Chapter 22

CHEMICAL PROPULSION

With a few exceptions, propulsion systems for rockets and spacecraft today use chemical propellants. These propellants can be solid, semisolid, gelled or liquid, depending on whether they are pressurized. However, they are most often in solid or liquid form.

How rapidly a solid propellant burns depends on how much of its surface is exposed to burning at any one moment. Of course, this depends on the design or molding of the solid-propellant charge within its container. It is relatively easy to throttle or change the thrust of a liquid-propellant rocket, but it is very difficult to control the thrust of a solid-propellant type. Why and how these conditions exist will be examined in this chapter. We will look at special factors and conditions influencing the use of liquid propellants and examine rocket engine (or motor) design and function.

Objectives

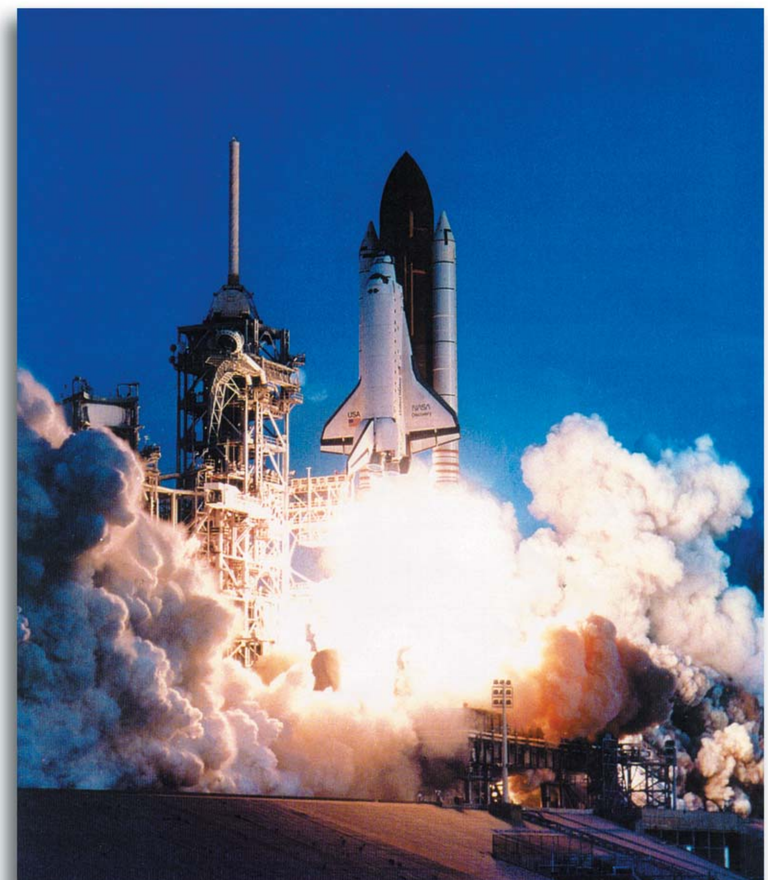
Explain oxidation.
State the difference between an oxidizer and a reducer.
Define cryogenics, hydrocarbons and a self-reacting compound.
State the difference between a propellant, a bipropellant and a monopropellant.
List the four qualities of a good propellant.
Explain why a rocket propellant does not need air.
Explain the difference between an air-breathing engine and a rocket engine.
Define hypergolic propellants, mass flow and low explosives.
Identify a way to get more force from a load of propellant.
Describe the purpose of the rocket engine.
Describe the function of the rocket motor throat and nozzle.
Compare the features of the liquid and solid-propellant chemical systems.
Name two systems that use solid propellants.
Describe the solid-propellant chemical system.
Explain how the burning rate of solid propellants is controlled.
State the purpose of a squib in a solid-propellant rocket.
Describe a liquid-propellant engine system.
Discuss the combustion chamber of a liquid-propellant system.
Explain the function of the coupled valve in a combustion chamber.
Explain the function of the injector in a liquid-propellant engine.
Describe the hybrid propellant system.
State the advantages of a hybrid propellant system.

Oxidation and Combustion

Combustion is nothing more than very rapid oxidation, but what is oxidation? Oxidation is the combination of oxygen with another substance. The time it takes for this combining process to take place determines whether the substance rusts or corrodes, burns as a fire or explodes violently.

A chunk of rusting iron and the heat, pressure and light of a functioning rocket engine are doing the same thing. It just takes one longer to become oxidized than it does the other. Another similarity between these two extremes of oxidation is that both require oxygen (oxidizer) and a substance to be oxidized. The substance to be oxidized is also known as the reducer. Thus, the iron in the example is the reducer and the oxygen in the air touching the iron is the oxidizer. For the rocket, one chemical compound is the reducer, while the oxidizer is either another chemical compound or perhaps oxygen in pure form—liquid oxygen.

