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ABSTRACT

This instructional guide, intended for student use, develops the art of model rocketry through a series of sequential activities. A technical development of the subject is pursued with examples stressing practical aspects of the concepts. Included in the minicourse are: (1) the rationale, (2) terminal behavioral objectives, (3) enabling behavioral objectives, (4) activities, (5) resource packages, and (6) evaluation materials. Activities lead through a development of the laws of motion through the actual construction and launching of a model rocket. This unit is one of twelve intended for use in the second year of a two year vocationally oriented physics program. (CP)

# CAREER ORIENTED PRE-TECHNICAL PHYSICS

## Model Rocketry

## Minicourse

ESEA Title III Project

1974

dallas independent school district

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October 8, 1974

Nolan Estes
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This Minicourse is a result of hard work, dedication, and a comprehensive program of testing and improvement by members of the staff, college professors, teachers, and others.

The Minicourse contains classroom activities designed for use in the regular teaching program in the Dallas Independent School District. Through minicourse activities, students work independently with close teacher supervision and aid. This work is a fine example of the excellent efforts for which the Dallas Independent School District is known. May I commend all of those who had a part in designing, testing, and improving this Minicourse.

I commend it to your use.

Sincerely yours,

Nolan Estes

General Superintendent

NE:mag

# MODEL ROCKETRY

## AN INTRODUCTION TO AEROSPACE TECHNOLOGY

RATIONALE (What this minicourse is about):

Model rocketry is an activity which can be full of fun, excitement, and learning. Model rocketry also provides a safe set of technical learning experiences for people planning on aero-space careers.

In this minicourse you will have an opportunity to build and to fly real rockets. In addition, you will learn something about the history of space flight, how a rocket functions, and the terminology of rocket technology. Part of this terminology is reflected in the acronym FROGS, meaning "Fun Rocket-try, Or Great Science." We hope you find this minicourse to be just that: "Great Science!"

TERMINAL BEHAVIORAL OBJECTIVES:

Upon completing this minicourse, you will be able to demonstrate your knowledge of aerospace technology by participating in a rocket launch; by correctly identifying eight (8) of ten (10) basic rocket parts and describing the basic funtion of each part; by describing how a rocket functions; and by correctly associating or identifying the names of four (4) out of five (5) places, persons or events in the history of rocketry.

| ENABLING BEHAVIORAL OBJECTIVE #1 | ACTIVITY 1-1 | RESOURCE PACKAGE 1-1 |
|---|---|---|
| Give the names of five places, persons, or events related to the history of rocketry and correctly identify or associate each. | Read a "History of Jets and Rockets," pages 19-23, Resource Package 1-1. | The booklet, "Space Age Technology," Estes Industries. |

| ENABLING BEHAVIORAL OBJECTIVE #2 | ACTIVITY 2-1 | RESOURCE PACKAGE 2-1 |
|---|---|---|
| Give a simple explanation of how a rocket functions. | Read "Theory of Flight," pages 15-18, Resource Package 2-1. | The booket "Space Age Technology," Estes Industries |
| | ACTIVITY 2-2 | RESOURCE PACKAGE 2-2 |
| | Complete Resource Package 2-2, including self-tests. | The booklet "The Laws of Motion and Model Rocketry," Estes Industries |
| | ACTIVITY 2-3 | RESOURCE PACKAGE 2-3 |
| | Complete Resource Package 2-3. | "Rocket Propulsion" |
| | ACTIVITY 2-4 | RESOURCE PACKAGE 2-4 |
| | Complete Resource Package 2-4 | "Force, Motion, Energy, Work, and Rockets" |
| | ACTIVITY 2-5 | RESOURCE PACKAGE 2-5 |
| | Complete Resource Package 2-5. | "Investigating: Air Has Weight; Air Pressure; Lift; Air Resistance (Drag); and Space" |
| | ACTIVITY 2-6 | RESOURCE PACKAGE 2-6 |
| | Observe a model rocket launch. THIS FIRST LAUNCH WILL BE FOR THE ENTIRE CLASS. (You may have already seen this launch; if so, proceed to the next activity. | Your instructor will launch a ready-to-fly model rocket. This is a "fun" launch for the entire class. After you have constructed (or helped to construct) a model |

| | | |
|---|---|---|
| | | rocket, you will participate in student launches. As such, you may be required to measure certain launch/flight data and/or to serve as a member of a launch/track/recovery unit. |
| <u>ENABLING BEHAVIORAL OBJECTIVE #3</u> | <u>ACTIVITY 3-1</u> | <u>RESOURCE PACKAGE 3-1</u> |
| Be able to correctly identify and describe simply the function of eight out of ten basic rocket parts. | Complete Resource Package 3-1. | Study the remaining sections of "Space Age Technology," Estes Industries. |
| | <u>ACTIVITY 3-2</u> | <u>RESOURCE PACKAGE 3-2</u> |
| | Read Resource Package 3-2. | "Model Rocketry Technical Manual," Estes Industries. |
| | <u>ACTIVITY 3-3</u> | <u>RESOURCE PACKAGE 3-3</u> |
| | Complete Resource Package 3-3. | Build and launch a model rocket. You can purchase and build your own personal rocket or you can work in a group to build a school rocket. |
| <u>EVALUATION</u> | <u>ACTIVITY 4-1</u> | <u>RESOURCE PACKAGE 4-1</u> |
| | Ask your instructor for the final achievement measure. | "Achievement Measure--Model Rocketry" |

RESOURCE PACKAGE 1-1

THE BOOKLET: SPACE AGE TECHNOLOGY

RESOURCE PACKAGE 2-1

THE BOOKLET: SPACE AGE TECHNOLOGY

RESOURCE PACKAGE 2-2

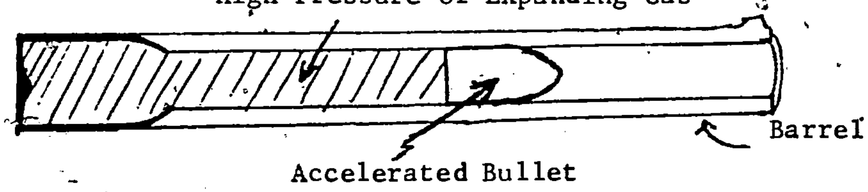
THE BOOKLET: THE LAWS OF MOTION AND MODEL ROCKETRY

RESOURCE PACKAGE 2-3

ROCKET PROPULSION

Rocket-propelled missiles differ from freely-falling projectiles because rockets have the capacity to change speed (and sometimes direction) after launch. In this Resource Package we will consider some aspects of rocket propulsion.

For a bullet to reach muzzle velocity it starts from rest the instant the cartridge is fired, and it gains speed until it reaches the end of the gun barrel. This increase in speed is called acceleration. But what causes the acceleration? When the cartridge is fired, the gun powder in the casing oxidizes to produce a gas at a very high pressure. The gas pressure energy does work on the bullet and forces the bullet out along the gun barrel. See Figure 1 below.




RIFLE SYSTEM
Fig. 1

This high pressure gas can be said to do all of the following inter-related activities: exert a force on the bullet, accelerate the bullet, do work on the bullet, change the energy of the bullet, and cause a change in the momentum of the bullet.

The high pressure gas force acts upon the bullet until it emerges from the muzzle of the gun. Because this pressure is exerted equally in all directions within the enclosed combustion chamber, pressure is exerted on the rear of the firing chamber as well as on the back side of the bullet. The force resulting from the gas pressure against the rear of the firing chamber is transmitted through the stock of the gun to the shoulder. We call this the kick when we fire a gun.

This kick phenomenon (event) is an example of an important physical quantity known as linear momentum. The linear momentum of an object can be calculated as the product of its velocity and its inertial mass. The notation for linear momentum is $\vec{P}$; mathematically, $\vec{P} = m\vec{v}$. Momentum is a vector quantity with the size mv, and with the direction of $\vec{v}$. The term inertial mass (or mass) is simply a term for the universal property of all objects to resist change in motional condition or rest condition.

This leads us to a fundamental conservation law of physics, Conservation of Momentum. This Law tells us that if we isolate things and watch their behavior when they bang together, fly apart, or otherwise interact forcewise, then we can rest assured that the initial momentum of the system of these isolated objects before they interact will be precisely equal to the momentum of the system after interaction.

