frac{150 \text{ meters}}{\text{sec}} \times \frac{1 \text{ mph}}{.447 \text{ meters/sec}} = 335.57 \text{mph}$$

The effective aerodynamic area is 1.8 in². Convert to metric.

$$1.8 \text{ in}^2 \times \frac{.0006452 \text{ m}^2}{\text{in}^2} = .00116 \text{ meters}^2$$

If $g = 32.17$ ft/sec² in the English system, what is it in the metric system?

$$\frac{32.17 \text{ ft}}{\text{sec}^2} \times \frac{.3048 \text{ meters}}{1 \text{ ft}} = 9.81 \text{ meters/sec}^2$$

The chamber pressure of an engine is 150 lbf/in². In the metric system:

$$\frac{150 \text{ lbf}}{\text{in}^2} \times \frac{6895 \text{ nt./m}^2}{1 \text{ lbf/in}^2} = 1,034,250 \text{ nt/meter}^2.$$

The total impulse of an engine **is .56 lbf-sec.** What is this in metric?

$$.56 \text{ lbf-sec} \times \frac{4.48 \text{ nt}}{1 \text{ lbf}} = 2.50 \text{ nt-sec.}$$

A rocket engine has an average **thrust of 1.3 lbf.** How many newtons is this?

$$1.3 \text{ lbf} \times \frac{4.48 \text{ nt}}{1 \text{ lbf}} = 5.82 \text{ nt.}$$

The only way **to master metric is to use it.** Start now by trying **to visualize in metric sizes,** weights, **etc. If you don't understand the mass-**weight, bit, **go to the library and get a good** introductory **text on physics. Metric is easy,** and **it is ideal for model rocketry calculations. Get** with it! Learn **metric!**

APPENDIX

Some constants:

1 standard atmosphere = 101,325 nt/meter²

density of air at STP (standard temperature and pressure) = 1.293 kg/meter³

g (on earth's surface) = 9.807 meters/sec²

speed of sound in dry air at STP = 331 m/sec

Some definitions:

1 meter = 1,650,763.73 wavelengths, in a vacuum, of a certain radiation emitted by Kr^{86}, an isotope of Krypton

1 kilogram = mass of international kilogram at Sevres, France

1 pound-force = weight of .45359237 kg

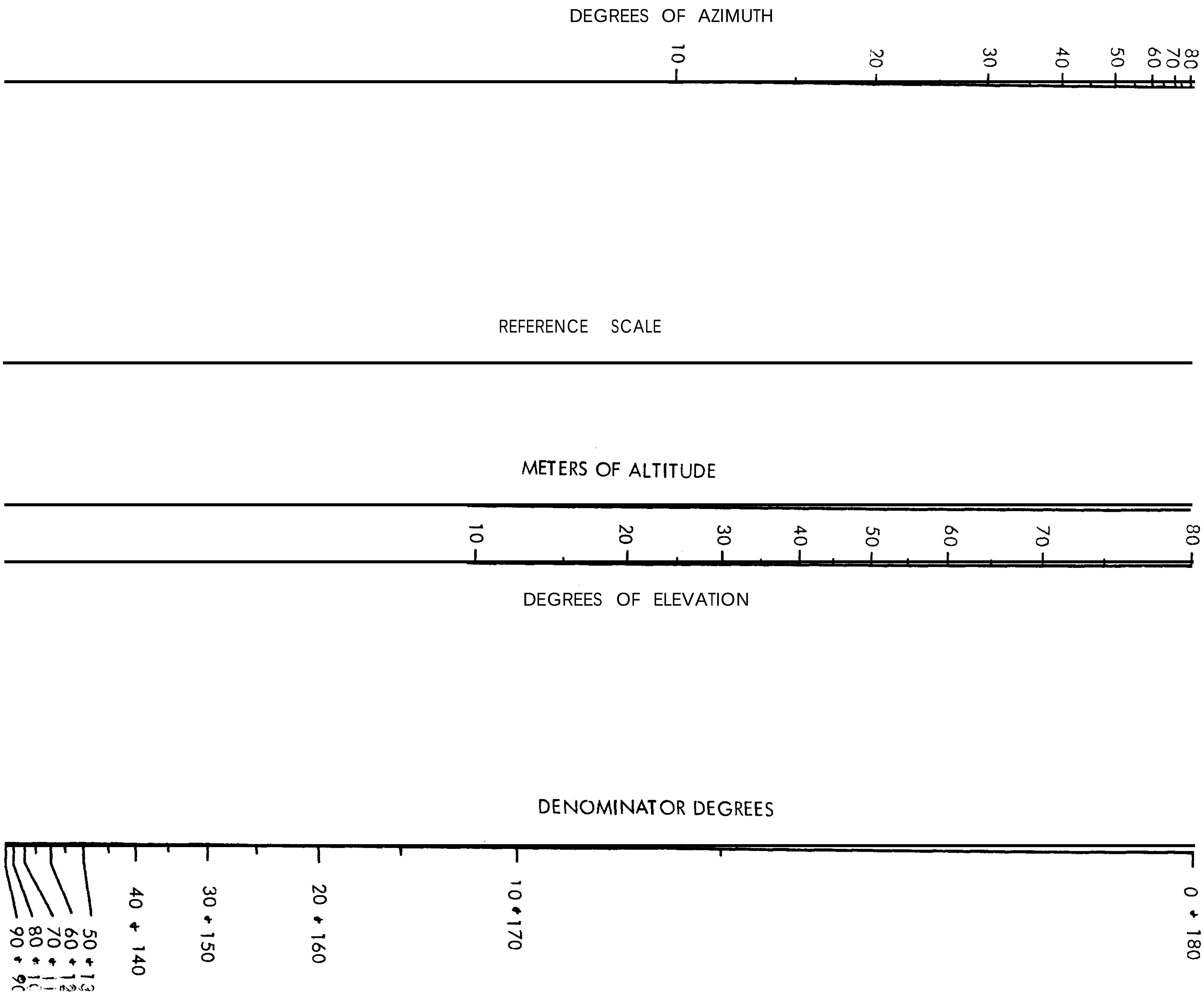
1 BTU (British Thermal Unit - unit of energy in the English system) = energy needed to raise the temperature of one pound of water from 62° F to 63°F