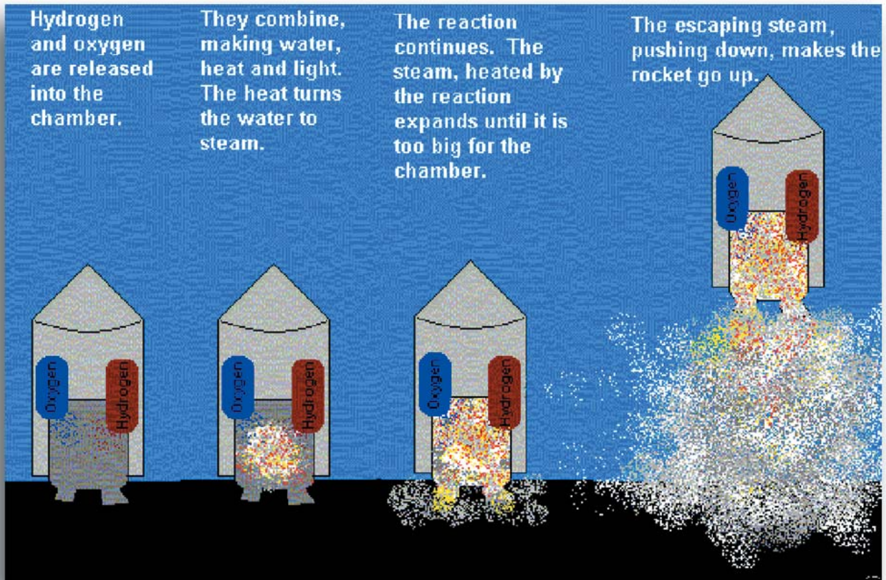
Oxidizers and Reducers



Various combinations of oxidizer-reducers can produce an almost endless variety of oxidation reactions. When it comes to rocketry, however, a few elements occurring in a wider variety of compounds (molecular bonding of two or more elements) dominate the field.

Oxidizers. The element oxygen exists in air as two molecules. To use it in its pure form as an oxidizer for rocket fuels (or reducers), it must be chilled until it becomes liquid. This means that the oxygen must reach and be kept at a temperature of -297 degrees F. The reason why this temperature (or lower) must be maintained is that the oxygen will boil (become gaseous) at any higher temperature. Temperatures in this range come within a classification known as cryogenics.

Cryogenics is an area of science concerned with the production of low temperatures and the effect of such tem-



The chemical reaction of hydrogen and oxygen provides thrust for a rocket.

peratures on matter. Thus, wherever you see cryogenics used with reference to an oxidizer, fuel or propellant, you know that the substance is "super cold."

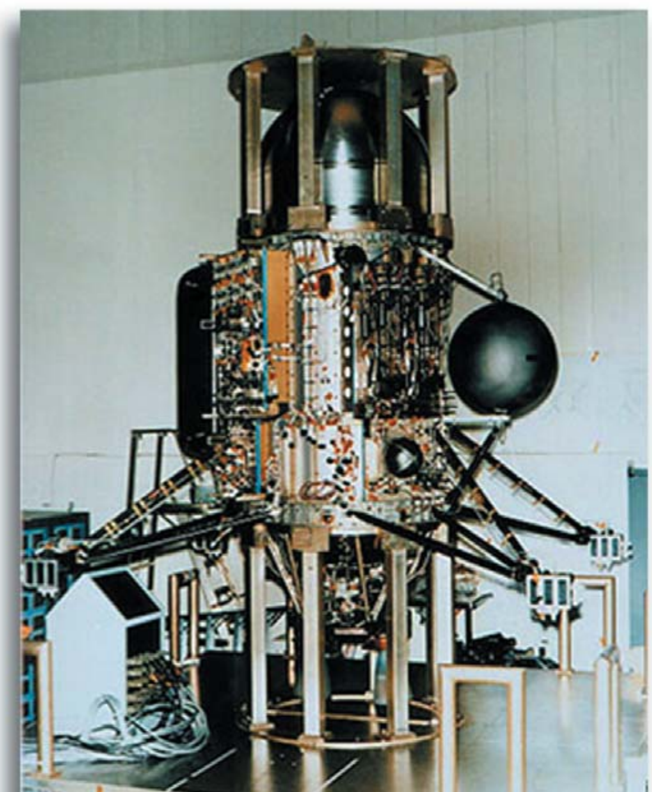
There are other oxidizers that do not have to be kept at as low a temperature as pure oxygen. These are chemical compounds that contain oxygen atoms as part of their molecular structure.

Reducers. Any list of fuels (or reducers) must begin with the elements hydrogen, carbon and nitrogen. Certain compounds of hydrogen and carbon are called hydrocarbons. As you probably know, the fuels we use for heating and transportation are usually hydrocarbons that include coal and products obtained from crude oil.

The first stage of the *Saturn* V rocket used the hydrocarbon kerosene as its fuel. The remaining stages all used hydrogen. Pure hydrogen is an excellent rocket fuel, but it is even more cryogenic than oxygen. Hydrogen must be chilled to -423 degrees F to liquefy it.

In the atmosphere, nitrogen is inert, but it is highly reactive in other forms. Nitrogen is very important to the manufacture of high explosives and other high-energy compounds and mixtures.

Propellant Combinations. Since it takes both an oxidizer and a reducer to propel a rocket, it is correct to call either of them a propellant, However, the term **propellant** is most often used as a single reference to the oxidizer and reducer. For example, we could say, "the rocket uses an oxygen-hydrogen propellant." We could



Bipropellant Tank and Assembly

also say that a rocket uses 1,000 pounds of propellant. It is not necessary to say there are 500 pounds of oxidizer and 500 pounds of reducer, nor is it necessary to say that they are stored within the same container or in separate containers.

Speaking of propellant storage, other terms are used to describe the storage arrangement of a propellant's oxidizer and reducer. If the oxidizer is stored in one container and the fuel (reducer) in another, the term **bipropellant** is used. Bipropellants are not mixed until they reach the engine's combustion chamber. Back to the *Saturn* V: the first-stage bipropellant was oxygen and kerosene; the second- and third-stage bipropellants were oxygen and hydrogen. For all three stages, the propellants were pumped into the combustion chamber of the engine where ignition and burning took place. The majority of liquid-propellant rockets use the bipropellant arrangement.

In some cases, the liquid oxidizer and fuel can exist together in the same storage tank. Here the propellant also is pumped into the combustion chamber of the rocket engine and ignited. However, the fact that separate storage tanks are not necessary qualifies the propellant to be called a **monopropellant**.