Mathematically, we write

$$\vec{P}_{before} = \vec{P}_{after}$$

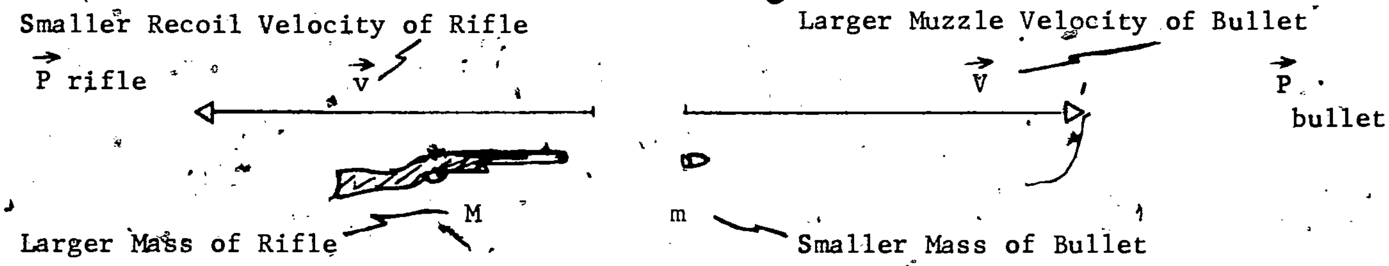
$$\vec{mv}_{before} = \vec{mv}_{after}$$

Where $\vec{mv}$ is the vector sum of all the individual linear momenta of each object in the system.

Realize that this discussion has dealt only with linear momentum. There exists, also, an equivalent <u>angular momentum</u>. It, too, is conserved, and is treated as a vector quantity. Mathematically, angular momentum $\vec{L}$, is the product of angular velocity ($\vec{\omega}$) and <u>inertial moment</u> (I), where the latter is a measure of the resistance all bodies have to a change in their spin condition. We write $\vec{L} = I\vec{\omega}$.

For a more comprehensive treatment of linear and angular momenta, look at the minicourses <u>Physics of Sports</u> and <u>Physics of Toys</u>.

Let us apply the Conservation of Linear Momentum Law to the firing of our rifle. Isolating the system in terms of gun and bullet, the <u>linear momentum before</u> firing is zero (Why? Because both the gun and bullet are at rest relative to each other; i.e. their respective velocities are zero!) The Conservation of Momentum Law implies that the momentum after firing must also be zero. Because linear momentum is a vector quantity, two such vectors can add to zero if and only if they act along the same line, are equal in size, and have opposite directions. In other words the $\vec{mv}$ of the bullet must be equal and opposite to the $\vec{mv}$ of the rifle at all times. See Fig. 2.




$$\vec{P} = Mv \text{ (Rifle)} = mV \text{ (Bullet)} = \vec{P}$$

CONSERVATION OF LINEAR MOMENTUM
Fig. 2

Consider this example:

A bullet of 10-gram mass property has a muzzle velocity of 300 meters per second when fired from a rifle which has a mass property of 2 kilograms. What is the <u>magnitude</u> of the linear momentum of the bullet? What is the recoil velocity of the gun?*

* If the dimensional units meter, kilogram, etc., bother you, perhaps you should examine the section on the metric system in the minicourse, <u>Metric System and Slide Rule</u>.

Solution: First, convert all measurements to the same system of measure. We will use the MKS system, since it is preferred by scientists and since the United States is "going metric" to keep up with the rest of the world.

$$10 \text{ gm} = .01 \text{ kgm}$$

Second, the size of the linear momentum $\vec{P}$ (of the bullet) $= mV$

$$= (.01\text{kg})\ (300 \text{ m/sec})$$

$$= 3.00\ \frac{\text{kg-m}}{\text{sec}}$$ (A scalar quantity, since only magnitude was asked for.)

Third, the linear momentum $\vec{P}$ (of the gun) has a size, $P = Mv$

$$= 2 \text{ kg } (v)$$

Momentum conservation assures us that the <u>size</u> of these two momenta is the same and that their directions are opposite; therefore, the size of the momentum of the bullet = the size of the momentum of the gun or,

$$mV = Mv$$

$$2 \text{ kg } (v) = \frac{3\text{kg - m}}{\text{sec}}$$

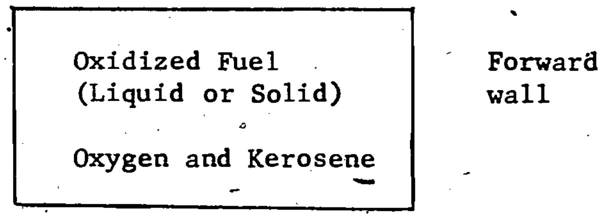
$$= \frac{3}{2}\ \frac{\text{kg - m}}{\text{kg - sec}}$$

Therefore, <u>v = 1.5 m/sec</u>, about 5 feet/sec, in a <u>direction</u> opposite to the bullet. If the gun were floating somewhere in outer space when fired, with little friction and little gravitational force, the gun would actually reach this recoil speed! But in real life, we hold a rifle to our shoulder. Under these conditions, the mass property of our body is added to the mass property of the gun and the recoil momentum is thus imparted to both. Because the gun-plus-shoulder constitutes a relatively large mass, the kick speed is reduced even though the recoil momentum remains the same. The kick from a small calibre gun is not relatively great because the mass property of the bullet is very small when compared to the combined mass of the gun and the person firing it. Conversely, the kick from a large-bore gun is relatively great because of the larger mass of the bullet (which usually has a higher muzzle velocity, too!). The firing of large-bore naval guns can cause an entire ship to recoil.

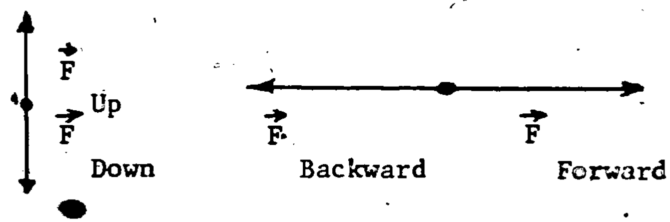
This momentum problem was restricted to linear analysis. But real rifles derive their name from the fact that when the rifle barrel is bored, screw-like ridges called riflings are left as an inner lining of the barrel. These riflings cause a bullet to spin as it moves linearly down the gun barrel toward the muzzle. When a bullet leaves a rifle barrel, it really has two velocities: a linear velocity, $\vec{v}$, and an angular velocity, $\vec{\omega}$. Obviously, it must then have two momenta: the linear momentum $\vec{P} = m\vec{v}$, and the angular momentum $\vec{L} = I\vec{\omega}$. It is the spin momentum which stabilizes the bullet in flight (See the minicourse, Physics of Sports or Physics of Toys for more about spin momentum). Further, to conserve spin momentum the rifle must rotate opposite to the rotation of the bullet!

A Thought to Ponder: Probably you have observed the firing of machine guns and heavy artillery in war films. You likely noticed that the machine gun recoil caused the gun to bounce around as it spewed forth its bullets at a rate of 600 rounds per minute, or more. On the other hand, the artillery firing of large projectiles resulted in a much slower recoil over a much larger distance (the barrel may have moved back several feet!). Can you account for these two different kinds of recoil activity?

We will now apply the momentum concept to rocket propulsion. The rocket engine contains a fluid consisting of hot gas molecules. These high-speed gas molecules exert an explosive pressure (force) equally on the walls of the engine's combustion chamber. But because there is a hole (exhaust nozzle) in the rear engine wall, the gas force on the forward engine wall is greater than on the rear wall. The rocket must respond to the unbalanced forward force by moving off in the forward direction. The net forward force is called thrust, and the thrust accelerates the rocket quite like exploding gunpowder accelerates a rifle bullet. By symmetry, it is obvious that the gas force on the upper wall is exactly balanced by the force on the lower wall. Study the diagrams below:



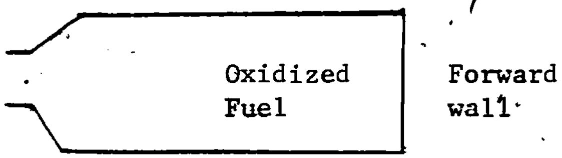

CLOSED ENGINE CHAMBER



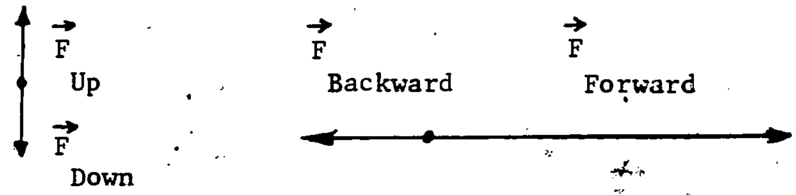

BALANCED FORCES WITHIN CHAMBER

The forces up, down, forward and backward cancel one another. No thrust results.

Now, let's consider an engine with an open chamber, as shown below:




OPENED ENGINE CHAMBER




UNBALANCED FORCES WITHIN CHAMBER

The forces up cancel the forces down, but the force on the forward wall of the engine is greater than the force on the backward wall of the engine. Thrust results! From a momentum conservation point of view, the hot gases expelled from the exhaust orifice (port) acquire linear momentum in the backward direction; therefore, the rocket engine must acquire an equal linear momentum in the forward direction.