1 calorie (metric system of energy) = energy needed to raise 1 gram of water at 15°C to 16°C

1 joule (metric unit of energy) = work done when a mass of 1 kg is accelerated at 1 m/sec² for a distance of 1 m.

Conversion **factors:**

Length:	1 foot = .3048 meters
	1 inch = 2.540 centimeters
	= .0254 meters
	1 mile = 1609 meters
	1 meter = 100 centimeters
Area:	1 inch² = .0006452 meter²
	1 foot² = .0929 meter²
Volume:	1 inch³ = 16.39 cm³
	1 foot³ = 28,320 cm³
Mass:	1 kilogram = 1000 grams
	1 kilogram = 2.20 pounds mass
	1 pound mass = 453.6 grams
Force:	1 pound force = 4.48 newtons
	1 newton = .225 pounds force
Impulse:	1 nt-set = ,225 pound-seconds
Speed:	1 ft/sec = .3048 meters/second
	1 mile/hour = .447 meters/sec
Energy:	1 BTU = 1055 joules
	= 252.1 calories
	= 778.2 lbf-ft
	1 joule = .7376 lbf-ft
	= .0009478 BTU
Pressure:	1 millimeter of mercury = 133.3 nt/m²
	1 lbf/in² = 6.895 nt/m²


DEGREES OF AZIMUTH
10
20
30
40
50
60
70
80
REFERENCE SCALE
METERS OF ALTITUDE
10
20
30
40
50
60
70
80
DEGREES OF ELEVATION
DENOMINATOR DEGREES
40 + 140
30 + 150
20 + 160
10 + 170
0 + 180

NOMOGRAPHIC DATA REDUCTION

by Calvin Tracy

This report is intended to be used as a guide in making a quick and inexpensive altitude reduction system for use at the range. The nomograph should be scaled up and calibrated in smaller increments and the table should be calculated for smaller increments if more accuracy is desired. Altitudes derived from this graph are accurate to within 10% of the actual result.

Sample: East Az = 23 El = 36
West Az = 45 El = 53

1. connect line East az on azimuth scale and West el on elevation scale
2. mark point on reference where the previous line intersects
3. connect the mark on the reference scale with the sum of the East and West az readings on the denominator scale
4. mark intersection of this line with altitude scale and measure distance between mark and bottom of scale with metric ruler
5. substitute this value in the table to obtain result in meters for a 300 meter baseline
6. repeat above procedures with West az and East el, adding elevations in place of azimuths
7. average the two results.