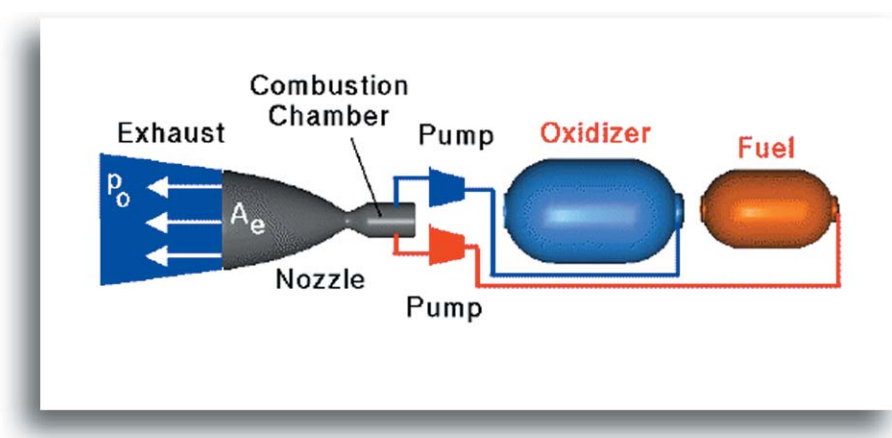
Chemically, when an oxidizer and a reducer occur in a mixture, they are considered to be two separate ingredients. There is such a thing as a self-reacting compound. In such a compound, one molecule contains atoms of both oxidizer and reducer and, upon ignition, reacts with itself, yielding energy as it breaks down or decomposes.

Combustion for Propulsion

The final objective in considering any combination of chemicals as a propellant is how much force can be obtained as the mixture oxidizes. However, there are other considerations which are recognized as the qualities of a good propellant: (1) The propellant must contain oxidizer and fuel. (2) It must ignite correctly every time. (3) It must produce energy in the form of force. (4) The force produced must be controllable. Let's consider these four qualities individually.

Need for Packaged Oxidizers. Aside from propulsion in space, where no free oxygen is available, there is another reason for putting oxidizer in a concentrated package. An oxidizer-reducer mixture will burn forcibly in a confined or semi-confined space in which an air-breathing fire would be smothered.

People knew this fact for centuries without knowing the reason why and used it long before air-breathing engines were ever imagined. Old-fashioned gunpowder or "black powder" needs no air to burn its carbon and sulfur fuel ingredients because it has an oxidizer built into a third ingredient, potassium nitrate or saltpeter.



An Example of Rocket Thrust

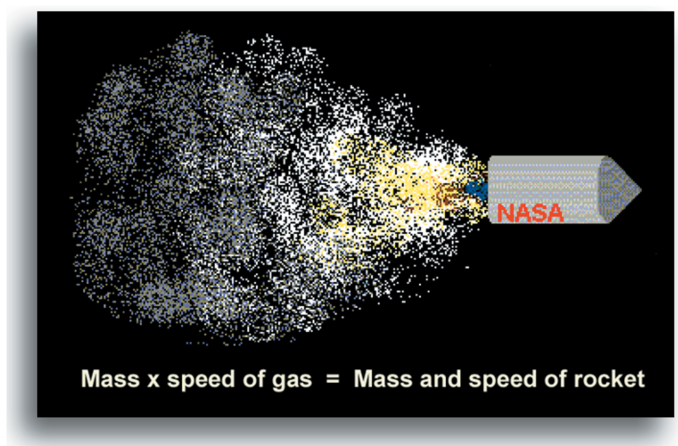
The ability of this mixture to propel a rocket or hurl a cannonball out of an iron tube was known and employed in warfare centuries before Lavoisier discovered oxygen and the principle of oxidation in the eighteenth century. To this day, all chemical rocket propellants, all gun munitions, and all chemical explosives contain an oxidizer, burn in confinement and do their work by bursting out of confinement or rushing out of semi-confinement.

Rushing out of semi-confinement describes rocket-propellant action. In a rocket-propellant mixture, the oxidizer outweighs the fuel something like five to three. Because the packaged oxidizer is expensive and a rocket propellant needs so much of it, the air-breathing engine is much less expensive to operate than any type of rocket engine. Still, the air-breathing engine cannot operate within both the atmosphere and space as does the rocket engine.

Ignition Characteristics. How fast a mixture burns is not necessarily related to how easily it starts. What properties of a propellant should be considered? Since the starting time of the rocket engine is important to controlling it, the propellant must start every time in the same way.

Another factor that must be considered is a choice between a continuous or restartable propellant. Some propellants can be started, but continue burning until all of the propellant is exhausted (a burnout). Others can be repeatedly started and stopped.

Safety is also a very important factor. This does not mean the propellant can stand up to any kind of rough or careless handling without igniting, but it does mean that its safety requirements should be known and feasible. Some propellants are ignitable the old-fashioned way with a match flame or hot wire. Others require greater and more concentrated heat. Some require an explosive shock. Some are hypergolic; that is, under normal temperatures, the oxidizer and reducer burst into flame the instant they meet. The main safety requirement in this case is to keep the ingredients separated.



Gas Changes to a Propellant

Energy for Force. Not light and not heat, but force is what we're looking for from a propellant's release of energy—the sheer momentum of moving molecules. What is desired is mass flow of combustion exhaust, but this mass can be no greater or less than the mass of ingredients before combustion.