The mass property of the entire rocket at any given instant is a variable, because the mass of the fuel is decreased as it is oxidized and ejected from the rocket. But the rocket thrust is a constant when its engine oxidizes a fixed amount of fuel in equal intervals of time. Therefore, as the mass of the rocket fuel decreases, the payload and airframe of the rocket gain more and more momentum until burn out occurs. This momentum increase can result in a terminal speed of hundreds or thousands of miles per hour!

Now let us look at some technical physics of a near-earth (inner space) vertical rocket launch, where we must take into account the force of gravity. The thrust upward will be constant, if the rate at which the oxidation gases ejected is constant and if we neglect any change in $\vec{g}$ as the rocket moves away from the earth's surface. Assume the rate of fuel ejection to be a constant 665 lb/sec and to yield an average force of 60,000 lb thrust from ignition to burn-out. This fixed upward force (thrust) will be opposed by the downward gravity force (weight). Assume this weight force initially of rocket and fuel to be 30,000 lb, and assume the final weight of the rocket, after fuel is consumed, to be 10,000 lb. Then, the net upward force initially is 30,000 lb (60,000 - 30,000); and the net upward force finally is 50,000 lb (60,000 - 10,000)! The ratio of the net upward force to the force of gravity is:

$$\text{initially: } \frac{30,000 \text{ lb}}{30,000 \text{ lb}} = 1:1$$

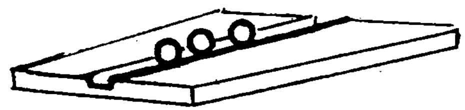
$$\text{and, finally: } \frac{50,000 \text{ lb}}{10,000 \text{ lb}} = 5:1$$

In other words, during the first moment of launch the thrust force upward just equals the rocket weight force downward. The rocket appears to hover on its launch pad. But as the fuel is consumed, the rocket thrust force upward (though <u>constant</u>) <u>becomes increasingly greater than the weight force downward</u> (weight force <u>decreases</u> as burning goes on). Now, can you understand why rockets appear to hover, then to rise slowly from their launch pads during blast off, and finally to accelerate faster and faster into space? The Atlas, a U. S. intercontinental ballistic missile, has an initial upward thrust which gives it only a net acceleration of 6 or 7 ft/sec$^2$; whereas, its final acceleration may be 30 times greater than this!

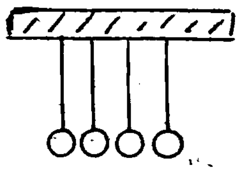
CONSERVATION OF MOMENTUM--INVESTIGATION I

1) Obtain a collision apparatus from your instructor. This Resource Package assumes you will have either a device consisting of a grooved board and some elastic balls, or a device consisting of elastic balls suspended by strings. You may investigate either the track type (the balls roll along the groove in the board) or the suspension type (the balls are suspended from strings attached to a supported stand), or both types of apparatus.

2) If you have the track type, go to step 8.



TRACK TYPE



SUSPENSION TYPE

3) If you have the suspension type, line the balls up so that their centers lie along the same line.

4) Pull one of the end balls away from the others and release it. How many balls are set in motion, and which one(s)?

5) Repeat step 4, pulling two (2) balls away from the others and releasing them together. Record your observations.

6) Now pull three (3) balls away, and repeat step 5. Record your observations. In each experiment you should have noticed and recorded that the number of balls set in motion after the collision was equal to the number of balls pulled to one side. Also, you should have noticed and recorded that the balls after the collision moved about the same distance as the balls moved before the collision. How do these observations relate to the Law of Conservation of Linear Momentum? (Write out a short statement.)

7) When two (2) balls were released, the same number were also set into motion. From a mathematical point of view, why couldn't one ball be set in motion with twice the speed of the initial balls? The answer is not immediately obvious. It would seem at first glance that if linear momentum magnitude equals mass times velocity (mv), then if the mass property is cut in half ( $\frac{m}{2}$ ), while the speed of the remaining ball is doubled (2v), the product $mv = \frac{m}{2}(2v)$ remains the same and momentum is conserved! True! Momentum would be conserved, but we have overlooked yet another conservation law: Conservation of Energy.

The analysis of this problem brings up another physical concept--energy. Just as momentum is conserved for an isolated classical system, so is energy. If one ball moves away with twice the speed, energy cannot be conserved. Energy is discussed in greater detail in other minicourses, but this kind of energy (<u>kinetic</u> or "motional" energy) is mathematically expressed as $\frac{1}{2} mv^2$. Can you see that doubling the speed would quadruple (increase by <u>four</u> times) the energy? Go to step 10.

8) Arrange the balls so that they contact each other and are midway between the ends of the groove. Separate one of the end balls and set it in motion so that it strikes the others. Record your observations.

9) Go to step 5, above, and complete the investigation procedures, 6 through 10, inclusive.

10) Turn in your observations, sketches, etc., for evaluation.

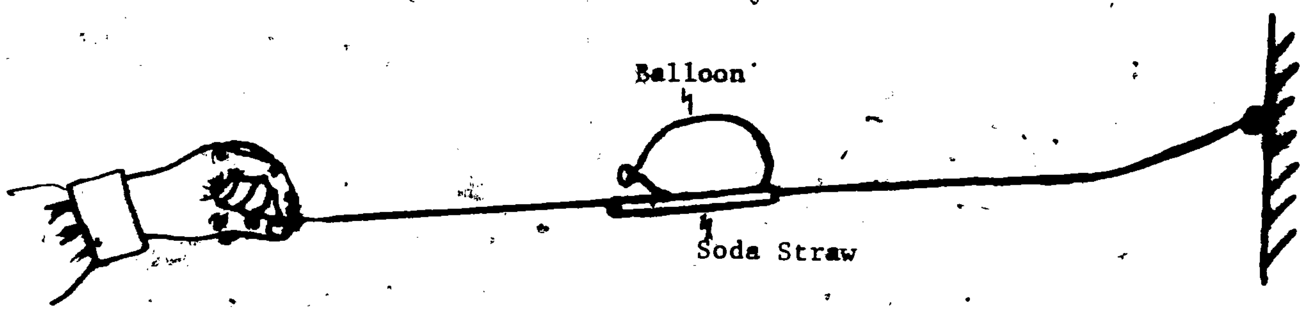
ROCKET PROPULSION--INVESTIGATION II

1) Blow up a toy balloon. The higher pressure on the inside of the balloon corresponds to the hot gas pressure inside a rocket motor. Release the balloon. As the pressurized air inside escapes, the air molecules gain momentum away from the balloon; to conserve momentum, the balloon must gain an equal momentum away from the air molecules. Some people like to call this an <u>action-reaction</u> phenomenon ("happening").

Repeat the investigation a time or two to see if you can get the balloon to fly straight. What is missing on the balloon that is built onto a rocket to insure that it follows a desired course? List some of these missing components.

2) Try to design something simple that will cause the balloon to better follow a prescribed course.

3) Tape a soda straw to the balloon (see the sketch below). Thread a long light string through the straw and attach the string to a solid object while you hold the other end! Now release the inflated balloon and observe the "guided balloon rocket."




"GUIDED ROCKET"

4) Submit your notes, your answers, and design. They will be evaluated by your instructor.

## MOMENTUM PROBLEMS

Solve the following on separate paper. Show all calculations and diagrams. Please do not write on this sheet.

1) Discuss this statement: "A rocket cannot move under its own power in outer space because there is no air for its exhaust to push against."

2) The speed of the final stage of a multi-stage rocket is much greater than the speed of a single-stage rocket of the same total launch weight and fuel supply. Account for this.

3) A rocket is set for a vertical firing. It is to be spin-stabilized when in flight. List the kinds of momenta conservation involved.

4) What is the magnitude of the momentum of a race car of mass 1,000 kg and of speed 30 m/sec? At what speed would a bus of 5,000 kg mass have the same linear momentum magnitude as this race car?

5) A 200-lb person standing on a surface of negligible friction kicks forward a 0.1-lb stone lying at his feet so that the stone acquires a speed of 10 ft/sec. What velocity does the person acquire? Remember that lb is NOT a mass unit; to convert from the force unit lb to the inertial mass unit slug, one divides lb by 32 ft/sec$^2$. In this special case; however, the answer will be correct if you simply leave the units of lb as is, and plug into the appropriate equation.

## ANSWERS TO MOMENTUM PROBLEMS

1) Conservation of momentum does not require that the ejected gas push against anything external to the rocket. In fact, air friction would serve to slow the rocket down!

