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STUDENT BOOK

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CONTENTS

Chapter One
AERODYNAMIC FORCES:
What They Are and What They Do

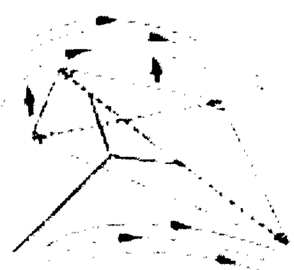
Aerodynamics

Aerodynamics is the study of the motion of air and the relative motion between air and objects in the air. Model rockets rely on aerodynamics to fly properly, just as butterflies, kites and airplanes do. The flight performance of any model rocket is the result of the combined effects of aerodynamic and other forces acting upon it.

The four basic forces on flying objects, such as a model rocket, are *lift, drag, gravity* and *thrust.* Aerodynamic forces are the forces generated as a result of the motion of an object through air. Therefore, lift and drag are aerodynamic forces. Thrust can be generated by aerodynamic forces, such as a propeller, but is not inherently aerodynamic in nature.

Lift

The faster a fluid moves, the lower the lateral pressure it exerts. By causing air to move faster over certain surfaces of an object, air pressure is reduced which creates lift. This law is know as Bernoulli's Principle. A kite, for example, is pushed up when the air moving over the top of the kite moves faster than the air moving beneath the kite. There is less force against the top of the kite than beneath it. The force which is created pushes the kite up and is called *lift.*



Lift is generated by *relative wind.* Relative wind is the motion in the air in relation to an object, such as a kite in a breeze. It can also be created by running with a kite, if no wind is blowing.

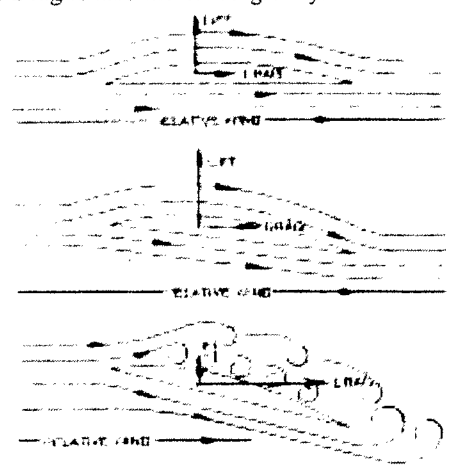
The angle of attack is the angle at which a wing or fin or kite moves in relation to relative air stream or "relative wind". The greater the angle of attack of a wing, the further and faster the air must flow over the wing and the greater the lift force produced.

However, when a flying object has too great an angle of attack, it will stall because the airflow becomes turbulent and detached from the object, no longer traveling along its surface. When an object stalls, the lift produced decreases drastically, most likely falling to zero. Drag is also increased greatly.

No angle of attack
Small lift force
Small drag force

High angle of attack
Large lift force
Large drag force

Excessive angle of attack and stall
Very small or zero lift force
Very large drag force

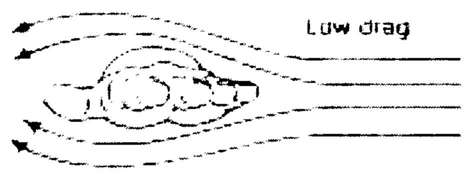


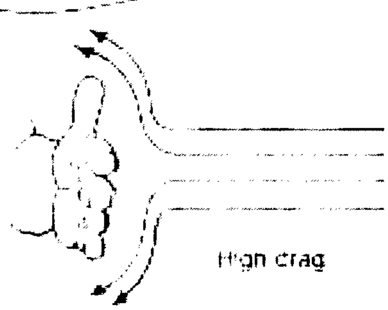
Drag

Drag is the force experienced by any object moving through fluid, such as air or water, that opposes the motion of the object. It is the resistance caused by the motion of the water or air as it drags past the object or is pushed out of the way. Drag increases the larger or rougher the surface, the thicker the fluid or the faster the object is moving. Drag can also be increased by a difference in pressure between the front and rear of the object.

While lift can be a favorable aerodynamic force, drag can be an unfavorable force. Drag and gravity limit the height a model rocket can reach. Drag can be minimized but it can not be eliminated.

Drag can be understood by thinking about what is experienced when you pass your hand through a bathtub of water. As described above, water is a fluid with many of the same drag characteristics as air. Using your hand as a test "model rocket" and the bathtub of water as a "wind tunnel", you can gain an intuitive idea for how air resists the motion of a model rocket in flight.





As you pass your hand under the surface of the water, you can vary the speed of your hand and feel the varying resistance to motion (drag effect) of the surrounding water.

The effect of the size of the surface can also be experienced by changing the orientation or shape of your hand as you pass it through the water. More drag will be experienced against the back of your hand than against the edge of your hand. Drag will also vary as the shape of your hand ranges from a fist to outstretched fingers.

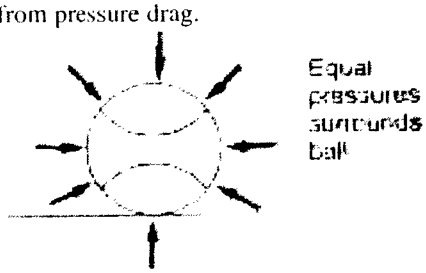
You can also experiment with different shaped objects other than your hand. Place spheres, blocks or streamlined shapes on sticks and pass them through the water. You should be able to feel the difference in resistance to motion the water develops for each shape at a given speed.

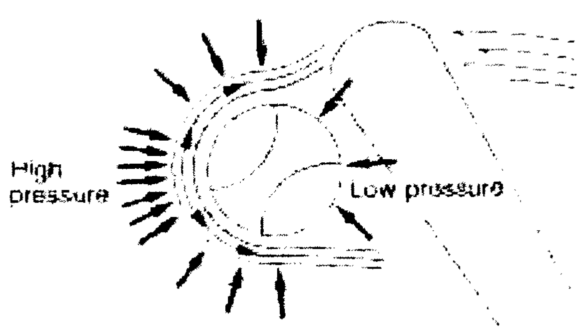
You have experienced drag when you have been riding a bicycle fast. You could feel air rushing past you and you could feel air pushing against you slowing you down.

Two types of drag affect the flight of a model rocket. They are pressure drag and friction drag.

When a baseball is sitting still on the ground, the pressures all around it are the same. The atmospheric pressure on all parts of the ball are equal. There is no drag because there is no unbalance of pressure forces. If the ball is thrown or hit by a bat, the air around the ball starts to move, the pressures around it change and a pressure imbalance is created. This is called pressure drag.

Drag is demonstrated as the ball slows down after it is thrown or hit. 95% of the drag on a sphere comes from pressure drag.

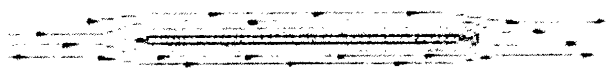




Pressure drag is the retarding force caused by the imbalance of air pressures on a moving abject. Pressures on a moving object vary with the object's speed, direction of motion and its size and shape.

Friction drag is the retarding force produced by an object sliding past the molecules of the fluid through which it is moving. The amount of friction drag produced by the motion depends on the amount of surface exposed to the motion of the fluid, the roughness of the surface, the density of the fluid and the *viscosity* of the fluid.

Imagine a very sharp thin plate moving through the air. It is moving at zero angle to the air stream and there is no unbalance of pressure forces. However, there is still drag because the air is rubbing on the surface. This friction drag is confined to a thin region close to the body surface.



Friction drag

Viscosity measures the resistance to motion of a fluid moving over a surface. Low viscosity fluids, such as air and water, flow easily. Substances which do not flow easily, such as motor oil or molasses, have high viscosity.

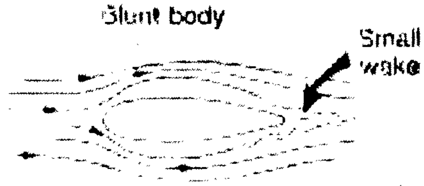
On the surface of the object the velocity is zero. Just off the surface, the air speed increases with height above the object to a maximum speed called the free-stream velocity. This is the speed at which the object is moving through the air. The thin region where the air speed changes is called the *boundary layer*. Within the boundary layer, the effects of viscosity are dominant and cause friction drag.

Viscosity is a factor in both friction and pressure drag. In friction drag, viscosity acts directly to produce shearing stresses in the boundary layer. For pressure drag, viscosity triggers a flow "separation" from the body. *Separation* is the behavior of the flow when the air does not follow the the body contour of an object, but breaks away into a turbulent wake. This separation of the air flow is a reason for the pressure unbalance which causes pressure drag on aerodynamic shapes, such as model rockets.

The two figures show the difference in flow about a circular cylinder with a large wake and the flow about a streamlined shape with a small wake.

The figures show that the streamlined shape is designed to reduce the amount of flow separation. The size of the wake is reduced. Drag is reduced because the flow attached to the body allows the pressure to build back up to levels near the pressure of the nose. This reduces the pressure unbalance and cuts the drag.