Although a designer might wish to lighten the propellant load aboard a vehicle, there must be a certain amount of propellant on board to produce the needed thrust. This load alone constitutes most of the initial weight of a launch vehicle. The only way to get more force per load is to increase the velocity of the mass flow—that is, to get more "speed" per molecule. Therefore, it is better not to increase mass flow by means of heavier molecules that are too sluggish. The ideal exhaust gas consists of plenty of lightweight molecules, which excel in energy and velocity.

Controllable Force. When a propellant burns, the speed of the combustion should not be excessive. Fast, but not too fast is the rule of thumb. How is this combustion process regulated? If a liquid propellant is used, the task of controlling the force is basically easy. All that is necessary is to govern the amount of propellant reaching the combustion chamber. This is similar to governing the amount of fuel/air mixture reaching the cylinders of an automobile engine through actions of the throttle and carburetor.

Controlling the force of a solid propellant is slightly more difficult. There are ways of controlling the force desired from a solid-propellant rocket. Basically, a solid propellant is selected (or developed) according to its ability to produce force without causing a massive, destructive explosion.

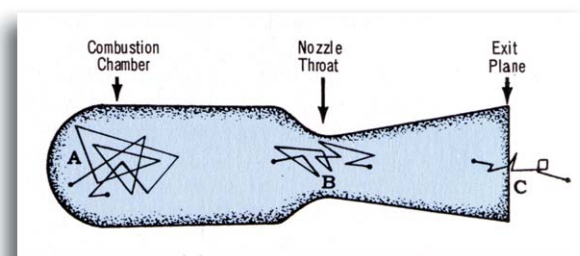
In fact, solid propellants sometimes are called "low explosives." Modern solid propellants are considerably more energetic than the black-powder-type propellant used with very early rockets. Yet, they have the black powder's property of burning so that each particle ignites its neighbor particle and the burning continues as a swiftly spreading reaction.

Pressure and Mass Flow

Adding pressure to a medium will increase its molecular activity and consequently, its temperature. Increase the temperature of a medium and its molecular activity and pressure will be increased—this is particularly true with a gaseous medium that is enclosed by a container. Thus, the purpose of the rocket motor or engine is to provide a container in which the temperature (of the oxidizing propellant) increases the pressure of the gaseous portion of the medium.

If some means were not provided to relieve the constantly building pressure of a burning propellant, the container would burst. Among the functions performed by the nozzle throat and nozzle of the rocket motor are to provide an exit for the burned propellant mass, reduce the pressure within the combustion area and direct the flow of the mass involved.

We can imagine what happens within the "business end" of a rocket on a molecular scale. The diagram below shows what happens to a single molecule that has been energized by combustion and pressure. Loaded with this energy, the molecule zips about at location A. It beats madly at its prison walls, creating pressure. However, there is a way out of its prison, and the molecule will get there along with a crowd of its highly active fellow molecules. We see it again at location B and again at location C. Note that its path continues to be erratic, but less and less so—more zig and less zag, one might say. Finally, it escapes.



Concept of a molecule's path to exit a rocket engine.

This wandering molecule would seem to be going through a great deal of wasted motion and taking much too long to make its exit. Actually, it is making excellent progress. The whole journey is accomplished in a fraction of a second.

More significantly, at each stage of the journey it is traveling faster than before and in the right direction. Furthermore, the greater the pressure in the chamber, the greater the velocity through the nozzle. It is its speed out the nozzle that counts most. The net result, acceleration, is the essence of thrust. The mass of molecules is accelerating in respect to the motor, and the motor itself is moving. As long as combustion is going on inside and mass flow is passing out the nozzle, the motor adds velocity to velocity and accelerates.

Today, chemical systems are the most often used means of propulsion, When a lot of thrust is needed, rockets are usually propelled by a liquid fuel, such as kerosene and liquid oxygen (oxidizer). The propellants are mixed as they enter the combustion chamber to be ignited. A spark or small flame is used to start the ignition process. From then on, continuing combustion ignites the fuel and oxidizer as they enter the combustion chamber. The drawback to liquid chemical systems is that they require expensive plumbing, turbines, pumps,and engines.

Solid Propellants and the Solid-propellant Engine

Solid Propellants

The chemical system may have a solid rather than a liquid propellant. The fuel and oxidizer of a solid propellant are mixed together from the start. The skyrocket is a good example of a solid propellant; all it takes is ignition of the mixture. The combustion chamber and the propellant container are one and the same. This means that the solid-propellant chemical system is simple, much less costly than the liquid type and is very reliable. Today, solid propellants are used for our submarine-launched ballistic missiles, the Minuteman intercontinental ballistic missiles, the first three stages of the MX missile and as boosters for the space shuttle system.

Fuels used in solid propellants include asphalts, waxes, oils, plastics, metals, rubbers and resins. The oxidizers for solid propellants come from two general sources: the organic (the source of nitrocellulose and nitroglycerin) and the inorganic (the source of chemicals such as sodium nitrate and potassium perchlorate).

Chemical and Physical Properties

A look at the contents of a typical double-base propellant tells much about the requirements of a solid propellant. Typical of today's solid propellants are composites in which the fuel and oxidizer are two different compounds. Usually the oxidizer is crystalline in form (like salt or sugar) and is embedded in the fuel base. Specific impulses of a double-base propellant and several composite propellants are as follows:

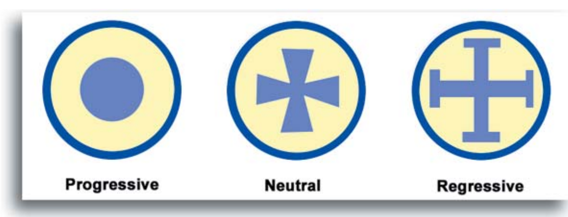
> In a solid rocket motor (motor usually is associated with solid propellant whereas engine is associated with liquid propellants), the propellant substance is molded into its motor and casing as a single solid mass called a grain. The shape and consistency of the grain determine its burning properties.