2) The single-stage rocket carries all of the rocket weight (and equivalent mass) throughout the flight; therefore, acceleration must be less than that of a multi-stage rocket whose empty fuel stages (sections) are jettisoned as the fuel is consumed.

3) 1) linear momentum

   2) angular momentum

4) a) $30{,}000 \frac{kg - m}{sec}$

   b) 6m/sec

5) $\frac{1}{200}$ ft/sec, in a direction opposite to the stone. Your answer MUST have included direction, since velocity, not speed, was asked for!

## RESOURCE PACKAGE 2-4

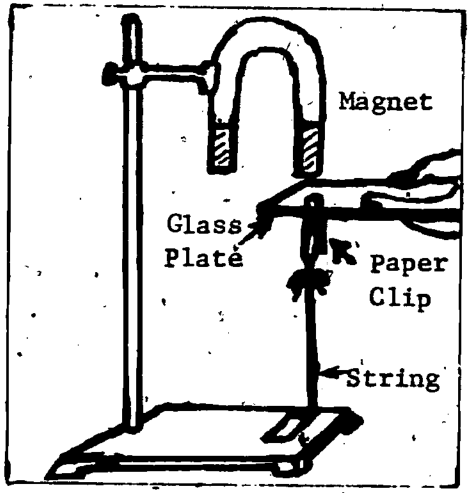
## FORCE, MOTION, ENERGY, WORK, AND ROCKETS

This Resource Package has been mostly borrowed from the "Physics of Toys" minicourse. If you have studied the minicourse on toys, this Resource Package will serve as a good review. If you have not studied the minicourse on toys, this will give you some acquaintance with its content and style.

Force. To move an object which is at rest, to stop an object which is moving, or to change the speed or direction of an object which is moving requires the use of force. Force is defined as a push or a pull. Pushes and pulls have the two important properties of size and direction. (And whenever a force acts to change the motional state of an object, we say the force has accelerated the object.)

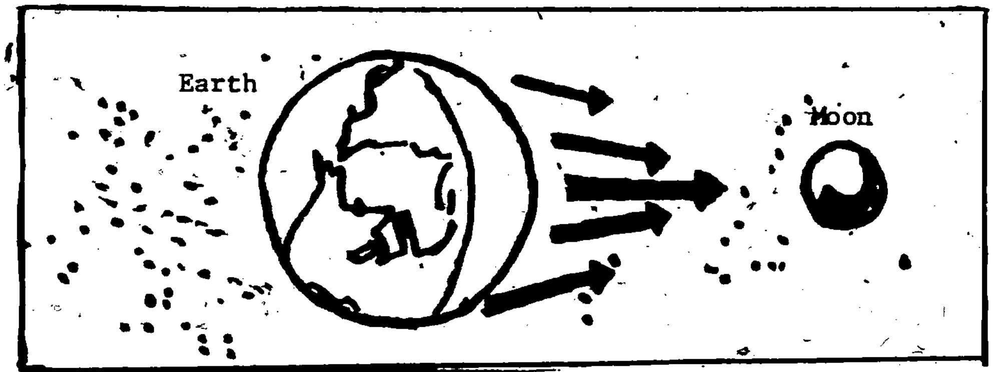
A force does not always "touch" (contact) the object it acts upon. Some forces can act at a distance. Examples of these are gravity forces, electric forces, and magnetic forces. See Figures 1 and 2.

Gravity is the name given to a force which acts at any distance and which causes all objects in the universe to be mutually attracted to one another. For example, the earth gravity force pulls the moon toward the earth and thus holds it in orbit around the earth. Of course, the gravity force of the moon pulls mutually upon the earth (See Fig. 2). This pull upon our ocean waters by the moon is a principal cause of tides. Did you know that the earth causes tides in the moon's crust? And earth tides, caused in the earth's crust by the moon, result in a change of several feet in the Washington Monument's elevation.




Magnetic force acts at a distance and through the glass plate.

A MAGNETIC FORCE
Fig. 1

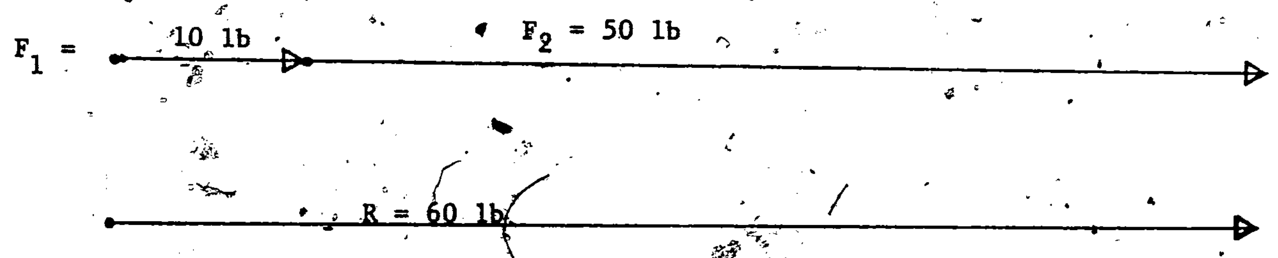



GRAVITY FORCE OF MOON ON EARTH
Fig. 2

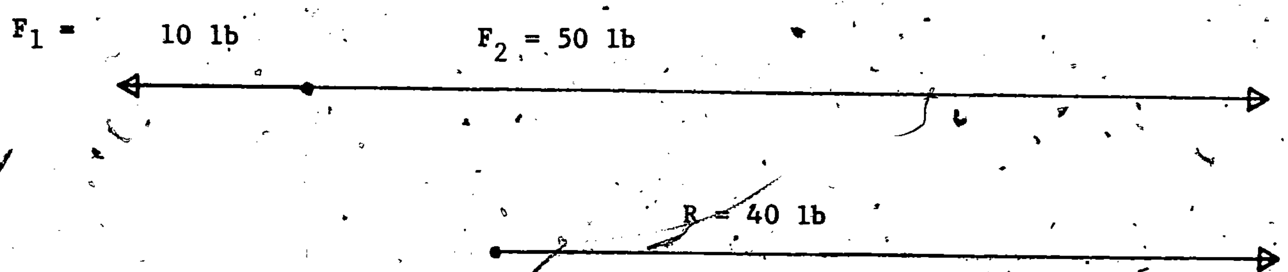
An understanding of forces and their effects will help you to better understand many devices (machines) in common use, as well as the operation of rockets.

Graphic (Picture) Representation of Force. Forces are often represented by directed segments of a straight line. These dotted line segments are called vector representations. Any physical measure which has both a size and a direction qualifies as a vector quantity and can be represented by a line segment whose length is scaled to represent size and whose direction is specified by an arrowhead (⟶).

Some Ways To Combine Vectors Graphically. We can use pictures (vector arrows) to represent the effects of combining vector quantities. In the case of forces, when two forces act along a straight line the resultant (effective) force is equal to their vector sum. See Figs. 3 and 4.

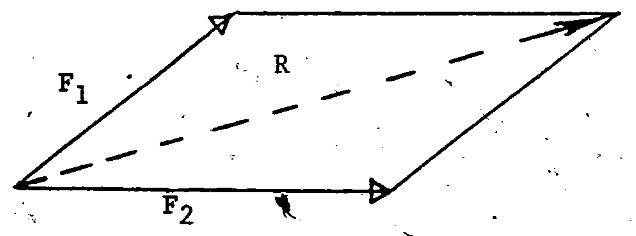



FORCES ACTING ALONG LINE (SAME DIRECTION)
Fig. 3




SAME FORCES ACTING ALONG LINE (OPPOSITE DIRECTIONS)
Fig. 4

When two forces act at an angle, the resultant vector force can be found from the diagonal of the parallelogram formed by the two force vectors. Your reference readings and/or your teacher can explain how the resultant can be found graphically, trigonometrically, or algebraically.



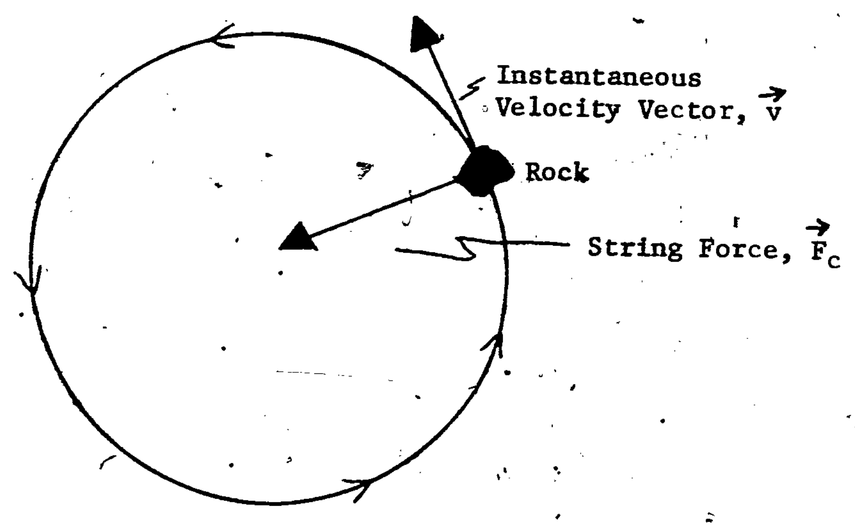

RESULTANT (DIAGONAL OF PARALLELOGRAM)
Fig. 5

Friction. Friction forces always oppose the motion of an object in contact with another object.