Blunt body



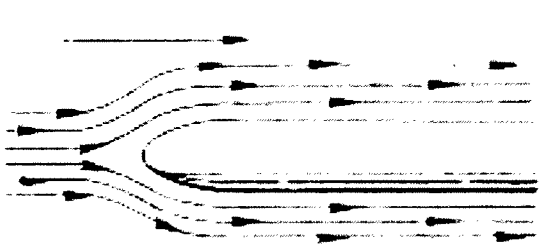
Streamlined body

To prevent flows from separating, it is essential to use aerodynamic shapes that are rounded gently and never have any sharp changes in direction. When there are sharp changes, the viscosity of the air makes the flow resist these changes in directions and forces the flow to break away.

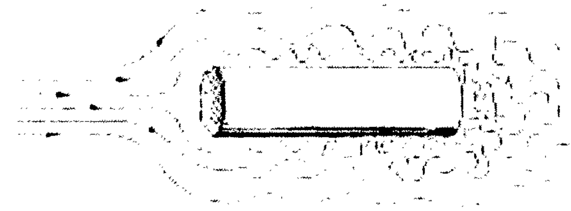
There are two patterns of flow, turbulent flow and laminar flow. Viscosity affects these flow patterns in the air boundary layers moving over aerodynamic shapes.

Laminar flow exists when the boundary layer of fluid or air next to the surface is smooth and "attached" to the surface. The acts as if it were in layers. The molecules in each layer slide over the other molecules. The molecules in the layer next to the surface have zero velocity. Each succeeding layer further from the surface has a higher velocity of motion relative to the surface. Friction darg depends upon the rapidity with which the velocity changes.

Turbulent flow exists when the boundary layer of fluid or air next to the surface is not smooth. The motion of the molecules is much less regular because of the mixing of the different layers and the large fluctuations of velocity of the molecules at different distances from the surface.



Laminar boundary layer



Turbulent boundary layer

Drag increases as velocity or speed increases. The drag experienced by the object directly varies with the square of the velocity of the moving object. The basic drag formula for the effect of velocity on drag is: $D = C_D \times A \times \frac{1}{2}\rho \times V^2$

CD is the "coefficient of drag" which depends on the shape and surface smoothness of the rocket.
A is the cross sectional area of the rocket or the frontal area of the rocket as seen from directly in front of it.
ρ is density of air through which the rocket is moving, symbolized by the Greek letter Rho (pronounced "row").
V is the velocity or speed of an object in relation to the wind. V^2 means VxV, the velocity squared.
As you can see, if the velocity of an object doubles, the amount of drag is four times as great. If V or velocity tripled, the drag increases nine times.

For more detailed discussion of model rocket drag, see Estes publication,
Aerodynamic Drag of Model Rockets.

Gravity

Gravity is the force that pulls down on the mass of any object near the Earth through its center of gravity. Gravity and drag limit the height a model rocket can reach. In general, light weight helps overcome gravity.

The force of gravity varies inversely with the square of the distance between the center of gravity of the object and the center of the Earth. An object, B, which is twice as far as from the center of the Earth as an object, A, will experience one fourth the gravitational attraction as object A. Because model rockets remain at nearly the same distance from the center of the Earth, gravity remains a near constant.

Thrust

Thrust is a forward propulsive force that moves an object. On an airplane, thrust is generated by the engines, propellers or exhaust. The flapping wings of a bird provide thrust for a bird. In a model rocket, thrust is produced by the rocket engines. Thrust must be greater than the weight of the rocket in

Chapter 2
LAWS OF MOTION
How They Govern All Objects

Newton's Laws of Motion were described by Sir Isaac Newton in 1687 in his book, *Philiosphiae Naturalis Principia Mathematica.* These laws of motion or principles govern the motion of all objects, whether on Earth or in space. The laws of motion provide a scientific basis for understanding how rockets work.

Newton's First Law
Objects at rest will stay at rest, and objects in motion will stay in motion in a straight line unless acted upon by an unbalanced force.

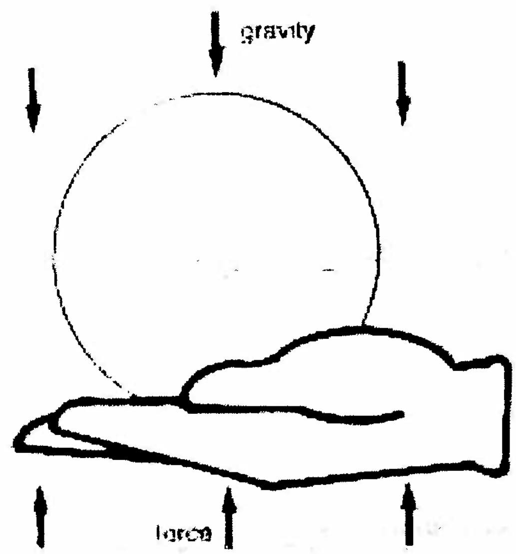
This law is also referred to as the law of inertia. Inertia is the tendency of a body at rest to remain at rest unless pushed or pulled by an unbalanced force.

Rest and motion can be thought of as opposite. *Rest* is the state of an object when it is not changing position in relation to its surroundings. *Motion* means an object changing position in relation to its surroundings. These are both relative terms. The important idea with these two words is *in relation to immediate surroundings.*

As you are sitting in your chair, you can think of yourself as being at rest. What if your chair is on an airplane in flight? You would still be said to be at rest *in relation to your immediate surroundings.* Rest, as a total absence of motion, does not exist in nature. Even as you are sitting in your chair, you are still moving because your chair is sitting on the surface of our moving planet that is orbiting the sun, which is moving through the universe. While you are at rest in relation to your immediate surroundings, you are traveling through space at hundreds of miles per second.

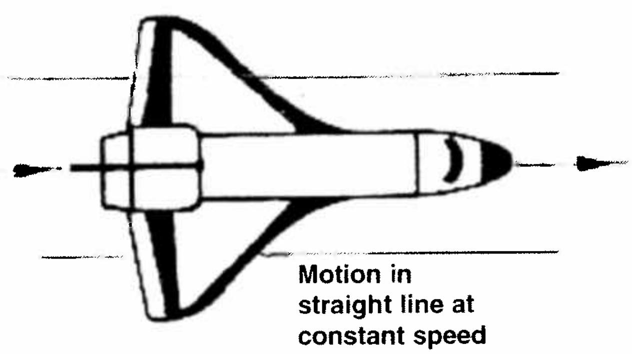
Motion is defined as an object changing position in relation to its surroundings. Think of a ball sitting on the ground. It is at rest. When the ball is rolling, it is in motion, because it is changing position in relation to its immediate surroundings. When a rocket blasts off the launch pad, it changes from a state of rest to a state of motion.

Newton's first law also involves the idea of *unbalanced force.* When you hold a ball in your hand without moving it, the ball is at rest. As the ball is held there, it is being acted upon by forces. The force of gravity is pulling the ball downward. Your hand is pushing against the ball to hold it up. The forces acting on the ball are balanced. The tendency of the ball to remain at rest when no unbalanced forces act on it is called *static inertia.*



The ball changes from a state of rest, being acted upon by balanced forces to a state of motion, being acted upon by unbalanced forces when you let the ball go or when you move your hand upward. When an object is at rest, it takes an unbalanced force to make it move.

The law also states that once an object is in motion it will continue in motion in a straight line. It takes an unbalanced force to stop it or change its direction or speed. This is called *kinetic inertia.*



If you threw a ball, what unbalanced forces prevent it from staying in motion in a straight line forever? The forces of drag and gravity cause it to fall to earth.

Newton's Third Law
Whenever one body exerts a force on another, the second body exerts a force equal in magnitude and opposite in direction on the first body.
or
For every action there is always an opposite and equal reaction.

Here is an illustration of the third law. A skateboard and its rider are at a state of rest. They are not moving. The rider steps off the skateboard. This is called an *action*. The action causes the skateboard to travel a distance in the opposite direction. The skateboards motion is called a *reaction*.

You can demonstrate Newton's third law by gently pressing your index finger on your desk or table. Keep pushing, harder and harder. Do you think the tale is pushing back? Push even harder. If the table is not pushing back, why doesn't your finger go through the spot where you are pushing with your finger? As you exert a force or action on the table, the table pushes back on your finger. The force you apply with your finger is the action. The table's resistance is the reaction.

When the force applied is greater than the force with which the object can resist without motion, part of the force being applied will produce motion. When you apply more force with your finger than the force with which the table can react, the finger will dent or punch a hole in the table or the table will move. Since every action always causes an equal reaction, an equal amount of force is present in both the action and the reaction.

Newton's Second Law
If an unbalanced force acts on a body, the body will be accelerated; the magnitude of the acceleration is proportional to the magnitude of the unbalanced force, and the direction of the acceleration is in the direction of the unbalanced force.
or
Force is equal to mass times acceleration.

The second law of motion is a statement of a mathematical equation. The three parts of the equation are mass (m), acceleration (a) and force (f). The equation is written as follows:

$$F = m \times a$$

An unbalanced force is one that is not matched or balanced by an opposing force. An acceleration is a change in velocity. Mass refers to quantity or the amount of matter an object has.