The polyurethane fuel base of the most common solid-fuel mixture is a type of synthetic rubber. It maintains about the same consistency as that of tire rubber. Various other rocket propellants have similar plastic consistencies. It is very important that this constancy be even and free from internal bubbles or surface cracks. Exposure of more burning surface than intended could result in the danger of uncontrolled burning or an explosion. The casing into which the gain is molded must be tough and heat resistant. A lining material is used as an insulator, and the case itself is made of various materials such as special steels, titanium and fiberglass.

Grain Design and Thrust Control

Once a solid propellant is ignited, it is going to burn. It can't be turned off and then restarted as is done with liquid-propellant systems. Some solid propellants can be stopped from burning by dousing them with water, but others cannot be stopped. So, how does one control the burning rate of a solid propellant? How can the amount of thrust produced be controlled? The primary way of doing this is to mold the propellant into a shape that will provide the desired burning rate.

The flame front (where actual oxidation is taking place) of a solid propellant always eats its way into the mass in a direction that is perpendicular to the surface The flame eats its way into a mass at a fixed rate depending on the contents of the propellant. For example, a typical double-base propellant's burning rate is about 0.40 inch per second; a dense polyurethane composite burns at about 0.22 inches per second. Since these rates do not change, the only way to control the amount of force (or thrust) generated is to control the surface area exposed to the burning process.



Grain Designs for Solid Propellants

The grain of a common skyrocket more than likely is a solidly packed propellant, with a space for ignition between the charge and the nozzle. Once ignited, this grain can burn only straightforward and the flame front is limited to the surface diameter. Thus, the burn rate (whatever it is) does not change until burnout. Since the burn rate doesn't change and the flame-front area doesn't change, the amount of thrust produced is constant. When this type of situation exists, the grain design is neutral.

What if a hole is bored the length of the grain, or charge, along its longitudinal axis? There will be an instantaneous spread of the flame-front along the entire surface of the hole. This, of course, provides a larger surface area of flame and greater force. As the grain continues to burn, more and more surface area is exposed so more and more thrust is produced. This is called a progressive burn rate.

Suppose a considerable amount of thrust is needed, but the designers want the thrust to be neutral. The design shown above might be used. Ignition produces a large amount of thrust very quickly, but the design keeps the surface area constant. Remember, the flame eats its way into the mass perpendicular to the surface.

The third design is one for a regressive rate. With this design, the most thrust is produced shortly after ignition, and it diminishes thereafter. A similar approach is used for the space shuttle's solid rocket boosters. The most thrust is produced upon ignition and during the first 55 seconds of the 2-minute burn. The grain of these boosters is shaped so that it then reduces thrust by approximately one-third until burnout.

There are other ways of controlling the amount of thrust or burn rate of a grain. The grain can be made up of different propellant mixtures that have different burn rates. Another method of control is to paint certain surfaces of the propellant with a heat resistant compound, leaving the other surfaces to burn at their regular rate.

Control of a solid rocket motor's thrust depends primarily on the design and composition of the grain, as indicated earlier. It is also possible to stop thrust in a solid propellant by injecting a high-pressure inert (or neutral) gas into the chamber. A grain stopped in this manner could be restarted. However, such arrangements have not proven worth the effort. So, once the grain is ignited, it continues to burn and produce the amount of thrust for which it was designed. Control of the direction of thrust is another matter. Thrust directional control for the solid-propellant rocket can be obtained from the same type devices used with liquid-propellant rockets.

Igniters

Solid propellants are ignited by a composition that both heats the grain to ignition temperature and increases the pressure in the combustion chamber until propellant reaction is assured. The heat produced by an electrical wire could ignite a few of the older solid-propellant mixtures. Today, this type ignition device is found in model-rocket launching devices, but the real rockets use devices like the squib. The squib consists of an enclosure filled with a combustible powder that is ignited electrically. The flame of the burning squib, in turn, ignites the grain.

Two igniter compositions frequently used are common gunpowder and a metal-oxidizer mixture such as magnesium and potassium perchlorate. Each of these has advantages over the other. Each also has certain disadvantages. Gunpowder is inexpensive, but it tends to absorb moisture, which can adversely affect its performance. Metal-oxidizer igniters are generally more efficient and ignition delays are shorter. However, they are more hazardous to handle than black-powder igniters. If magnesium is used in igniter composition, surface oxidation is likely to occur. Once oxidized, the igniter doesn't work very well.

A critical part of an igniter is the case that contains the composition. Manufacturers of igniters have a variety of materials to choose from, ranging from paper to metal. The strength of the container must be sufficient for demands made upon it. For example, rapid ignition requires the container to be strong enough to remain intact, until all the composition has ignited. However, the container must be designed so that no part of it is large enough to block the exhaust nozzle. Such blocking could cause extremely high pressures and damage the engine. The location of the igniter depends upon the design of the grain.