States of motion. To describe something's motional state (motional condition), we can say it is: (1) at rest, (2) moving linearly (along a line), (3) moving angularly (spinning), or (4) moving linearly while spinning. Further, we say whether or not the object is accelerating. To accelerate is to change linear speed, change angular speed, change direction of translation (linear motion), or change direction of spin axis. Spin is always around an axis, and to tilt or to tip this axis is to change the spin direction.

How States of Motion Change. To change the motional condition of an object requires a force (push or pull) or a moment (twist). For example, if a car is parked in your yard on a level surface it does not suddenly "take off" by itself. The car will move if the engine is started and the gears are engaged so as to move the wheels. It will move, also, if a wrecker tows it, some people push it, etc. But the car will stand still forever unless it is moved by some force.

4. Centripetal Force. Whenever something moves in a circular path you can rest assured that an accelerating force is acting upon it. Non-accelerated objects are in both linear and rotational equilibrium and so must move in straight lines at constant speeds if they are translating. The force which "bends" the path of an object in a circle is called the centripetal force. "Centripetal" derives from "center seeking" and reminds us that this force is always directed toward the denter of the curved path. See Fig. 6 below:




A ROCK ON A STRING
Fig. 6

Even though the rock whirls around the center at a constant rate (constant angular speed), the rock is always accelerated by the "center seeking" force $\vec{F}_c$ acting along the string.

<u>Laws of Motion</u>. Sir Isaac Newton, a genius to rival even Einstein, discovered some great laws of physics over 300 years ago. His descriptions of force and motion are commonly called his Laws of Motion and are frequently expressed as follows:

a) Newton's First Law of Motion (Equilibrium Law). Bodies at rest remain at rest forever, unless disturbed by an outside force or <u>moment</u>.* Bodies in <u>steady motion</u>** remain in steady motion forever, unless disturbed by an outside force or moment.
b) Newton's Second Law of Motion (Acceleration Law). When an unbalanced force or moment acts upon a body, it accelerates that body in the direction of the force or moment. The acceleration produced is directly proportional to the force.
c) Newton's Third Law of Motion (Action-Reaction Law). Whenever one body exerts a contact force or moment upon a second body, the second exerts an equal and opposite force or moment upon the first. For every contact action there is an equal and opposite reaction. (See Fig. 7 on the next page).

There are some precise terms used in the technology and science of motion. Some of these are <u>vector</u> terms because they imply both a <u>size</u> and a <u>direction</u>. Others are <u>scalar</u> terms because they imply only a <u>size</u>. Study the following terms:

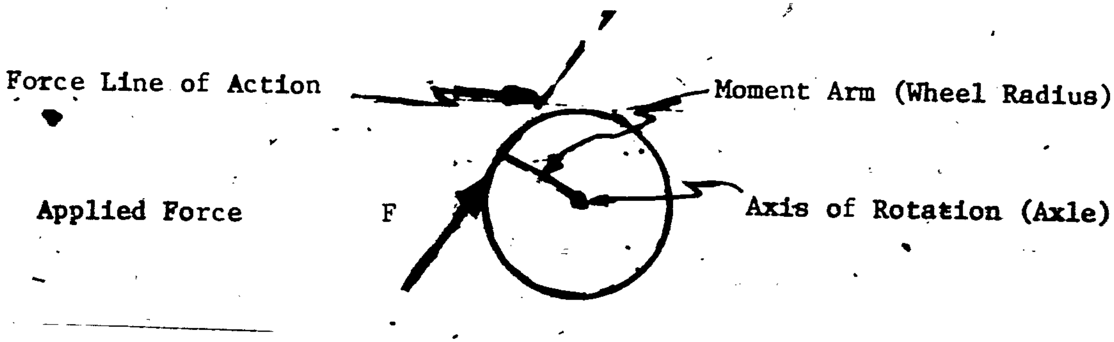
a) <u>Distance</u>. Length of path from one position to another (scalar).
b) <u>Displacement</u>. Length and direction of path from one point to another (vector).
c) <u>Speed</u>. Rate of change of position; rate of distance traversed (scalar).
d) <u>Velocity</u>. Rate of change of displacement; rate of change of direction and/or speed (vector).
e) <u>Acceleration</u>. Rate of change of velocity, rate of change of magnitude or velocity direction (vector). For example, you can accelerate a car by speeding up, by slowing down, or by changing direction. Also, you accelerate a rock tied to a string when you whirl it around your head <u>at constant speed</u> because you are continually changing the rock's direction.

* A moment is a torque or twist; this concept will be discussed in later sections.

** Steady motion means non-accelerated <u>linear</u> and <u>rotational</u> motion.

EXAMPLES OF ACTION-REACTION
Fig. 7

<u>More On Rotary Motion</u>. In the real world, things rotate (spin) as well as translate (move linearly). So an understanding of rotary (circular) motion is <u>just as important</u> as an understanding of linear motion. When a force acts on an object which is free to move about an axis, the force results NOT in a linear effect but rather in a twisting-about-the-axis effect called a <u>moment</u> or <u>torque</u>. A push (force) on a wheel rim can produce a moment (torque) which can cause a rotation of the wheel (See Fig. 8 below).



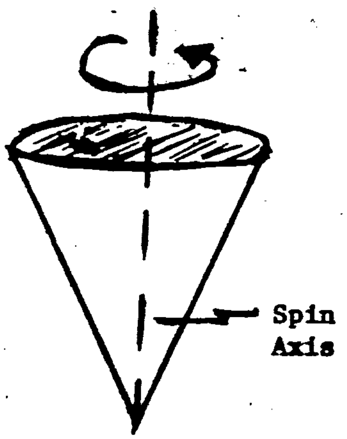

VECTOR MOMENT (TORQUE)
Fig. 8

To calculate the size of the twist (moment), the length of the <u>perpendicular distance</u> from the force's <u>line of action</u> to the rotational axis is multiplied by the force size.

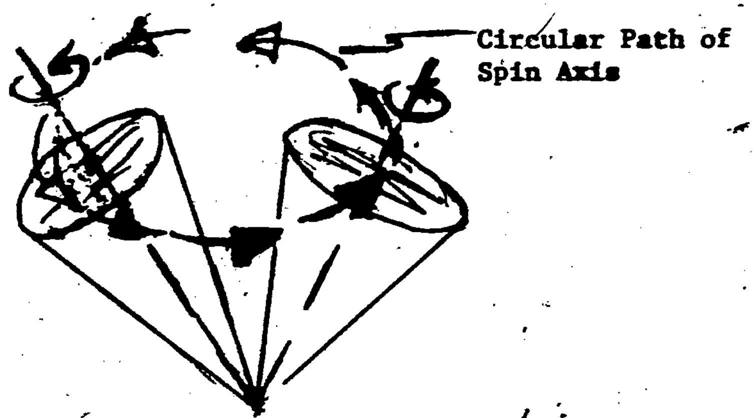
In this case the perpendicular distance is the wheel radius; therefore, the moment's size is:

| M (Moment) Size | = r (Perpendicular Distance) | X | F (Force Size) |
|---|---|---|---|

The direction is obviously clockwise. A moment (like a force) is a vector quantity; this moment has a size (rF) and a direction* (clockwise; as viewed from above). Consider Figs. 9 (a) and 9 (b); diagrams of a spinning top. Study the terminology (labels) carefully.




TOP SPINNING RAPIDLY
Fig. 9 (a)




TOP SLOWING DOWN
Fig. 9(b)

* For a more precise statement of vector moment direction, see Section II of the minicourse, Basic Machines - The "Nuts and Bolts" of Technical Physics.

The Greek letter omega ($\omega$) is used to represent angular speed, or angular velocity when the orientation of spin is indicated.

In Fig. 9 (a), the rapidly spinning top's axis is stabilized (fixed) in space.