Sample results: 171 and168 meters; average 170m

ALTITUDE CONVERSION CHART

cm	meters
6.3	3
7.6	6
5.3	9
8.8	12
9.2	15
9.5	18
9.8	21
10.0	24
10.4	30
10.8	36
11 .o	42
11.3	48
11.5	54
11.8	65
12.0	72
12.2	81
12.4	90
12.6	101
12.8	113
13.0	126
13.2	141
13.4	156
13.6	174
13.8	195
14.0	219
14.1	231
14.2	245
14.3	258
14.4	273
14.5	288
14.6	305
14.7	323
14.8	341
14.9	360
15.0	381
15.1	402
15.2	426
15.3	450
15.4	476
15.5	503
15.6	531
15.7	561
15.8	594

IDEAS IN ADVANCED MODEL ROCKETRY

by Joseph Persio

Most of the unsolved problems in model rocketry involve quantities of interest such as thrust, pressure and temperature. The following section details several unique ways to measure these quantities. They are not meant to be complete but rather basic in their approach;

details are left up to the interested rocketeer.

For the initiated researcher, it is best that an understanding of several measurement problems be obtained, before plunging into construction of any apparatus. In order of importance:

1. accuracy - when any motion is involved in measurement, (such as compression of a spring to measure force) friction at bearings will lead to error. In cases where oscillation occurs (e.g., weight bouncing up and down at the end of a spring),some means of reducing the oscillation is needed if accuracy is to be maintained. Often an intended increase in friction is allowable to decrease the magnitude of each oscillation. A useful device to accomplish that end is called a dashpot. It may consist simply of a plate moving in a viscous fluid (e.g., oil); the friction between plate and fluid reduces speed of the plate and any parts connected to it. One of the chief ways to avoid friction, dashpots, etc. is to utilize electrical systems instead of mechanical systems.

2. data recovery - in static testing, data recovery rarely presents a problem as means of recording are usually available on the spot (e.g., a rotating drum). When instruments are separated from the testing device, as in flyable payloads, the problem of obtaining useful data becomes a bit sticky. The usual method is to radio the information back to a receiver and recording device such as a tape recorder. Of course, such complexity adds to the possibility of error. Furthermore, obtaining useful data from a tape recording may require an oscilloscope or chart recorder. Once again it is suggested that mechanical systems be avoided and replaced by optical or electrical systems; a favorite method is to film the wave-forms on an oscilloscope and later view the frames in a film editor editor to sample data at various times.

3. calibration - going hand in hand with data recovery and accuracy, is the problem of knowing in advance what output will occur with an certain output. For example, if thrust is doubled, spring compression may be doubled on an ideal test stand. Unfortunately, few systems ore so linear. In the case of a temperature probe, a 20% increase in temperature may lead to a 10% change in electrical resistance, which may lead to a 5% change in audio amplitude in a transmitter. Another 20% increase in temperature may not lead to the same change in audio amplitude, however. Thus, it is necessary to carefully check variations of cause and effect over the entire region of expected values. Finally, such a check should be run several times to note the accuracy of repeat performances, Variances should be calculated so that reasonably accurate data is obtained in the end.

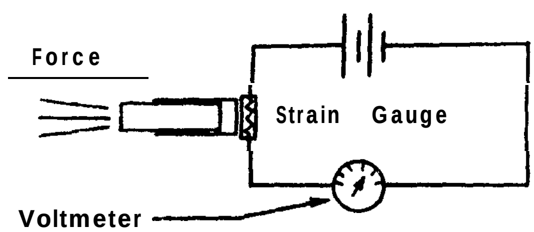
With the advent of large model rocket engines, up to about 100 newton seconds, research using model rockets has become more practical. Any model rocket can now be lofted several kilometers. Now that we have ample rocket power all that is needed is some equipment in the form of probes and thrust-time recording equpment so that we can start mglsuring things.

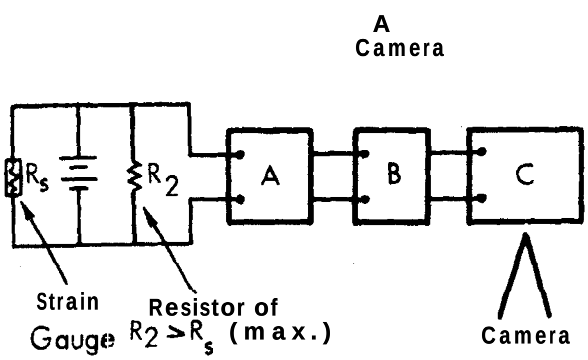
The most important piece of equipment in any project involving a flying model rocket is a thrust-time recorder to accurately measure thrust and total impulse of the engine, Three systems are shown that should give the rocketeer some idea as to what can be done. The two systems that utilize motion picture cameras must have thrust-time curves obtained with them graphed by hand. Each frame advances at. a set interval, giving time, and forces obtained from the position of the light beam or pressure indicator with respect to the screen/scale arrangement. For a simple, explanation of strain gauges, see the Mcgraw-Hill Science Encyclopedia. The most accurate thrust-time recording system mentioned here is the one involving the strain gauges. Large electronic supply houses such as Lafayette carry everything heeded for the strain gauge system.