Newton's second law can be illustrated by dropping a small ball. The ball accelerates rapidly gaining speed as it falls from your hand. The ball falls because of the unbalanced force of gravity acting on it. The ball is accelerating positively as it falls-it is gaining *momentum*. Momentum is the product of mass times velocity. The mass or weight of the ball stays the same, but the speed or velocity changes.

Does this mean that a ball dropped from an airplane high in the sky would accelerate indefinitely? It would not because of another force acting upon it. The ball is passing through air. The air resists the movement of the ball through it. The resistance is a force called *drag*.

The ball is subject to acceleration toward the ground because of gravity. It is prevented from accelerating indefinitely because of the drag of air. The ball will eventually reach a speed where the drag force is equal to the force of gravity on the ball. This is called *terminal velocity*. When the ball reaches terminal velocity, there is no longer any unbalanced force on the ball so it no longer accelerates and it falls at a constant speed.

When you toss a ball up in the air, will it continue up indefinitely? As it leaves your hand, it achieves a certain velocity and ceases to accelerate positively. This is the maximum velocity of the ball. As the ball rises, its motion is resisted by drag, an unbalanced force, which is acting on the ball to slow it down. This force is also producing negative acceleration.

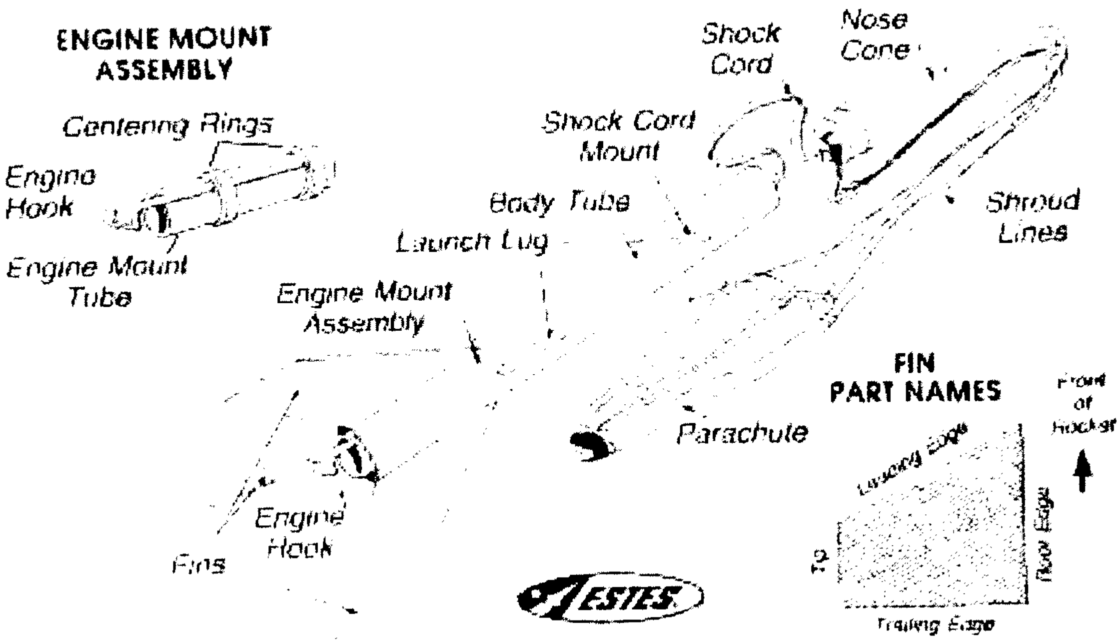
These two forces acting on the ball slow it down and cause it to stop. At this moment the ball has zero momentum because it has zero velocity. The force of gravity which produced the negative upward acceleration continues to act, producing a positive downward acceleration, causing the ball to fall back to Earth with increasing speed. This is resisted by the drag the ball encounters as it moves through the air. The drag force now acts upward, opposing gravity, because the ball is now falling downward through the air.

Chapter 3
MODEL ROCKETS
Taking Aerodynamic Forces into Account

Model Rocket Components

In Chapter 1, you studied the four forces of lift, drag, thrust and gravity. In this chapter you will study the construction of model rockets to learn how these forces affect the flight sequence of model rockets.

All model rockets have the same basic components. The diagram below shows a typical model rocket.



A. Nose Cone

The front end of a rocket which is usually shaped to minimize air resistance or drag. The shock cord and parachute are often attached to the nose cone.

B. Recovery System

A recovery system slows a rocket's descent, bringing the rocket safely back to earth. The recovery system can be a parachute, as in this diagram. A shock cord is attached which is anchored to the body tube of the rocket. The shock cord absorbs much of the force of the deployment of the recovery system when the ejection charge functions. There are several types of recovery systems and many are stored in the rocket's body during the thrust and coast phases of the flight sequence.

C. Body Tube

The body tube is the basic structure of the rocket to which other parts are attached. It is usually long and slender. Most body tubes are made of paper that is tightly wound in a spiral pattern. The tube is designed to be strong, but light. Other names for the body tube are fuselage or the airframe.

D. Launch Lug

The launch lug is attached to the airframe. It is a tube that slips over the launch rod to guide the model during the fraction of a second after engine ignition until it reaches the speed necessary for the fins to control the flight. The launch lug is a small tube shaped like a soda straw. It is usually made of paper or plastic.

E. Fins

Acts like the feathers on an arrow, guiding the rocket in a precise flight pattern and providing stability. Fins may be made of balsa, fiberboard, thin plywood or plastic.

F. Engine

Provides the power that causes the rocket to move. It is a pre-packaged solid propellant engine.

G. Engine Mount Assembly

Holds the engine in the proper position in the body tube.

Model Rocket Flight Sequence

The diagram pictured illustrates the flight profile of a model rocket. As you trace the sequence, you can begin to understand how the combined effects of the forces you read about in Chapter 1 act upon the rocket.

As the rocket is launched, *thrust* is provided by the engine and overcomes the force of *gravity*. Thrust has to be greater than the weight of the rocket in order for it to lift off. *Drag* is another force acting on the rocket. Drag and gravity limit the height a model rocket can reach. Drag can be minimized but it cannot be eliminated. As you study the flight sequence you can determine at which point gravity and drag are causing the rocket to slow down rapidly. This is during the coasting phase, after the delay element is ignited. The recovery system is deployed at apogee, the highest point in the flight. During the recovery phase, the drag or lift forces of the recovery device are used to oppose the force of gravity, allowing the rocket to descend slowly for a safe landing.

As you construct and launch your own model rocket, there are some things you can do either to take advantage of the aerodynamic forces or to minimize their effects. The best rockets are stable, have as little drag as possible, have little lift during the thrusting and coasting phases, and have a gentle, safe recovery. This allows the rocket to be flown again and again.

Your model rocket is designed to perform in a certain way at each stage of flight sequence. Each part has to function properly so that the rocket can fly well. It is important for you to understand what occurs at each phase of the sequence.

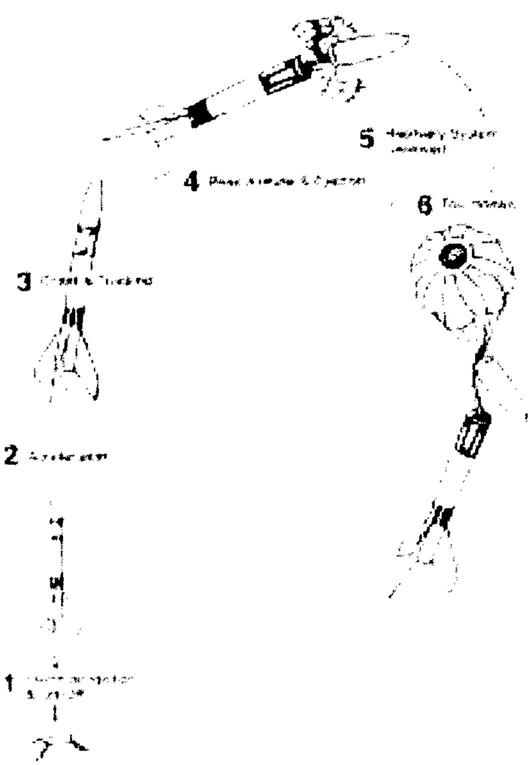
Thrust Phase

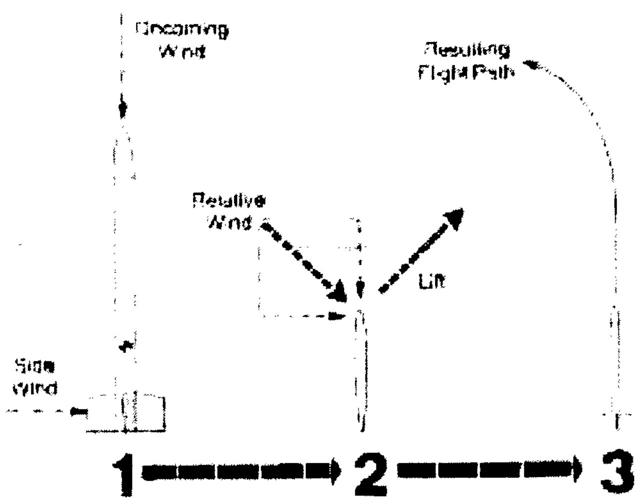
The rocket is launched by the ignition of the engine. This is the powered phase of the flight that lasts until the engine has consumed all its propellant. During this phase, model rockets accelerate positively.