In Fig. 9 (b), the spin axis of the slower spinning top is "circling in space," this rotation (circling) of the spin axis is called <u>precession.</u>

<u>Conservation of Momenta.</u> A basic principle of physics is that of momentum conservation. This principle tells us that when the bodies within an isolated <u>system</u> (collection of bodies) <u>interact</u> (collide, or otherwise act upon one another), then the momenta properties of the system must be <u>conserved</u>. In other words, the system's total momenta before the interaction occurs must equal the system's total momenta after the interaction. Mathematically, it is possible to represent two kinds of momentum properties of objects; both are treated as vector quantities:

1) linear momentum, $\vec{P}$. Mathematically $\vec{P}=m\vec{v}$, where $\underline{m}$ is the <u>inertial mass</u> property of a body and $\underline{\vec{v}}$ is its linear velocity. Inertial mass may be thought of as the measure of <u>that property of all objects which causes them to resist linear acceleration</u>.

2) angular momentum, $\bar{L}$. Mathematically $L = I\bar{\omega}$, where $\underline{I}$ is the <u>inertial moment</u> property of a a body and $\vec{\omega}$ is its angular velocity. Inertial moment may be thought of as the measure of <u>that property of all objects which causes them to resist angular acceleration.</u>

Energy and Work. Mechanical energy is often classified as potential (static) or kinetic (motional). An un-fired rifle cartridge is associated with potential energy (chemical potential energy); after firing, this potential energy of the cartridge is converted to the mechanical kinetic energy of the moving bullet. This exemplifies the Conservation of Energy Principle.

The mechanical linear kinetic energy of the moving bullet is expressed mathematically as $\frac{1}{2} mv^2$*; the rotational kinetic energy is expressed mathematically as $\frac{1}{2} I \omega^2$*. The work done on the bullet by the released chemical energy of the gun powder shows up as the linear kinetic energy of the speeding bullet and the rotational kinetic energy of the spinning bullet.**

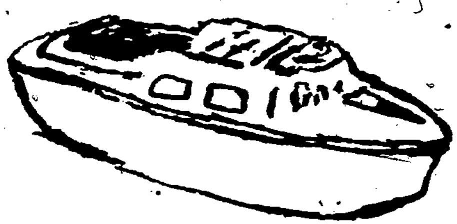
This exemplifies the Work-Energy Principle: work done on a system results in an energy change of that system equal to the amount of work done.

* The equations are discussed in textbooks; consult your instructor if these equations are of further interest to you.

** Rifles are rifled. This means that their barrels have grooves inside them to impart spin to bullets, because spinning bullets are more stable in flight; see your textbook, The Physics of Sports minicourse, and the Ballistics, Bullets and Blood minicourse for further explanations.

# THE WATER-JET BOAT

The water-jet boat is a toy which demonstrates an application of Newton's Third Law of Motion (Action-Reaction Law). It also demonstrates the principle of conservation of linear momentum. See Fig. 10. The principles of water-jet boat propulsion are identical to those of pulse-jet rockets (See p. 25, Space Age Technology, Estes Publications). The hull of the water-jet boat contains a small heat chamber (boiler). Connected to the underside of this chamber are two metal tubes which have their open ends at the stern (one on the starboard and one on the port). Between the open ends of the tubes is a rudder. Underneath the heat chamber is a small metal cup to accomodate a small candle.



WATER-JET BOAT
Fig. 10

Investigation I. Take a medicine dropper and squirt some water into one of the tubes until the boiler chamber is filled. The boiler is filled when water comes out of the other tube. Now place the boat in the water and prepare to light the candle. (To fix the candle to the cup, light it and let some wax drip off into the cup. Place the candle base into the melted wax, which anchors the candle as it cools.) Place the candle underneath the boiler, light the candle, and very soon the boat will begin to move.

Heat energy from the candle brings the water in the boiler nearly to the boiling point. The heated water expands in the boiler chamber and this pressure drives a bit of water out of one of the tube ends. The bit of water leaving the tube causes a momentary decrease in pressure in the boiler and in the other tube end. Atmospheric pressure on the other tube end drives a bit of cool water into the boiler. The cycle then repeats itself; therefore, a series of pulses of ejected bits of water drives the boat. Since the tubes are on both sides of the rudder, the boat goes either clockwise or counter-clockwise depending on which tube is taking in or letting out bits of water. Of course, changing the position of the rudder affects the direction of boat movement.

Why The Boat Moves. An explanation of the boat's motion can be found in the Conservation of Linear Momentum Principle. This Principle implies that if you were standing in a boat near a shoreline and suddenly jumped shoreward, the boat must move away from the shore. It implies that if you are motionless on a skateboard and jump off it in one direction, the skateboard will move off in an opposite direction. If we release an inflated balloon, it speeds off in one direction as it deflates and spews air in the opposite direction. This Principle is also known as action-reaction.

In the case of our boat, it is quite free to move over the water in a direction opposite to the "spitting" of the bits of water backward out of the tube. The backward momentum of many bits of water is compensated for by the forward momentum of the boat, as it must be to conserve the linear momentum of the system.*

* Precisely speaking, this system of boat-and-bits-of-ejected-water is not completely isolated, principally because of the "outside" force of friction between the hull and water, which tends to slow the boat down (so total linear momentum is not conserved).

<u>Impulse</u>. Related to momentum is the concept of <u>impulse</u>. An impulse is defined as that which produces a <u>change in</u> the <u>momentum</u> of a body. <u>Linear impulse</u> can be expressed mathematically as the product $\vec{F}(\Delta t)$, where $\vec{F}$ is the vector force and $\Delta t$ is the time interval over which this impulse force acts. <u>Angular impulse</u> can be expressed as $\vec{M}(\Delta t)$, where $\vec{M}$ is the vector moment (torque) and $\Delta t$ is the time interval that the impulse moment acts.

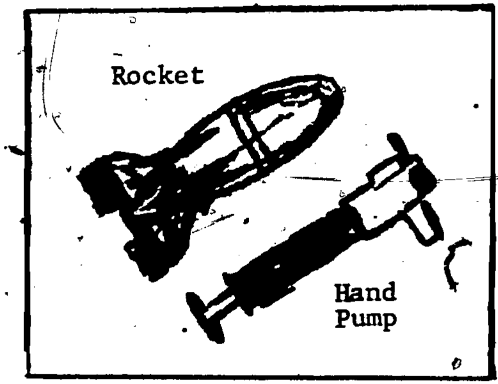
In terms of linear impulse, a bit of water ejected backward by the boiler pressure (force) has its linear momentum changed in accordance with $\vec{F}\Delta t = m\Delta\vec{v}$. The $\Delta\vec{v}$ tells us that the "boiler force" results in a change in the speed of the boat such that $m\Delta\vec{V}_{(water)} = M\Delta\vec{v}_{(boat)}$ In other words, conservation of linear momentum tells us that the change in water momentum in a backward direction must equal the change in boat momentum in the forward direction.

<u>Evaluation</u>. When you have finished investigating the boat and studying the resource material, write out responses to the following: Turn them in for evaluation.

1) In your own words, why does the boat move?
2) What factors govern the speed of the boat?
3) Does a jet plane propel itself by "pushing backward" against the atmosphere? Why or why not?
4) Assume you are marooned on a flat, frictionless surface and have no tools. Devise a means of moving across that surface.

## THE WATER ROCKET (ROCKET WITH A COLD TAIL)

The water rocket is a toy which can be used to illustrate some physics of rocket propulsion. This toy is truly a rocket-propelled missile. Its hull is made of plastic; it is about 8 inches long and about 2 inches in diameter at the midsection; and the tail section has a ¼-inch exhaust opening. A hand pump fits over the exhaust opening (see Fig. 11). A funnel is provided to facilitate fueling the rocket with water.



WATER ROCKET
Fig. 11

You are to play with this toy and to investigate some related physics. To operate the rocket, first fill about one-third of the rocket fuel chamber with water. Then lock the hand pump onto the orifice (opening for the exhaust) and pressurize the fuel chamber by pumping 15 to 20 times. Point the rocket skyward, free the pump-locking mechanism, and pull the launch trigger. The pressurized water will rush out the nozzle, and the rocket will be driven some 300 feet or more into the air. (If fired horizontally from shoulder height, the rocket's range is 100 feet or more. Therefore, this rocket is a <u>dangerous weapon</u> which can seriously injure someone. Don't be a dummy! Be CAREFUL!!) The quantity of water (fuel) ejected is governed by the pressure built up in the fuel chamber by the hand pump, as is the speed of the ejected water. Also, the greater the load of water, the lower the speed of the rocket, since the rocket has the additional weight of any unexpelled water to carry upward with it.

You will find that in flight the rocket is aerodynamically stable because it is <u>spin stabilized</u>. Its direction of spin is governed by adjustment of the tail fins and the spin velocity is governed by the pitch of these adjustable tail fins. The rocket trajectory is parabolic, and the rocket falls nose first. You can vary the rocket's range and altitude by varying its angle of firing.