As for payloads, no one has done very much with them yet, part of the problem being the lack of a good, lightweight transmitter. In our next issue, we plan to feature one that has been found satisfactory. Many walkie talkie can be easily converted for use as transmitters, though. Before attempting any of the payload projects a basic understanding of mechanics and electronics is needed. It is suggested that you obtain and study a copy of Modern College Physics, fifth edition by Harvey White, printed by D, Van Nostrand Co. , Inc. New Jersey,

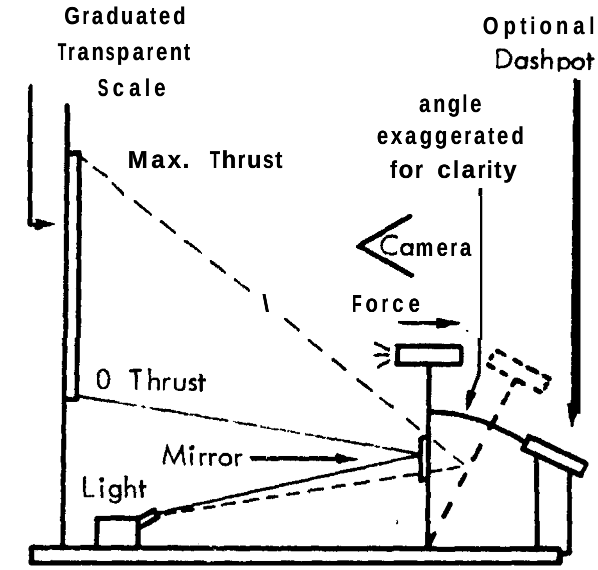
If you do try any of the ideas listed, please write us to let us know how you went about building the equipment and how the data was reported and reduced. If you have any good' ideas please feel free to send them in, too.

THRUST-1 TIME RECORDERS

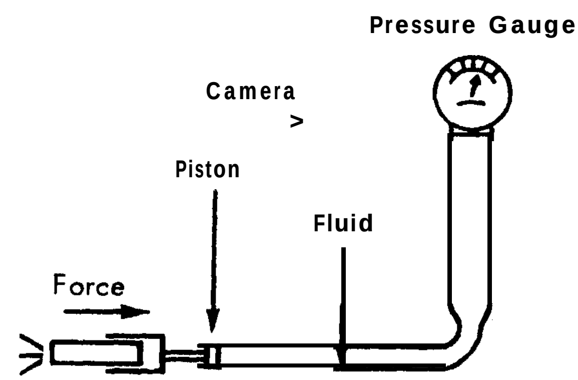




Force on a strain guage changes its resistance which alters voltmeter reading which is recorded by camera. Alternatively, the variation in resistance (R) may be put into on amplifier (A) then into an oscillator (B) and, finally, viewed on an oscilloscope (C). The change in wavelength due to change in R would be recorded on film.

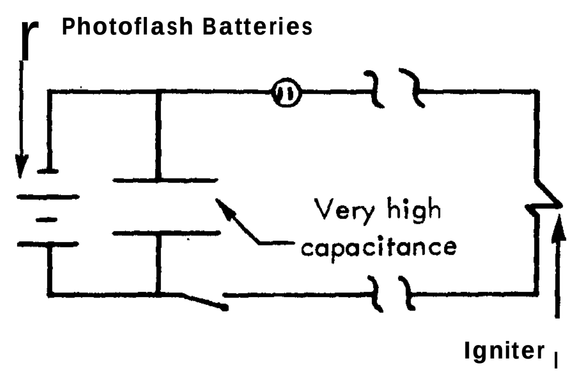


Force bends a flexible metal strip and changes the angle of reflection of a light beam. The beam falls on a translucent graduated scale and a camera records the thrust.

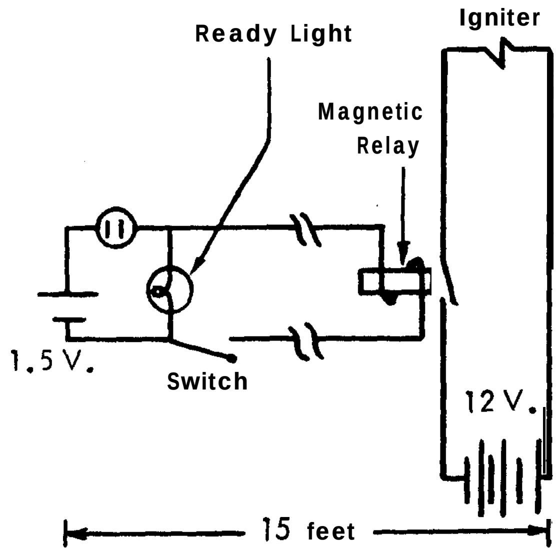


Force on fluid is measured as pressure on guage and recorded on camera.