During this phase, the rocket moves in response to the forces of thrust, gravity, drag and lift.

In order for this phase of flight to be successful (as well as during the coasting phase), the rocket must be stable. A rocket is stable if the aerodynamic forces acting on it cause it to fly into the relative wind. The fins enable the rocket to correct the flight when it is momentarily deflected. When deflected, air moving over the "top" of a fin travels faster than the air under the fin and lift is created. This lift, generated by relative wind, causes the rocket to rotate so it is flying straight again.

Because a stable rocket always flies into the relative airflow (relative wind), the presence of wind blowing across the launch field can affect the flight path of a model rocket. In this case, the relative wind is the sum of two components - the airflow opposite to the direction of the rocket's motion and the wind blowing from the side. The net result is a relative wind coming from slightly off to one side so the rocket's flight path will tend to curve away from vertical and into the upward direction. This is called "weathercocking". This effect is more pronounced in high winds or with a slow moving rocket.





As you can see, the fin is the stabilizing and guiding unit of a model rocket. It should be in a symmetrical form of three, four or possibly more fins and made of reinforced paper, balsa or plastic. The fin is an aerodynamic surface projecting from the rocket body.

If you study the diagram of the rocket components (page 22) you can see how the fins are attached to the rocket. As you study the diagram of the flight profile, try to imagine the rocket being deflected by wind. Think about how the fins provide stability for the rocket by generating lift.

As you have read, the aerodynamic force of drag can be minimized but never eliminated. Some things that contribute to drag are more speed, greater size and surface roughness.

It is helpful to re-examine the formula for determining drag to help understand some of the methods to be emphasized when constructing a model rocket.

The formula for drag is as follows:

$$D = C_D \times A \times \frac{1}{2} \rho \times V^2$$

C_D is the coefficient of drag. This element of the formula depends heavily on the shape and smoothness of the rocket. It is often estimated at 0.75 but with a smoothly finished rocket, it could be much lower.

Rho (ρ) is the density of the air through which the rocket is moving. The colder the air, the denser it is. Air is also denser at sea level than at higher altitudes. Denser air will produce more drag at a given velocity than "thin" air.

V is the velocity of an object in relation to the wind.

In Chapter I you read about pressure drag that comes from flow separation, the behavior of the air when it does not follow the body contour, but breaks away into a turbulent wake.

To minimize pressure drag as much as possible it is important to construct your rocket to avoid turbulent flow and boundary layer separation. You will be striving for laminar flow. Things that contribute to turbulent air flow are a crooked nose cone, a nose cone that is larger than the body tube and makes a ridge where they join, a wrinkled body tube, a crooked launch lug, crooked fins, uneven fin shapes and a poor, rough finish. It is important to know that drag increases as the square of the velocity of the rocket. In the formula mentioned earlier, V is the symbol for velocity. Drag increases rapidly with velocity because it depends on V^2. If the velocity of an object doubles, the amount of drag is four times as great. If V is tripled, the drag increases nine times.

A high thrust engine will cause a rocket to experience more drag than a low thrust engine because the rocket will reach high velocities. But remember, a high thrust engine helps overcome the force of gravity.

Coasting Phase
This phase begins when the propellant is exhausted. The delay element is ignited and burns for a set length of time. The delay element acts as a timing device to control the deployment of the recovery system. Recovery system deployment should occur at apogee, the highest point or peak altitude in the flight, because velocity is at its lowest and therefore stress on the recovery system is minimized.

During the coasting phase, the forces of gravity and drag are causing the rocket to slow down rapidly. The engine is no longer producing thrust. The smoke that is observed comes from the smoke-tracking and delay element of the engine. The smoke is useful in tracking the rocket as it coasts upward into the air.

Recovery Phase
As soon as the smoke-tracking and delay element is exhausted, the engine's ejection charge activates the recovery system. This should occur at apogee or peak altitude. During this phase, the rocket drifts safely back to Earth, using the recovery system. In the diagram, the recovery system shown is the parachute recovery. During this phase of flight, the rocket is subject to the forces of gravity, drag and sometimes lift.

NOTES

Chapter 4
THE LAWS OF MOTION
Putting Them Together With Model Rockets

The laws of motion and model rockets come together particularly when we understand the design of model rocket engines. An unbalanced force must be exerted for a rocket to lift off from a launch pad. This relates to the first law. The amount of thrust or force produced by a rocket engine will be determined by the mass of rocket fuel that is burned and how fast the gas escapes the rocket. This relates to the second law. The reaction to the rocket is equal and in opposite direction from the action of the gases exiting the nozzle. This relates to the third law.

Rocket Engines

Rockets engines provide the thrust for a rocket to leave the launch pad and travel upward. A rocket on the launch pad is balanced. The surface of the pad pushes the rocket up while gravity tries to pull it down. As the propellant is ignited, the thrust from the engine unbalances the forces and the rocket travels upward.

There are two main types of propellant which operate rockets today, solid or liquid. The word *propellant* means fuel and oxidizer. The *fuel* is the chemical the rocket burns. For burning to take place, an oxidizer must be present. Rockets differ from jet engines because jet engines draw oxygen into their engines from the surrounding air. Rocket engines must carry their oxygen with them.

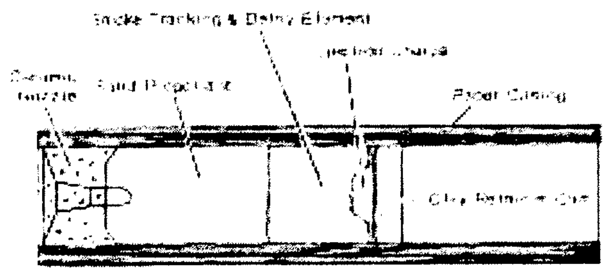
Solid rocket propellants, which are dry to the touch, contain both the fuel and the oxidizer in the chemical itself. Usually the fuel is a compound containing predominantly hydrogen and carbon. The oxidizer is made up of oxygen containing compounds.

Liquid propellants, which are often gases that have been chilled until they turn into liquids, are kept in separate containers, one for the fuel and the other for the oxidizer. When the engine fires, the fuel and oxidizer are mixed together in the engine. Liquid propellants are much more powerful than solid propellants.

Model rockets use solid propellants enclosed in a casing. At the base of the engine is the nozzle, which is made of a heat-resistant, rigid material. The *igniter* is placed in the rocket engine nozzle and is heated by a battery powered launch controller. The hot igniter ignites the solid rocket propellant inside the engine. The burning propellant produces gas and releases heat energy while it is being consumed. The hot gases produce very high pressure inside the rocket engine which forces the exhaust gases to accelerate out through the nozzle. The opposing force to this acceleration is thrust.

Above the propellant is the *smoke tracking/delay element*. Once the propellant is used up the engine's time delay is activated. The engine's time delay produces a visible smoke trail used in tracking but does not produce any thrust. The fast moving rocket now begins to *decelerate* as it coasts upward toward apogee. The rocket slows down due to the force of gravity and drag.

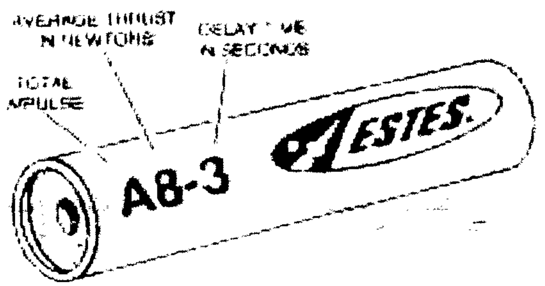
When the rocket has slowed enough, it will stop going up and begin to arc over and head downward. This high point is the apogee. At this point the engine's time delay is used up and the *ejection charge* is activated. The ejection charge is above the delay element. It produces hot gases that expand and blow away the *clay cap* at the top of the engine. The ejection charge generates a large volume of gas that expands and activates the rocket's recovery system which provides a slow, gentle, safe, soft landing. The diagram below shows the elements of a model rocket engine.



Model rocket engines are manufactured in a range of sizes. They come in over thirty varieties, each one varying in total impulse, average thrust, thrusting time and time of delay between propellant burnout and activation of the ejection charge.

Estes Industries prints the information on its model rocket engines in color to supply information at a glance. Green print indicates that the engine is used for a single-stage flights. Red print indicates that the engine is a booster engine and has no delay/smoke tracking elements, ejection charge or caps. Purple or blue print indicates that the engine has an extremely long delay and should be used only for the upper stage of multistage rockets or for very light, high performance model rockets.

Additional printing on the engine identifies the manufacturer of the engine and the type of engine, instructions on disposal of the engine, Department of Transportation classification, and the date of the engine's manufature.