Liquid Propellants and the Liquid-propellant Engine

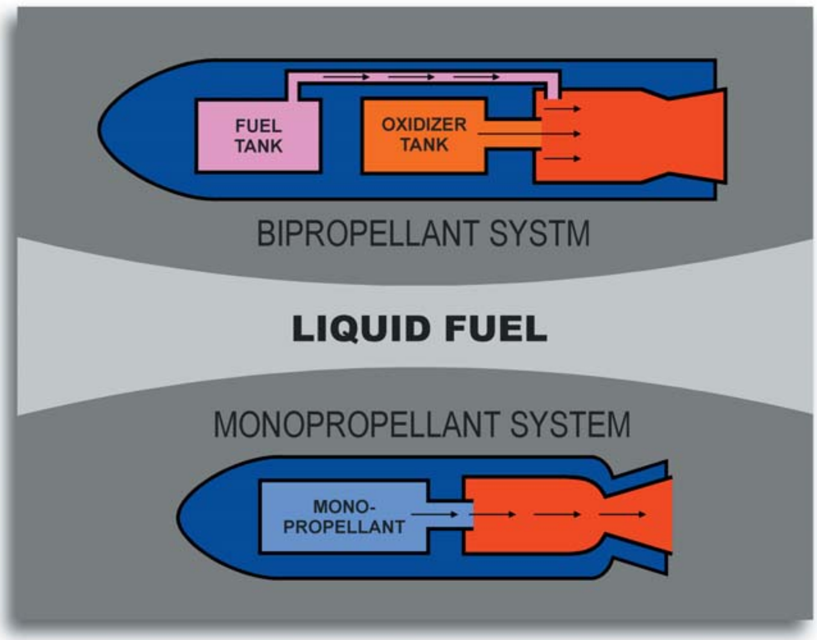
Liquid Propellants

You will remember that there are two general classifications of liquid propellants: bipropellant and monopropellant. When the oxidizers and fuels are separated, we refer to the two as a bipropellant. Any rocket that uses a bipropellant has a liquid-bipropellant propulsion system. However, it is not necessary for all liquid propellants to have their oxidizers and fuels kept separate. When a liquid propellant contains its oxidizer and fuel in one solution, it is called a monopropellant.

Bipropellants have an advantage over monopropellants in that they are more stable and capable of better performance. Bipropellants consist of two types: the nonhypergolic (nonself-igniting) and the hypergolic (self-igniting). Each of the two types of bipropellants has advantages and disadvantages. Malfunctioning of equipment and accidents involving a system using either type of bipropellant can be disastrous.

An ignition delay, even a brief one, results in a sufficient accumulation of nonhypergolic fuel and oxidizers in the combustion chamber to cause a damaging explosion. The components of a hypergolic propellant catch fire when brought into contact one with the other.

The design of a liquid-monopropellant system is much simpler than the design of a bipropellant system. A monopropellant system requires only half the storage, pumping and controlling equipment required by a bipropellant system. It doesn't require metering to keep the fuel and oxidizer in correct proportion.



Comparison of Bipropellant and Monopropellant Propulsion Systems

The drawback of a monopropellant is its sensitivity to temperature and shock. This sensitivity results in instability and restricts its handling. Generally, monopropellants also require more heat for ignition and react more slowly than bipropellants. These factors mean that monopropellants require larger combustion chambers.

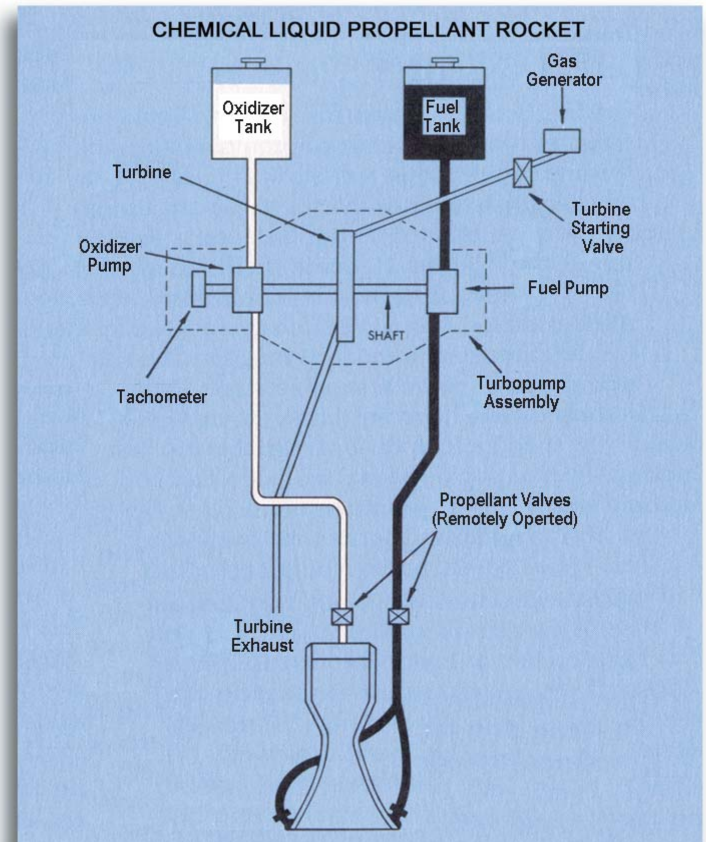
Just as there are two general types of bipropellants, there are two general types of monopropellants: those that obtain energy by combustion and those that obtain energy by dissociation reaction (decomposition). A catalyst initiates the dissociation reaction.

To ignite a liquid propellant, it is necessary to raise the temperature of a small part of the mixture to its ignition point. The flame will then spread throughout the total mixture. Mixtures that contain liquid oxygen have a high reaction rate, so these mixtures are easy to ignite. For example, an ordinary spark plug can be used to ignite a flow of oxygen and alcohol.

One method of igniting a liquid-propellant mixture is to inject a limited amount of hypergolic fuel into the combustion chamber along with the oxidizer just before the main fuel flow starts. Another method uses a pyrotechnic fired electrically from an external circuit. If repeated ignitions are required during flight, a small precombustion chamber makes the ignition of a small amount of the propellant possible by means of a spark plug. The flow into the main chamber is delayed until the propellant in the precombustion chamber is ignited. The flame from the precombustion chamber is then used to ignite the mixture in the main chamber.