The rocket thrust can be accounted for in terms of linear momentum conservation and energy conservation. Mechanical energy is stored in the fuel chamber as the air is compressed by the hand pump (pressure energy). Once the trigger mechanism is fired, this energy is converted to motional energy of the rocket. Further, at the instant of launch the system of the rocket and its load can be considered as isolated. In terms of momentum conservation, as the water rushes out the exhaust the rocket must acquire an equal and opposite momentum such that the momentum of the rocket forward exactly equals the momentum of the water backward. Can you see that if the linear momentum <u>before</u> launch is zero (no $\vec{v}$ in the momentum product, $\vec{P} = m\vec{v}$), then for linear momentum to be conserved the momentum product <u>$m\vec{v}$ of the rocket</u> forward must at all times be <u>precisely</u> equal to the momentum product <u>$m\vec{v}$ of the water</u> backward?

Write out responses to the following and turn them in to your teacher (unless directed otherwise).

1) Does the rocket need the atmosphere to push against? That is, does the effluxing (outgoing fuel need the air to push against?

2) Consider the statement: "This toy works best where there is no air (in a vacuum)." Explain your reasons why this statement is valid or invalid.

3) At what approximate firing angle does the rocket:

(a) reach the highest altitude?

(b) have its farthest range?

4) Can a rocket go faster than its exhaust? Hint: Consider the equation, $\vec{P} = m\vec{v}$.

5) You have read and have seen that the rocket is spin-stabilized.

(a) Relate this stability to Newton's First Law. Hint: Consider <u>inertial moment</u>.

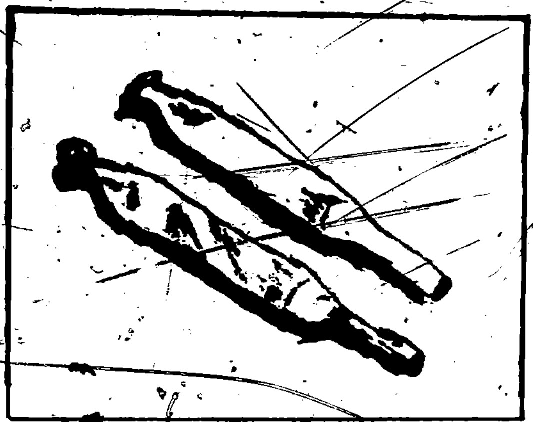
(b) In question 2, did you consider the rocket's stability as a part of "works best"?

(c) Would this rocket be spin-stabilized if fired in a vacuum?

(d) How might one launch a space craft and then spin-stabilize it if it were in a vacuum after launch? Note: Many space vehicles are spin-stabilized, and manned space vehicles are sometimes spun to produce an artificial gravity effect!

## THE AIR BALLOON ROCKET

The air balloon rocket is a device which can also be used to illustrate Newton's Third Law of Motion and conservation of momentum. The rocket balloon is an elongated rubber balloon with a flattened mouthpiece at its open end. See Fig. 12. The balloon is inflated by mouth or by pump.

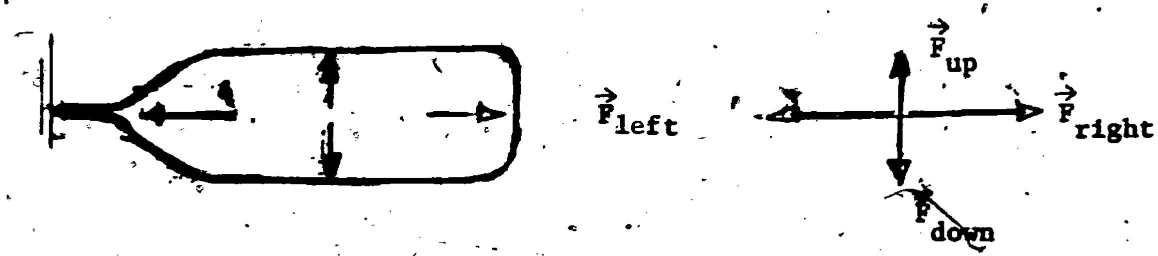


ROCKET AIR BALLOONS
Fig. 12

Inflate the balloon. Hold the mouthpiece closed until ready to launch. When you release the mouthpiece, the pressurized air will rush out (backward) and the reaction effect will cause the balloon to be driven forward. The flight trajectory will be erratic and the sound of the escaping gas will vary in pitch (frequency) and in intensity (loudness).

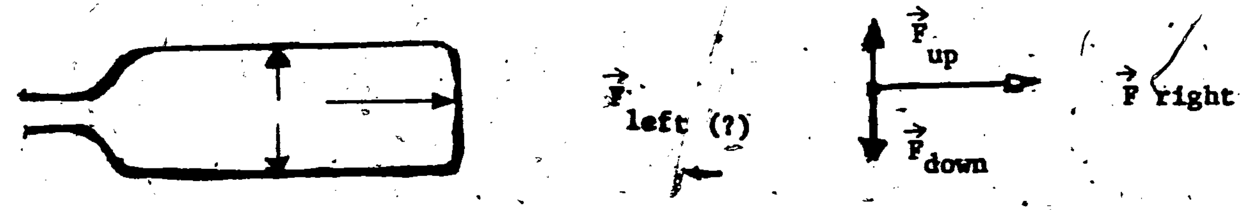
Mechanical energy is stored in the balloon's compressed air (pressure energy) and in the balloon's stretched wall material (elastic potential energy). When you release the balloon, this potential energy is converted to the kinetic energy of the ejected air and to the kinetic energy of the balloon as it drives opposite the direction of the expelled air.

The compressed air molecules within the balloon exert a pressure on the inside wall of the balloon. This pressure is <u>equal at all points</u> on that inside surface. This pressure is also exerted at the orifice (mouthpiece opening). Consequently, as the air rushes out of the balloon the force exerted by the air molecules on the front inside wall is NOT the same as is exerted on the back inside wall because the mouthpiece opening is essentially no wall at all! This results in an unbalanced force on the balloon, acting in the forward direction. So the balloon must be driven forward in accordance with Newton's Second Law of Motion. See Fig. 13 (a) below.




**INFLATED BALLOON, EXHAUST END CLOSED**
**Fig. 13(a)**

Air pressure inside is the same in all directions*; therefore; all forces up = all forces down, and, all forces left = all forces right. There is no unbalanced force to produce an acceleration. The balloon is at rest.




**INFLATED BALLOON, EXHAUST END OPEN**
**Fig. 13 (b)**

* You will study about gas pressures and Pascal's Law in other minicourses, such as <u>Physics of Toys</u>.

Examine Fig. 13 (b). Air pressure inside is the same in all directions; therefore, all forces up equal all forces down. BUT the forces right inside of the balloon must be greater than the forces left inside of the balloon because no wall exists at the orifice (opening) on the left side.

Can you see that an unbalanced inside force exists to the right, and that from Newton's Second Law ($\vec{F} = m\vec{a}$) the rocket must experience an acceleration in the direction of the force $\vec{F}$?

If you recall that $\vec{F}\,\Delta t = m\,\Delta\vec{v}$ (the impulse-momentum relation), then you can see that the unbalanced impulse force ($\vec{F}$) acts on the right wall during the time ($\Delta t$) that the air is expelled. This impulse produces a change in the balloon's momentum. So the balloon speeds away from the exhaust gases, and both linear momentum and mechanical energy are conserved for the balloon-compressed air system.

Answer at least four (4) of these questions and turn them in to your teacher:

1) How does the rocket balloon propulsion relate to that of the water-jet boat and the water rocket?
2) What are some factors which govern the time of flight of the balloon? (For example, if you double the volume of the balloon during inflation, do you double the flight time?)
3) Do you think the pressure in the balloon increases as the balloon gets larger during inflation?
4) Where do you suppose the sound of the balloon rocket comes from?
5) Is the balloon rocket aerodynamically stable?
6) List three (3) devices or techniques which are used to obtain flight stability.