The engine code on each engine consists of a letter, a number and another number preceded by a dash. The letter indicates the total impulse or power of the engine. The number indicates the average thrust of the engine. This value is in newtons. The last number is the delay time in seconds between the time of the engine's burnout and the activation of the ejection charge

TOTAL IMPULSE CLASSIFICATION:

Code	pound-seconds	newton-seconds
1/4A	0.00-0.14	0.000-0.625
1/2A	0.14-0.28	0.625-1.250
A	0.28-0.56	1.250-2.500
B	0.56-1.12	2.500-5.000
C	1.12-2.24	5.000-10.000
D	2.24-5.00	10.000-20.000

A newton is the measurement of force required to accelerate one kilogram of mass, at a rate of one meter per second per second. The average thrust of an engine in newtons multiplied by the thrust duration equals the total impulse (total power) in newton-seconds. Newton-seconds may be converted to pound-seconds by dividing 4.45.

newton seconds ÷ 4.45 = pound-seconds

The characteristics of an engine are important in selecting the proper engine for a specific model on a specific flight. The total impulse of the engine is one of the factors that determine the height a rocket can reach. The height a rocket will reach depends heavily upon the power of the engine. Generally, using an engine of the next higher power, i.e. substituting a B engine for an A engine, will cause the height reached by the rocket to nearly double. The rocket's total weight is also a factor in selecting which engine may be used for safe flights.

Each model rocket flight should be made with an engine that is recommended by the manufacturer for that model. The engine should be able to cause the ejection charge to activate the recovery system at or near apogee and return the model rocket safely to the ground within the recovery area. If the ejection charge activates the recovery device too soon, the rocket's drag is greatly increased and the rocket does not reach its maximum height. If the ejection charge operates few seconds past apogee, the rocket may be falling so fast that the recovery device will be damaged or detached when it is ejected. If the ejection charge operates more than a few seconds past apogee, the rocket may fall so fast that the recovery device cannot prevent its crash.

The chart that follows shows the approximate altitudes that can be reached by single stage rockets.

Engine Size	Altitude Range of a 1oz. Model in feet	Approximate Altitude of a Typical Model in feet
1/4A3-2	50 TO 250	100
1/2A6-2	100 TO 400	190
A8-3	200 TO 650	370
B6-4	300 TO 1000	725
C6-5	350 TO 1500	1000

The instructions for each model rocket kit contain an exact list of which engines are suitable for launching that rocket

NEWTONS FIRST LAW AND ROCKETS

Objects at rest will stay at rest and objects in motion will stay in motion in a straight line unless acted upon by an unbalanced force.

During a rocket flight sequence, forces become balanced and unbalanced all the time.

A rocket on a launch pad is at a state of rest. It is balanced because the surface of the pad pushes the rocket up while the force of gravity tries to pull it down. This is *static inertia*. A rocket blasting off the launch pad changes from a state of rest to a state of motion. Newton's law tells us that it will keep moving in a straight line at the same speed, unless it is acted upon by a unbalanced force. This is *kinetic inertia*. We have seen how the aerodynamic force of drag acts on a model rocket. The force of gravity also acts as an unbalanced force. Gravity is the force that acts upon objects near each other in space. The larger the objects, the greater the force with which they are attracted toward each other. Think of a spaceship moving through space. It will tend to keep moving in the same direction at the same speed unless acted upon by an unbalanced force. These forces can include the gravitational attraction between the spaceship and nearby planets or stars.

Momentum is a property of a moving object. Momentum is related to mass and velocity of an object. A rocket resting on a launch pad possesses zero momentum. The momentum possessed by a rocket moving through space varies as the velocity of the rocket changes. The momentum of a model rocket increases as the velocity of the model rocket increases. However, the mass of a model rocket is reduced slightly as the propellant of the engine is converted to hot gases and ejected from the engine's nozzle.

The formula for momentum helps to understand the relationship if the elements.

Momentum = Mass x Velocity

Transformation of energy is related to the momentum of a rocket. Energy is not created or destroyed. It is transformed. The *chemical energy* in a rocket engine is transformed into the *mechanical energy* of hot expending gases caused by combustion. Part of the mechanical energy is transformed into the kinetic energy of the rocket's motion. Part of the mechanical energy is transferred to air molecules as they are deflected by the passing rocket. Part of the kinetic energy is transformed into the *potential energy* of the rocket as it rises higher and higher.

Potential energy is energy due to an object's position. The formula for potential energy is as follows:

Potential energy = m x g x h

Kinetic energy is the energy of motion. The formula for kinetic energy is as follows:

Kinetic energy = $1/2 \times m \times V^2$

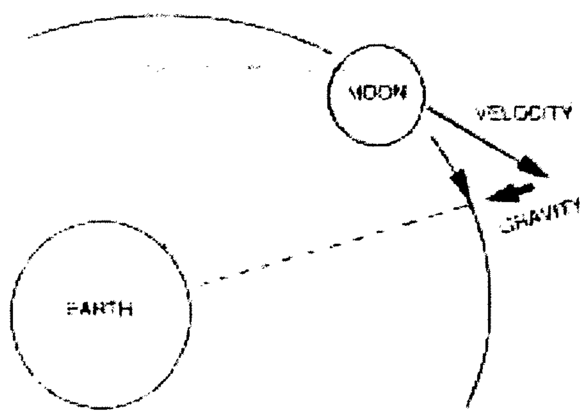
m = mass
V = velocity
h = distance the object can fall
g = acceleration due to gravity

During a rocket flight sequence, momentum builds to maximum as the engine produces thrust. The engine is losing a small amount of mass as propellant is expelled as exhaust. The rocket is going at a high velocity. At burnout, the momentum is at a maximum. The greater the momentum at burnout, the farther the rocket can "coast", even with drag and gravity slowing down the velocity.

There is an optimal combination of mass and velocity for each model rocket that can provide maximum altitude for a given engine impulse. This is called "optimum mass" for the rocket. Usually the rocket must be made lighter, but sometimes mass needs to be added for the rocket to coast to its maximum altitude value.

A model rocket will not make it to orbit. It is important to understand orbital forces, however, because rocketry is related to satellites. Artificial satellites are put into orbit with rocket power.

The first law of motion explains the orbit producing forces that allow a satellite to orbit the earth. For example, the moon is attracted toward Earth by Earth's gravitation. The force of Earth's gravity pulls the moon toward Earth as the moon revolves about Earth. The moon is in effect falling toward Earth. However, the moon's motion causes the moon to move laterally, or sideways, at the same time. The moon's velocity is just enough to keep it falling toward Earth at the same rate that the earth's curvature causes the earth's surface to become farther from the moon.



The farther an object is from the surface of Earth, the slower it falls. An object near the surface of Earth falls from rest about 16 feet in the first second. Earth's surface "curves down" 16 feet in about 5 miles. An object traveling horizontally at about 5 miles per second will fall at a rate that keeps it the same distance above Earth's surface. Earth's atmosphere is very dense at this level so drag will be very great. It is not practical to place an object in orbit near the surface of Earth.

The velocity that a satellite must have to go into a circular orbit near Earth's surface is about 5 miles per second. This is about 18,000 miles per hour (5 miles/second x 60 seconds/minute x 60 minutes/hour). To reach this high speed, man-made satellites have to be launched with very powerful rockets. If the velocity of an object is greater than 18,000 miles per hour, it will not stay in a circular orbit even if it is launched in the proper direction. Instead, it will go into an elliptical orbit or it will escape entirely. If the velocity is not high enough to go into a circular orbit, it will fall back to Earth.

The farther an object is from Earth, the weaker the force with which Earth's gravitation pulls on the object. Since this is true, the higher an object is above Earth's surface, the slower its rate of fall due to Earth's gravity. Since the object tends to fall at a slower rate the higher it is, the slower it will have to move to stay in orbit.

A satellite which is in orbit far from Earth has a very long orbital path and is moving relatively slowly so the satellite has a very long *period*, the time required to make one revolution around Earth.

A satellite in a lower orbit has a shorter orbital path. Also, the satellite must be moving faster since the force of gravity is stronger, and the satellite must have a high velocity or it will fall out of orbit. These factors cause the satellite to have a fairly short period.

VELOCITIES AND PERIODS OF EARTH SATELLITES IN CIRCULAR ORBITS AT VARIOUS ALTITUDES

Altitude Miles	Velocity Miles per Sec.	Period
0	4.92	1 hr. 24 min.
100	4.85	1 hr. 28 min.
400	4.68	1 hr. 38 min.
5,000	3.27	4 hr. 47 min.
22,300	1.91	24 hours

The table illustrates the effects of altitude on orbital speed and on the length of period.

So far, rockets are the only way satellites can be launched into orbit. Newton's laws provided the scientific basis for developing rockets. The first law, with the ideas of inertia and momentum, helps us see how rockets can be launched and how rockets can launch satellites into orbit.

Newton's Second Law and Rockets

If an unbalanced force acts on a body, the body will be accelerated; the magnitude of the acceleration is proportional to the magnitude of the unbalanced force, and the direction of the acceleration is in the direction of the unbalanced force.

or

Force is equal to mass times acceleration.

Newton's second law of motion can be restated in the following way:
The greater the rate at which rocket fuel is burned and the faster the velocity of the escaping exhaust gas, the greater the thrust of the rocket engine.