The Liquid-propellant Engine

The essential units of a liquid-propellant system include propellant tanks, a combustion chamber and a means of forcing propellants from the tanks through control valves to the combustion chamber. The simplest liquid-propellant engine system transfers oxidizer and fuel from tanks to the combustion chamber by pressurizing the tanks with an inert gas such as nitrogen. More complex systems employ turbopumps to transfer propellants to the combustion chamber.



Major Components of a Liquid-bipropellant Propulsion System

The nature of the propellant determines, to a great degree, the structural design of the engine or propulsion system. Quite often, the use that will be made of the liquid-propellant engine determines both the nature of the engine's design and the type of its liquid propellant.

There are many kinds of liquid fuels and a number of liquid oxidizers that are available for use in liquid propellants. It is possible for a single oxidizer to react with many different fuels. Also, a single fuel can react with a number of different oxidizers; for example, kerosene (a fuel) reacts with liquid oxygen, hydrogen peroxide or nitric acid. For this reason, many combinations of fuels and oxidizers are possible.

The basis for choosing a certain fuel-oxidizer combination might include economy, safety, ease of handling, and purpose. However, the fundamental factor underlying the choice of a propellant combination is generally the performance of such a combination.

Combustion Chamber

The combustion chamber is the "heart" of the liquid-propellant engine. Within this chamber, several phases of the combustion process take place. These phases include: (1) atomizing, (2) mixing, (3) preheating to ignition temperature and (4) the reaction of the propellant.

A combustion chamber may be cooled or uncooled. Combustion temperatures of propellants used in uncooled combustion chambers frequently are under 1,000° C. When it is desired to construct uncooled combustion chambers that will withstand relatively high temperatures over a comparatively long period of time, they are given an interior ceramic or carbon coating.

There are several methods of cooling a combustion chamber, but the most commonly used method is by regenerative cooling. In this method, fuel or oxidizer is circulated within small passageways between the inner and outer walls of the combustion chamber, throat and nozzle. As the propellant flows through the passageways, it absorbs heat, thereby cooling the combustion chamber. The absorbed heat also adds energy to the fuel or oxidizer before it enters the injector and increases the velocity of injection into the combustion chamber.

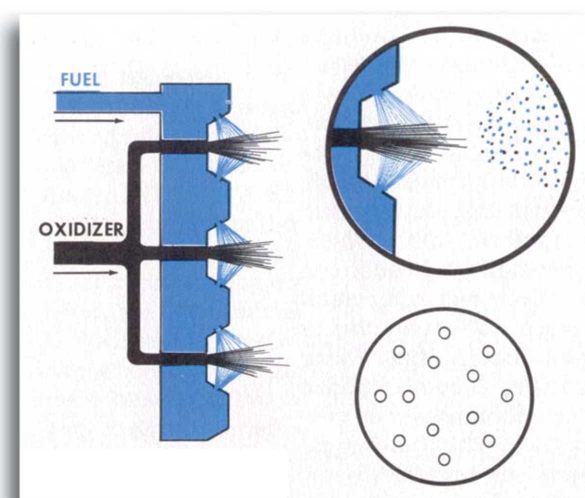
Valves

A propellant system's tanks and plumbing must be constructed of materials that are not adversely affected by the nature of the fuel and oxidizer the system uses. The nature of the fluids a system uses also determines the kinds of materials used to make valves. The scope of both the operating temperatures and operating conditions to which they are subject makes it necessary to use high-precision techniques in valve manufacturing.

Valves used in propellant systems range in type and size according to their specific functions. Comparatively large valves, for example, are used to control the high flow of fuel and oxidizer. A coupled valve, consisting of two propellant valves opened by a single piston, operates through a crosshead, causing fuel and oxidizer to enter the combustion chamber at the same time.

Injector

The function of the injector of a liquid-propellant rocket engine is similar to that of the carburetor used with some automobile engines. Just as a carburetor atomizes (reduces to small particles) and mixes fuel and air, preparing the mixture for combustion, the injector atomizes and mixes fuel and oxidizer.



Operating Principle of the Impinging-jet-type Injector

The type of injector used depends upon the type of propellant. Lightness, simplicity and low cost are factors that need to be considered by manufacturers of rocket-engine injectors. However, just as is the case with valves and other rocket-engine components, precision and exactness of construction of the injector are very important.

Two types of injectors are in common use. The difference between them is the difference between the methods each uses to mix fuel and oxidizer. In the swirl-jet type, each propellant is introduced into the chamber in an inverted-cone-shaped spray, finely atomized and sufficiently diffused for adequate mixing with the adjacent spray. In the impinging-jet type, the fuel and oxidizer enter the combustion chamber directly through openings arranged in such a way that the streams of fuel and oxidizer strike each other (impinge on one another). Their collision causes the required atomization and mixing.

Improved injection systems have contributed to the development of throttleable (variable control) liquid-propellant engines. One such system mixes, in a specially designed manifold, gas under high pressure with liquid fuel before it is injected into the combustion chamber. Depending on the ratio of gas to liquid fuel, the engine may be throttled from a low to a full thrust, and may be stopped and started in flight.