RESOURCE PACKAGE 2-5

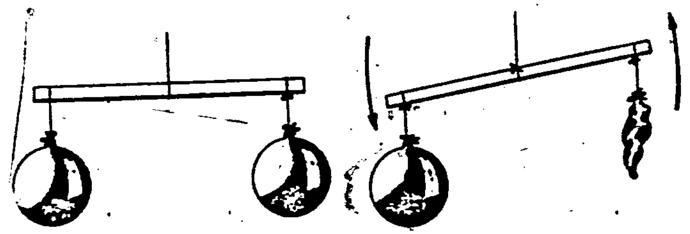
INVESTIGATING: AIR WEIGHT; AIR PRESSURE;

LIFT; AIR RESISTANCE (DRAG); AND SPACE

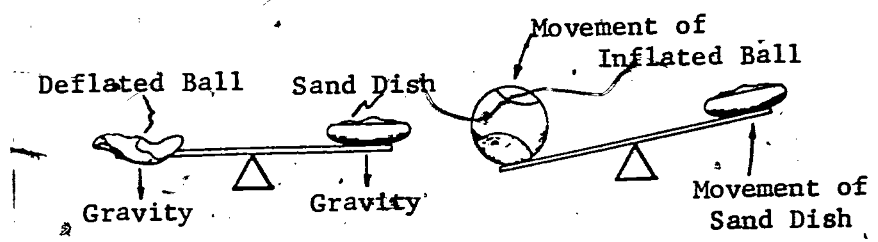
In this Resource Package, you will be instructed to investigate some physical properties of the atmosphere and of space.

Investigation I: Air Weight.

A) Materials needed: A wooden dowel rod or ruler or any straight stick approximately 12" long; 3 lengths of string; 2 balloons exactly the same size. Blow up the balloons to the same size and tie each of them with a piece of string. Then tie one balloon to each end of the rod as shown. Tie another piece of string around the center of the rod and move it until the balloons are balanced. Then hang the rod. Ask yourself what will happen if the air is let out of one of the balloons. Let the air out of one balloon. Does the air-filled balloon drop down? Can you see for yourself that the air trapped in the balloon has weight? The air in each balloon has weight because of the earth's gravity pull. The air pressure inside an inflated balloon is greater than the air pressure outside of the balloon, so the air inside an inflated balloon is denser (more mass per unit of volume) than the air around the balloon.

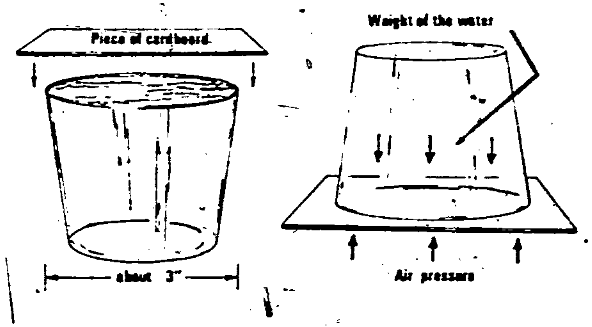


B) <u>Materials needed</u>: Playground ball; hand pump; a flat piece of wood approximately 12" long, ½" thick, and 1" wide; a triangular piece of wood to act as a fulcrum; a bowl; and aquarium sand. Deflate a playground ball and place it on the balance scale. Set the bowl on the opposite side and fill it with sand until the two objects are balanced. Carefully remove the deflated ball and inflate it. Now place the ball back on the balance. Can you see you have shown that air has weight?




Investigation II: Air Pressure.

A) Since air is a fluid, it exerts pressure on anything it contacts, and exerts its pressure equally in all directions. Now, let's illustrate that air pushes upward.
<u>Materials needed</u>: Water glass or small jar (opening no larger than 3" - 4" for easy handling); flat, thin piece of cardboard. Fill the glass <u>exactly</u> to the top with water. Carefully place the cardboard on top of the glass. Hold the cardboard tightly, and turn the glass upside down. Remove the hand holding the cardboard. The cardboard will stay in place against the glass. What keeps the cardboard in place? Why isn't the water coming out? (Hint: The pressure of the air against the cardboard is greater than the pressure caused by the weight of the water in the glass. The <u>adhesion</u> between the cardboard, the water, and the glass also helps to hold the cardboard in place.)




B) Materials needed: Gallon can; lid for can; heat source; small amount of water; insulated gloves. Pour the water into the can, and place the can over a heat source without the lid. Allow boiling to start and continue until a cloud appears around the can opening. Remove the can from the heat source, and immediately replace the lid tightly. Hold the can under a cold water faucet. Can you see that boiling water drives most of the air from the can? Hint: cooling causes the remaining water vapor to condense, causing a partial vacuum (lowers the air pressure); then the outside air pressure becomes greater than the pressure inside and crushes the can.

Investigation III: Lift

A) Materials needed: A strip of paper 1" wide and 12" long. Hold the strip of paper between thumb and index finger. Hold the thumb near to the chin and blow over the top of the strip. Explain the movement of the paper.
Hint: The paper is lifted because the rapidly moving air above the paper strip has less pressure pushing on the paper than the slower moving air beneath the paper strip. This illustrates Bernoulli's Principle (When the velocity of a fluid increases, the pressure decreases.) and is one reason why an airplane wing produces lift as the wing moves through the air.

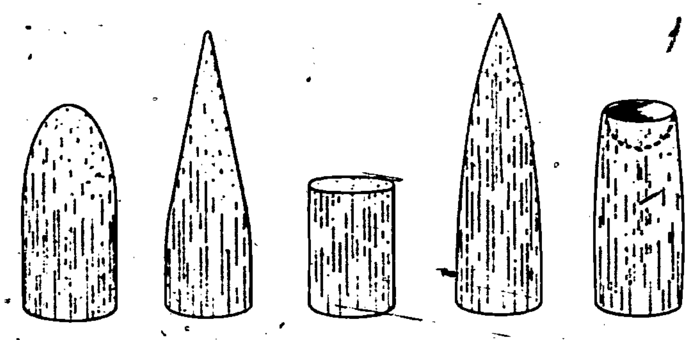
B) <u>Materials needed</u>: Two sheets of paper approximately 8" x 10" (regular notebook paper). Hold the sheets of paper approximately 4 inches apart and blow between them. Explain the movement of the sheets.

Investigation IV: Air Resistance (Drag)

A) Materials needed: Balsa wood; tray of water; sandpaper; light; string; rocket nose cones of various shapes.

Remember that both air and water are fluids. Of course, water is more dense and more viscous than air but since water resistance (drag) is quite like that of the atmosphere, you will test the qualitative drag of some nose cone shapes in water. Attach the string to the tip of each nose cone and pull the cone through the tray of water. Observe which makes the least disturbance. Shine a light through the water to help observe the shadows of the disturbance. Feel the drag on each nose cone as you pull it through the water. Notice which shapes have the least drag. Differences in the drag developed on these varied shapes is easily detected. Performing this investigation in a glass tray on the stage of an overhead projector produces good "ripple tank" effects visible to the whole class on a screen.

In your notebook, make a sketch of each shape studied and arrange each in order of drag, from least to greatest.



SUGGESTED EXPERIMENTAL NOSE-CONE SHAPES

Investigation V: Space

A) <u>Materials needed</u>: Vacuum pump; bell jar; vacuum hose; pressure can of shaving lather; marshmallow. Place a marshmallow and a small amount (about a golf ball size) of shaving lather on the vacuum plate just before starting the vacuum pump. Observe the size of the lather and marshmallow as the air pressure inside the bell jar is reduced. Can you imagine that what happens to the lather and to the marshmallow could also happen to an unprotected human in space? Now, perform a similar investigation using a partially-inflated balloon. Explain why the balloon gets larger as the air is pumped from inside the bell jar.

RESOURCE PACKAGE 2-6

ROCKET LAUNCH

Your instructor will launch a ready-to-fly model rocket, and you will be an observer.

RESOURCE PACKAGE 3-1

THE BOOKLET: SPACE AGE TECHNOLOGY

RESOURCE PACKAGE 3-2

THE BOOKLET: MODEL ROCKETRY TECHNICAL MANUAL

## RESOURCE PACKAGE 3-3

### BUILD AND LAUNCH A MODEL ROCKET

You can either purchase your personal rocket kit or you can work in a group to build a school rocket. Resource Package 3-2 will serve as a general guide.

Before launch, your instructor will check your overall launch plan and your knowledge of safe firing procedures. As preparation for this, carefully review p. 40 of Space Age Technology, Estes Industries, "Model Rocketry Safety Code."

Study the following Estes publications:

1) Alpha Book of Model Rocketry
2) Model Rocketry Study Guide

Select one of the following Estes publications; study it; then prepare a short written report of your study for your instructor to evaluate. As additional evaluation credit, give a brief (not over 10 minutes) talk on the subject to the entire class. These publications are: Model Rocket Launch Systems, Projects In Model Rocketry, Rocket Stability, Rocketronics Catalog, Multi-Staging, Altitude Tracking, Rear Engine Boost Gliders, Building A Wind Tunnel, Aerodynamic Drag of Models, Altitude Prediction Charts, Front Engine Boost Gliders, Designing Stable Rockets, Model Rocket Engines, Model Rocket Engine Performance, Is That Parachute Too Big? and The Fine Art of Payload Launching.

RESOURCE PACKAGE 4-1

ACHIEVEMENT MEASURE - MODEL ROCKETRY