Therefore, it follows that if we know these two values we could calculate the thrust of a rocket engine. The rate at which the propellant is burned is called *mass flow rate*, and the velocity of the escaping gases is the *exhaust velocity*. The formula for thrust is as follows:

Thrust = Mass flow rate x Exhaust velocity

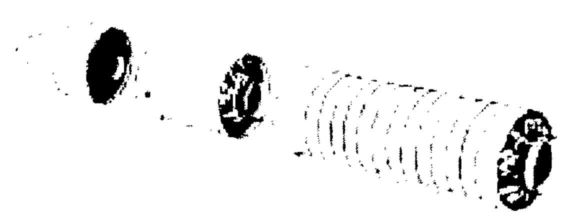
For example, if we have a rocket engine that burns 10 kg of propellant every second, with an *exhaust velocity* of 1900 meters per second:

$$\begin{aligned}\text{Thrust} &= 10\ \text{kg/s} \times 1900\ \text{m/s}\\ &= 19000\ \text{kg - m/s}^2\\ &= 19000\ \text{newtons}\end{aligned}$$

(1 kg - m/s^2 is called a newton and is the amount of force required to accelerate a mass of one kilogram at a rate of one meter per second per second. The newton is the standard unit of force in the metric system, which is why it is used in model rocket engine designation.) In real life, there are small losses in the system that cause the actual thrust to be slightly lower. Designers use a corrected figure for exhaust velocity to account for these losses.

Achieving the velocities required for Earth orbit (about five miles per second) or to escape orbit and travel to the moon (about seven miles per second) with a man-carrying vehicle weighing many thousands of pounds, requires an incredible amount of energy. The liftoff weight of the Saturn V rocket used on the Apollo moon launches was about six million pounds of which a major part was fuel and oxygen. At liftoff, the engines produced a total of 7 1/2 million pounds of thrust, and the rate of propellant consumption could be measured in tons per second.

Obviously, the goal is to reach these velocities with the least amount of propellant and hardware (and hence cost) as possible. This is why we see multi-staged rockets, such as the Saturn V or Space Shuttle. In a multi-staged rocket, the principle is basic:
As propellant is consumed, the mass of the vehicle decreases. Therefore, the force needed to keep the vehicle accelerating at tolerable levels (remember the human payload!) becomes less and less. Also, the hardware used to contain the spent propellant becomes useless, dead weight. By ejecting the dead weight as the vehicle is accelerating, much more efficient use is made of the available energy. Designers look carefully at the trade-offs between varying numbers of stages when designing new vehicles to achieve the best performance and cost.



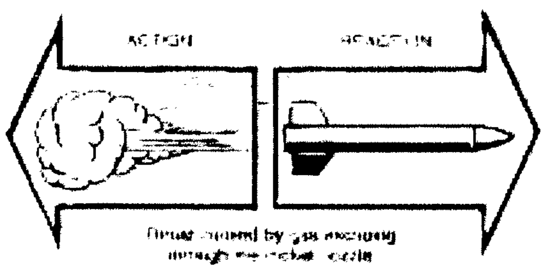
Newton's Third Law and Rockets

Whenever one body exerts a force on another, the second body exerts a force equal in magnitude and opposite in direction on the first body.

or

For every action there is always an opposite and equal reaction.

With rockets, the action is the expelling of gas out of the engine. The reaction is the movement of the rocket in the opposite direction. The rocket is pushed by the escaping gases produced by the chemical reaction of fuel and oxidizer combining in the combustion chamber.



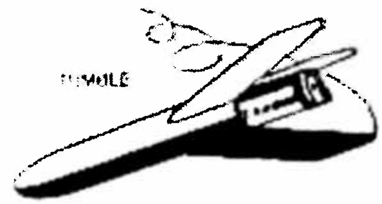
The sides of the combustion chamber prevent the gases from escaping sideways. The gases cannot escape forward. The only opening to the outside is the nozzle. A tremendous volume of hot gases is produced as the fuel is burned. These hot gases have mass and this mass can escape only through the rocket's nozzle at high velocity. The gases have a large momentum.

The escaping gases acquire momentum due to the action. The reaction gives momentum to the rocket which is equal but opposite in direction. The large mass of the rocket is given a small velocity so that the momentum (reaction) of the rocket is equal to the momentum (action) of the escaping low-mass, high-velocity gases.

<u>NOTES</u>

Chapter 5
MODEL ROCKET SAFETY
Safe Recovery and Safe Procedures

Model Rocket Recovery Systems
The purpose of all recovery systems is to bring the rocket safely back to earth by creating enough drag or lift to resist the force of gravity. There are several main types of recovery systems for model rockets.



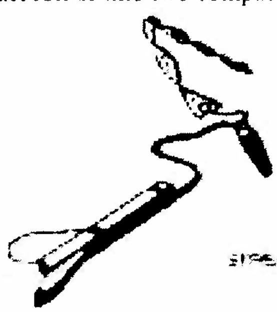
Featherweight Recovery
In this system, the model is very light, usually less than 7 grams (1/4 oz.). When the ejection charge activates, the engine ejects from the rocket. The rocket falls to the ground in a stable manner, but because of the very low mass in relation to the drag forces, terminal velocity is severely limited (similar to a badminton shuttlecock).

Tumble Recovery
Tumble recovery is achieved by shifting the center of gravity aft of the center of pressure (the point at which all of the aerodynamic forces appear to be centered). When this happens, the aerodynamic forces in operation during descent do not realign the rocket so that the nose of the rocket precedes the tail. The rocket is now unstable and tumbles end over end. The tumbling motion of the rocket produces extremely high drag on the rocket so it falls slowly. The most common method of shifting the center of gravity backward is by allowing the engine's ejection charge to push the empty engine casing backwards.

This method of recovery is rarely used on models that are not simple in design and sturdy in construction because the rate of decent is usually higher than with parachute, streamer or featherweight recovery. An important use of this method is for recovering the lower stages of multi-stage rockets. The booster stages are designed to be unstable after they separate from the upper stages.

Streamer Recovery
A streamer is attached to the rocket and ejected by the engine's ejection charge to whip around in the air, creating substantial drag with which to slow the rocket's descent.

The effectiveness of the streamer in slowing the descent of the model rocket is chiefly determined by the streamer's surface area and its roughness. The larger the streamer the slower is the descent of the rocket. On windy days, streamers are useful for returning rockets with a minimum of drift. The size of the streamer needed primarily depends upon the weight of the object being returned. Parachutes and streamers can be easily interchanged, depending on needs and wind conditions. However, streamers do not produce enough drag for heavier rockets. Streamers are packed by rolling them into a compact roll or into two compact rolls.



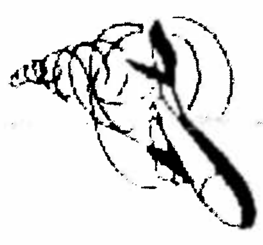
Parachute Recovery
The parachute recovery system produces great drag to slow the descent of a model rocket. It is usually stowed inside the body tube during the thrust and coast phases. The parachute is attached to the rocket and is ejected from the rocket body by the engine's ejection charge. It fills with air and creates tremendous drag to slow the rocket's descent and allow it to float gently back to earth.

Most parachutes used in model rockets are made of very light plastic. Between the parachute packed in the body tube and the engine is a layer of flame-resistant recovery wadding. If there is not enough wadding, gases from the ejection charge can pass through the wadding layer and either burn holes in the parachute or melt the parachute into a lump.

Helicopter Recovery
Vanes on the rocket are activated by the engine's ejection charge. These vanes are airfoils that generate lift when air flows over them. The arrangement of vanes and their orientation when deployed cause the rocket to rotate. The orientation is crucial because the lift on the blade must generate a force in the direction of rotation.

Lift is a result of the relative wind flowing over the airfoil. When the lift force is broken into horizontal and vertical components, it can be seen that the horizontal force component is an unbalanced force that causes the airfoil to react in the forward direction. This causes the rotation. The vertical component is the force that acts against gravity to keep the rocket in the air.

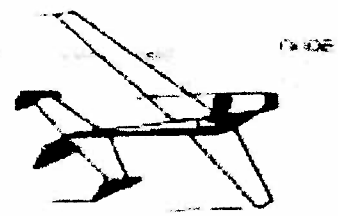
The relative wind is a combination of the real wind flowing upward (because the rocket is falling) and the wind flowing directly over the airfoil (because the rocket is spinning).



Glide Recovery
The rocket is launched and the engine's ejection charge causes it to convert into a glider. The wings of the glider generate lift as it flies through the air. This lift counteracts gravity and the glider glides through the air, descending very slowly. During glide recovery, the rocket moves forward as it descends. The horizontal motion decreases the rate of fall because it generates lift on the wings.

Most model rockets that use the glide recovery system are shaped much like airplanes. They move forward along their longitudinal axis as they descend and sink at the same time they move forward.

As with any recovery system, a glider can encounter an area of heated, rising air called a thermal which slows down the rate of descent. In some cases, the thermal is rising faster than the glider is descending and it can carry the glider away from sight. Large soaring birds use thermals for lift to stay up in the air so they don't have to flap their wings.