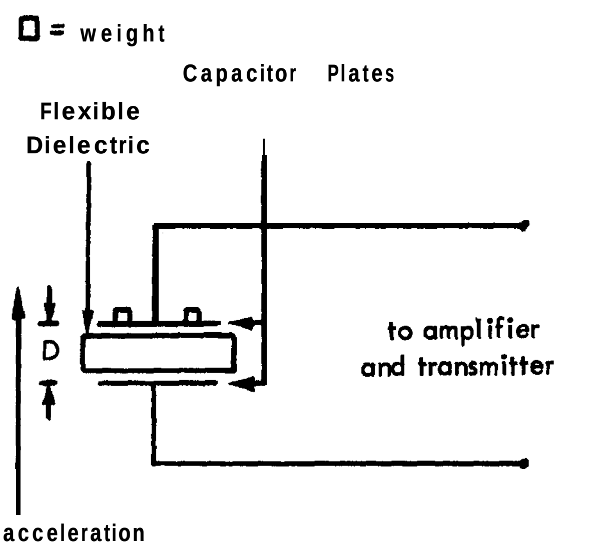
IGNITION SYSTEMS



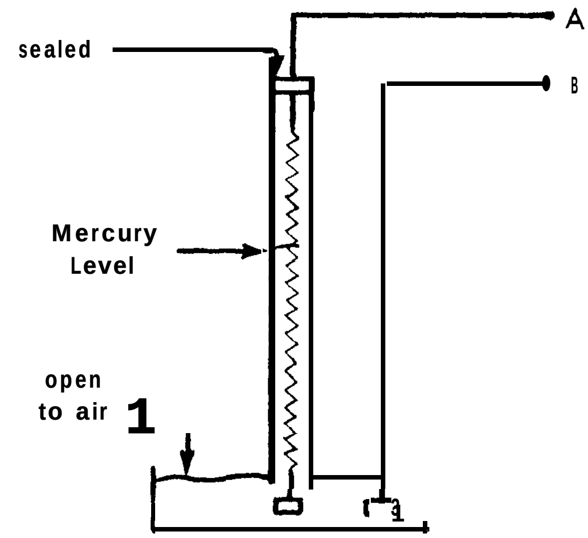
Batteries will last longer in small systems and the heavy car battery may become obsolete if calculations prove right in this capacitor firing system. Single capacitors of 4,000 to 36,000 microfarads are available and when discharged ignition is rapid and battery drain is reduced. A relay may be used to reduce the length of wiring between the firing battery and the igniter, thus reducing resistance and ignition time (possibly bv more than 30%).



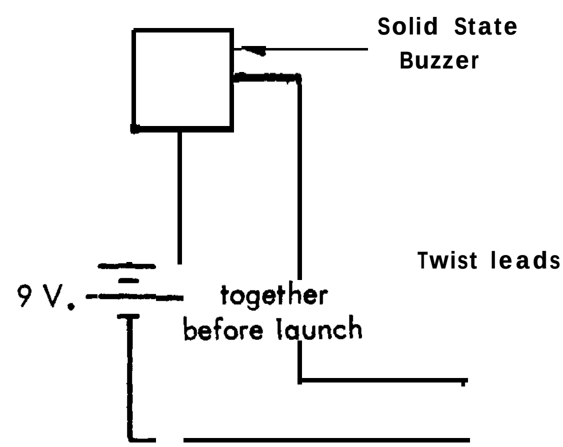
PAYLOADS



Acceleration (or vibration) may be measured as a change in capacitance if a flexible dielectric (non-conductor that stores charge) is used between capacitor plates. As acceleration-increases, weights press harder bringing plates closer together and increasing capacitance.



Pressure/nay be examined by utilizing the conductivity of mercury in a barometer. As pressure changes, mercury level changes and resistance between A and B changes. Errors are subtle: acceleration and temperature may also change the mercury level.



Velocity may be estimated by noting the change in frequency of sound emitted from a loud buzzer in the rocket . This system was tested with a Sonalert Model SC available from Electropac, Inc., Peterborough, N.H. and found feasible. The sound received must be recorded and velocity calculated according to the Doppler Effect.