Hybrid Propellants

Hybrid propellant systems use both liquid propellants and solid propellants in combination within the same engine. Thus, rockets that use this type propellant system are called hybrid rockets. Usually, solid material is used as the fuel, and a liquid is used as the oxidizer. However, there are systems that use liquid fuels and solid oxidizers. When solid fuel is used, it is packed into the rocket engine as an inert material without its oxidizer. The liquid oxidizer is stored in a separate tank. To create combustion and generate thrust, the oxidizer is fed into the solid-fuel combustion chamber at a desired rate. In one such system, the solid fuel and the oxidizer do not come into actual contact. Instead, the heat of ignition vaporizes the oxidizer and the fuel. These gases, approaching each other from opposite directions, unite and burn just above the face of the fuel grain. The thrust produced by the hybrid rocket can thereby be increased or decreased simply by increasing or decreasing the flow of oxidizer over the fuel charge. Thrust is stopped when the flow of oxidizer is closed off.

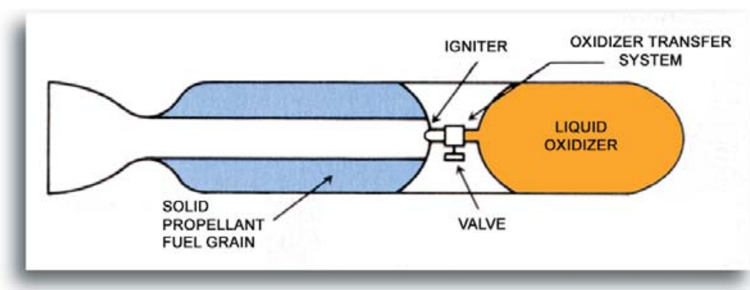


Diagram of a Hybrid Propellant System

The hybrid propellant system combines, in a single rocket, many of the advantages of both liquid-propellant rockets and solid-propellant rockets. It has the flexibility, controllability and high performance of liquid rockets, plus the simplicity, reliability and relative economy of solid rockets. Flexibility probably gives the hybrid rocket its biggest operational advantage. It can be throttled, like a liquid rocket, from zero to full thrust, and it can be stopped and started in flight.

The diagram above is a very simple diagram of how the parts of a hybrid propellant system might be arranged. In the system illustrated, the valve controls how much oxidizer is allowed to come in contact with the fuel. This amount, or rate of oxidizer to fuel, determines how much thrust the system produces. In this particular design, the grain has been molded for a progressive burn rate. To maintain a steady thrust could require less and less oxidizer as the process continues.

Key Terms and Concepts

- Oxidation
- reducer
- oxidizer
- cryogenics
- propellant
- bipropellant
- monopropellant
- self-reacting compound
- combustion
- ignition characteristics
- low explosive
- solid propellants
- liquid propellants
- compounds
- crystalline
- progressive burn rate
- regressive burn rate
- igniters
- grain
- nonhypergolic
- hypergolic
- catalyst
- combustion chamber
- atomizing
- coupled valve
- swirl-jet type
- impinging-jet type
- hybrid propellant
- hybrid rockets

? Test Your Knowledge ?

SELECT THE CORRECT ANSWER

1. *To use it in its pure form as an* **(oxidizer / reducer**), *oxygen must be* **(chilled / heated)** *until it becomes a* **(liquid / gas)**.
2. *A* **(neutral, progressive, regressive)** *burn rate design is used in the space shuttle' solid rocket boosters to provide the majority of thrust in the first few seconds of launch.*
3. *Generally,* **(mono- / bi-)** *propellants require more heat for ignition and react more slowly than* **(mono- / bi-)** *propellants.*
4. *The majority of liquid-propellant rockets use the* **(mono- / bi-)** *propellant arrangement.*
5. **(Motor / engine)** *is usually associated with (***liquid / solid***) propellants.*
6. *Solid propellants are sometimes called* **(low / slow)** *explosives.*

FILL IN THE BLANKS

7. *Rust and corrosion, a burning fire and a violent explosion are all examples of ______________, the combination of _____________ with ________________.*
8. *The propellant substance is molded into its motor and casing as a single solid mass called _______________.*
9. *______________ is the science concerned with the production of low temperatures and the effects of those temperatures on matter.*
10. *Bi-propellants are two types—________________(non-self-igniting) and ________________ (self-igniting).*
11. *A ________ ______, consisting of two propellants __________ opened by a single piston, operates through a ____________, causing both fuel and oxidizer to enter the _____________________ _______________ at the same time.*
12. *Which is not a solid propellant rocket mentioned in the text?*
    - *a. Submarine launched ballistic missile*
    - *b. Minuteman intercontinental ballistic missile*
    - *c. The main rockets for the space shuttle*
    - *d. The first three stages of the MX missile*
13. *Which is not a drawback to liquid chemical systems?*
    - *a. Their requirement for expensive plumbing,*
    - *b. Expensive turbines,*
    - *c. Expensive pumps and engines*
    - *d. Costly igniters*

MATCHING

14. **Match the terms with their correct definitions:**

a.	*Propellant*	*(1)*	*Separate storage tanks are not required*
b.	*Bipropellant*	*(2)*	*Molecules contain atoms of both oxidizer and reducer*
c.	*Monopropellant*	*(3)*	*Requires separate storage tanks for oxidizer and reducer*
d.	*Self-reacting compound*	*(4)*	*A single reference to the oxidizer and reducer*

TRUE OR FALSE

15. *Nothing is gained or lost in an oxidation.*
16. *Solid propellants are more costly and less reliable than liquid propellants.*
17. *Controlling the force of a solid propellant is more difficult.*
18. *The phases in proper order in a combustion chamber are atomizing, preheating, mixing and the reaction of the propellant.*
19. *It is possible to stop thrust in a solid propellant rocket.*

SHORT ANSWER

20. *What are the four qualities of a good propellant?*
21. *How can the amount of thrust produced by a solid propellant engine be controlled?*
22. *Describe a squib. What type of propellant is it used with?*