The key points to consider when choosing a recovery system are its suitability to the type of rocket being launched, the wind conditions and the safety of the return. Model rockets take time and care to construct. It is important to choose a recovery system that will ensure a safe return to earth so that the rocket can be launched again and again.

NAR MODEL ROCKETRY SAFETY CODE
The safety code was formulated by experienced rocketeers and has evolved with model rocketry. It should be followed in every model rocketry activity.

1. Materials - My model rocket will be made of lightweight materials such as paper, wood, rubber, and plastic suitable for the power used and the performance of my model rocket. I will not use any metal for the nose cone, body, or fins of a model rocket.
2. Engines/Motors - I will use only commercially made NAR certified model rocket engines in the manner recommended by the manufacturer. I will not alter the model rocket engine, its parts, or its ingredients in any way.
3. Recovery - I will always use a recovery system in my model rocket that will return it safely to the ground so it may be flown again. I will use only flame resistant recovery wadding if required.
4. Weight and Power Limits - My model rocket will weigh no more than 1,500 grams (53 ounces) at liftoff, and its rocket engines will produce no more than 320 newton-seconds (4.45 newtons equal 1.0 pound) of total impulse. My model rocket will weigh no more than the engine manufacturer's recommended maximum liftoff weight for the engines use, or I will use engines recommended by the manufacturer for my model rocket.
5. Stability - I will check the stability of my model rocket before its first flight, except when launching

6. Payloads - Except for insects, my model rocket will never carry live animals or a payload that is intended to be flammable, explosive, or harmful.
7. Launch Site - I will launch my model rocket outdoors in a cleared area, free of tall trees, power lines, buildings and dry brush and grass. My launch site will be a least as large as that recommended in the following table.

LAUNCH SITE DIMENSIONS

Installed Total Impulse (newton-Seconds)		Equivalent Engine Type	Minimum Site Dimensions (feet)	(meters)
0.00	1.25	1/4 A & 1/2 A	50	15
1.26	2.50	A	100	30
2.51	5.00	B	200	60
5.01	10.00	C	400	120
10.01	20.00	D	500	150
20.01	40.00	E	1000	300
40.01	80.00	F	1000	300
80.01	160.00	G	1000	300
160.01	320.00	2Gs	1500	450

8. Launcher - I will launch my model rocket from a stable launch device that provides rigid guidance until the model rocket has reached a speed adequate to ensure a safe flight path. To prevent accidental eye injury, I will always place the launcher so the end of the rod is above eye level or I will cap the end of the rod when approaching it. I will cap or disassemble my launch rod when not in use, and I will never store it in an upright position. My launcher will have a jet deflector device to prevent the engine exhaust from hitting the ground directly. I will always clear the area around my launch device of brown grass, dry weeds, or other easy-to-burn materials.
9. Ignition System - The system I use to launch my model rocket will be remotely controlled and electrically operated. It will contain a launching switch that will return to "off" when released. The system will contain removable safety interlock in series with the launch switch. All persons will remain at least 15 feet (5 meters) from the model rocket when I am igniting model rocket engines totaling 30 newton-seconds of less of total impulse. I will use only electrical igniters recommended by the engine manufacturer that will ignite model rocket engine(s) within one second of actuation of the launching switch.
10. Launch Safety - I will ensure that people in the launch area are aware of the pending model rocket launch and can see the model rocket's liftoff before I begin my audible five-second countdown. I will not launch a model rocket using it as a weapon. If my model rocket suffers a misfire, I will not allow anyone to approach it or the launcher until I have made certain that the safety interlock has been removed or that the battery has been disconnected from the ignition system. I will wait one minute after a misfire before allowing anyone to approach the launcher.
11. Flying Conditions - I will launch my model rocket only when the wind is less than 20 miles (30 kilometers) an hour. I will not launch my model rocket so it flies into clouds, near aircraft in fight, or in a manner that is hazardous to people or property.
12. Pre-Launch Test - When conducting research activities with unproven model rocket designs or methods I will, when possible, determine the reliability of my model rocket by pre-launch tests. I will conduct the launching of an unproven design in complete isolation from persons not participating in the actual launching.
13. Launching Angle - My launch device will be pointed within 30 degrees of vertical. I will never use model rocket engines to propel any device horizontally.
14. Recovery Hazards - If a model rocket becomes entangled in a power line or other dangerous place, I will not attempt to retrieve it.

This is the official Model Rocketry Safety Code of the National Association of Rocketry and the Model Rocket Manufacturers Association.

The largest legal "model" rocket engine, as defined by CPSC, is an "F" (80ns) engine. To launch rockets weighing over one pound including propellant or rockets containing more than four ounces (net weight) of propellant, a waiver must be obtained from the FAA. Check your telephone directory for the FAA office nearest you.

Questions for Discussion:

Why do you think a safety code was developed?

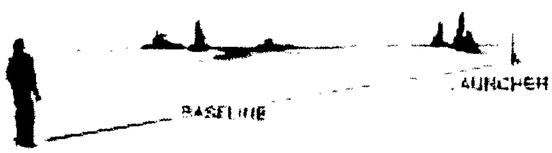
Why do you think it includes the statements that it does?

What could be some possible consequences of not following it precisely?

Chapter 6
USING MATH WITH MODEL ROCKETS

Determining Altitude
One of the most interesting things about building and launching model rockets is to determine how high your rocket went. Accurate determination of heights reached requires care and precision in measuring, recording and calculating.

Tracking
First, measure to determine the length of the baseline. The baseline is the distance between the launcher and the observer or tracker with an altitude measuring device. Measure the baseline with a meter stick, a yardstick or a measuring tape.

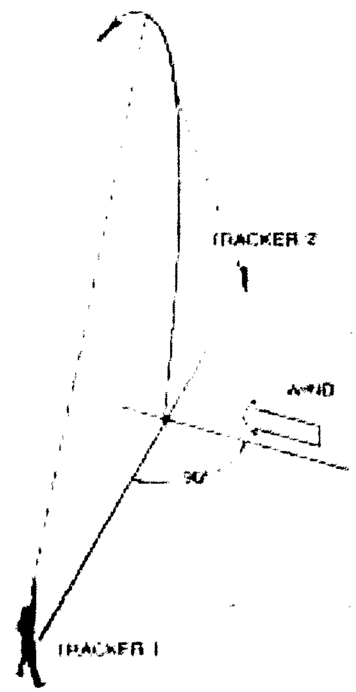


Second, determine the angular distance the rocket travels from launch to apogee. The angular distance is determined by measuring the change in elevation angle, as seen by the tracker, between the rocket's position on the launch pad and the highest point (apogee) reached by the rocket in flight. The measuring device used to find this angular distance can be homemade or may be a device such as the Estes AltiTrak™. (Directions for making and using a homemade altitude measuring device can be supplied by your teacher).

The use of either type of device involves tracking the rocket from the launch pad to apogee, noting and recording the angular distance and then determine the actual height reached by the rocket by the use of a mathematical formula to calculate it.
One or two station tracking teams may be used. Accuracy in making and recording all measurements is very important.

One station tracking is the easiest to use. The results are generally reliable. In one station, there is one baseline and one observer using an altitude measuring device. One station tracking assumes that the flight will be almost vertical. It is important to master this system before going on to more complex ones.

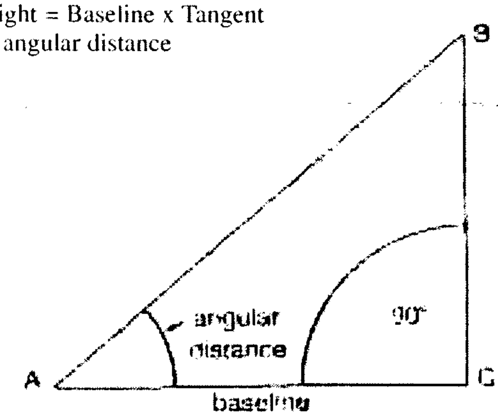
Two-station tracking is more accurate. In two-station tracking, the two help each other and check each other's work. With two-station tracking, place the two stations on opposite sides of the launch pad at a right angle to the wind direction. Each tracking station takes its own measurement of the angle reached. Both heights are calculated.



The two results are averaged, and the average is used as the height reached. Usually both heights will be thrown out if they are not within ten percent of each other. This assumes that at least one of the tracking stations made a mistake and the results cannot be considered reliable.

Calculations
The formula for determining the height reached by a model rocket flight is:

Height = Baseline x Tangent of angular distance



If we assume that the rocket flight is vertical, we can call angle C a right angle, 90°. B is equal to 90° minus A because the sum of the angles in a triangle is 180°. To find the distance from C to B or the height the rocket reached, take the tangent of Angle A times the distance along the baseline, side AC.

Example:

Baseline = 250 ft.
Angle observed by tracker = 62°
Tangent of 62°= 1.88
H = 250 ft. x 1.88
H = 470 ft.

We use the tangent to determine altitude because the tangent of an angle is the ratio of the opposite side to the adjacent side. In this example, the adjacent side is the distance along the baseline. The opposite side is the distance from the launcher to the rocket's maximum altitude. Tangents can be found in the Table of Tangents in the Appendix.

In the simplest method of two station tracking, the H from each station would be averaged together.

A more accurate system of two-station tracking uses two tracking stations placed on opposite sides of the launch pad in line with the wind. It uses sines instead of tangents (Extension Activity). An additional and even more accurate system of two-station tracking uses the azimuth angle. This method is also found in the Extension Activities.

Determining Average Speed
When you participate in a rocket launch with several people and their rockets, you will notice differences in altitude and in speed. A large relatively heavy rocket takes off fairly fast with a less powerful engine, but does not rise very high before the propellant is gone. You will notice that a rocket like this will gain speed very quickly as it starts on its flight upward, but the maximum speed reached is not very high. When a small, relatively lightweight rocket with a powerful engine is launched, you will notice that it accelerates even more quickly and reaches a much higher maximum speed. It also goes much higher than the heavy rocket with the less powerful engine.

A small rocket with a C6-7 engine can reach an altitude of 1700 feet in less than nine seconds (1.7 seconds of thrusting flight and 7 seconds of coasting flight), so it must be moving very quickly. An average speed for this upward flight would be 195.4 feet per second. To determine average speed, the altitude, 1700 feet was divided by the time to reach apogee, 8.7 seconds.

The rocket moves faster and faster as the engine is thrusting. At the end of this thrusting portion of the flight, 1.7 seconds into flight time from liftoff, the model rocket is traveling at maximum speed. This maximum speed is 670 feet per second or about 3.5 times as fast as the average speed. 670 feet per second is about 456 miles per hour.

After the propellant is gone, the rocket is moving upward without a thrust force pushing it. The forces of gravity and drag act to slow the rocket down.

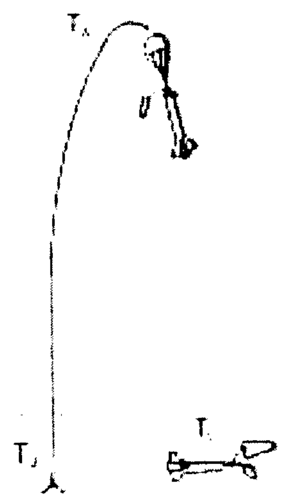
When you fly a larger, much heavier model rocket with a smaller engine, such as an A8-3 engine, it reaches a maximum velocity of 84 feet per second during its 3.32 second flight to parachute ejection. To convert from feet per second to miles per hour multiply by the conversion factor of 0.68.

84 x .68 = 57 miles per hour

This speed is certainly not as fast as the 456 miles per hour which the first rocket reached. The weight of each rocket has to be considered. The second rocket with its engine weighed over 2.5 times as much as the first rocket, 2.84 ounces compared to 1.075 ounces. The second rocket had an engine with one quarter of the power (total impulse) of the other rocket's engine, and had much greater drag. It is easy to understand why the heavy rocket only reached a speed of about one-eighth as great as that reached by the smaller rocket.

Calculations
The "launch to apogee" average speed and the "apogee to landing" average speed can be calculated. The formula is as follows:

Average Speed = Distance traveled ÷ Time it took to travel



On the diagram, distance traveled is the distance between T_O and T_A (launch to apogee). That is the altitude or height the rocket reached at apogee.

Use the following example data:

T_O = 0 seconds
T_A = 3.2 seconds
T_L = 7.3 seconds
Altitude = 288.7 feet

Average Speed Ascending = Altitude ÷ (T_A - T_O)
288.7 ÷ (3.2 - 0) = 90.22 feet per second

T_A is determined by using a stop watch starting at launch and stopping at apogee. Using the conversion factor of 0.682 to determine the miles per hour, multiply 0.682 x 90.22. The rocket's average speed was 61.53 mph.

To determine the average speed descending from apogee to landing, use this formula.

$$\text{Average Speed Descending} = \text{Altitude} \div (T_L - T_A)$$

288.7 ÷ (7.3 - 3.2) = 70.415 feet per second

Multiply by the conversion factor of 0.682.
70.51 x 0.682 = 48.02 miles per hour.

Due to the difficulty in determining the time from apogee to landing with a single stopwatch, a separate stopwatch may be used. Here, the watch is started when the rocket reaches apogee and stopped when the model lands. The average speed descending becomes:

$$\text{Average Speed Descending} = \text{Altitude} \div T_L$$

Where T_L is the time in seconds on the second stopwatch

The burnout velocity of a model rocket can also be determined. If you are interested in learning how to do this, the method may be found in the Extension Activities.

NOTES

GLOSSARY

Acceleration: a change in velocity.

Action/Reaction: Newton's Third Law of Motion.

Angle of Attack: the angle between the relative wind direction and an imaginary line through the center of a flying surface, such as an airplane wing or a rocket fin. Generally, as the angle of attack increases (raising the forward edge of the surface) so does lift and drag.

Angular Distance: determined by measuring the angle between the rocket's position on the launch pad and the highest point (apogee) reached by the rocket as seen by the tracking station or observer.

Apogee: the peak altitude of a model rocket.

Baseline: the distance between a tracker and the launch pad.

Body Tube: a specially wound and treated cardboard or lightweight plastic cylinder used to make the fuselage of a model rocket.

Coasting Phase: the period of time immediately following propellant burnout and preceding the ignition of the ejection charge of the engine during which the rocket coasts on its momentum.

Drag: the resistance or friction force experienced by any object moving through air.

Ejection Charge: charge contained in a model rocket engine that is ignited by the delay element which activates the recovery device.

Engine: (model rocket) a miniature solid fuel rocket motor that contains propellant, a delay element, an ejection charge and is composed of nonmetallic substances. Designed to impart force to accelerate the rocket during flight and to activate the recovery system at or near apogee.

Featherweight Recovery: rocket recovery system which involves a very lightweight model which falls slowly in a stable manner because it is very light relative to its size, so the drag force easily counteracts the force of gravity.

Fins: the stabilizing and guiding unit of a model rocket, an aerodynamic surface projecting from the rocket body for the purpose of giving the rocket directional stability.

Friction Drag: the retarding force produced by an object sliding past the molecules of the fluid it is moving through. The amount of friction depends upon the amount of surface, the roughness of the surface, the density of the fluid and the viscosity of the fluid and the characteristics of the flow (laminar or turbulent).

Fuel: the chemical the rocket burns.

Glide Recovery: rocket recovery system in which the engine's ejection charge causes it to convert into a glider which creates lift as it flies through the air.

Gravity: the force that pulls down on any object near the surface of the earth.

Helicopter Recovery: rocket recovery system in which vanes on the rocket are activated by the engine's ejection charge. The vanes are surfaces mounted on the rocket in such a way that air flowing over them generates lift, which causes the rocket to rotate (like a helicopter) safely to the ground.

Igniter: an electrical device which initiates the combustion process in a rocket engine.

Inertia: the tendency of a body at rest to remain at rest or a body in motion to remain in motion, unless pushed or pulled by an unbalanced force.

Kinetic Energy: energy of motion.

Kinetic Inertia: the tendency of a body in motion to continue in motion in a straight line at a constant speed.

Laminar Flow: smooth steady air flow parallel to the surface of a moving body, usually found at the front of a smooth body moving in relation to the air around it.

Launch Lug: round, hollow tube which slips over the launch rod to guide the model during the first few feet of flight until stabilizing velocity is reached.

Lift: the force that occurs when air moving over the top of a moving object travels faster than the air under it and uneven pressures are produced.

Mass: quantity or amount of matter an object has. Weight depends on mass.

Momentum: the property of a moving object equal to its mass times its velocity.

Motion: the property of an object changing position in relation to its immediate surroundings.

newton: a force or measurement of force. The amount of force needed to move a mass of one kilogram with an acceleration of one meter per second per second; one newton is equal to 0.225 pounds of force. Abbreviation: n.

newton-second: metric measurement for a rocket engine's total impulse. The metric counterpart of "pound-second".

Nose Cone: the foremost surface of a model rocket, generally tapered in shape to streamline it; usually made of balsa or lightweight plastic. Smoothes airflow around a rocket.

Nozzle: the exhaust duct of a rocket engine's combustion chamber; gases from propellant combustion are accelerated to higher velocities in the nozzle.

Oxidizer: made up of oxygen compounds to allow rockets to carry their oxygen with them to allow the rocket fuel to burn.

Parachute Recovery: rocket recovery system in which a parachute is attached to the rocket and is ejected from the rocket by the engine's ejection charge.

Payload: the cargo of a rocket.

Period: the time required to make one orbital revolution around the earth.

Potential Energy: a form of stored energy which can be fully recovered and converted into kinetic energy.

pound-second: the English measure of impulse, interchangeable with the metric unit, "newton-second".

Pressure Drag: the force that retards the motion of a moving object caused by an unbalance of pressure.

Propellant: the source of motive energy in a rocket engine; a mixture of a fuel and an oxidizer.

Recovery Phase: the period of time following the deployment of the recovery system which allows the rocket to drift safely back to earth.

Recovery System: a device incorporated into a model rocket for the purpose of returning it to the ground in a safe manner by creating drag or lift to oppose the acceleration of gravity. All model rockets must employ a recovery system, such as a parachute.

Relative Wind: the motion of air in relation to an object. Lift is generated at a right angle to the relative wind.