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Ordnance Technology

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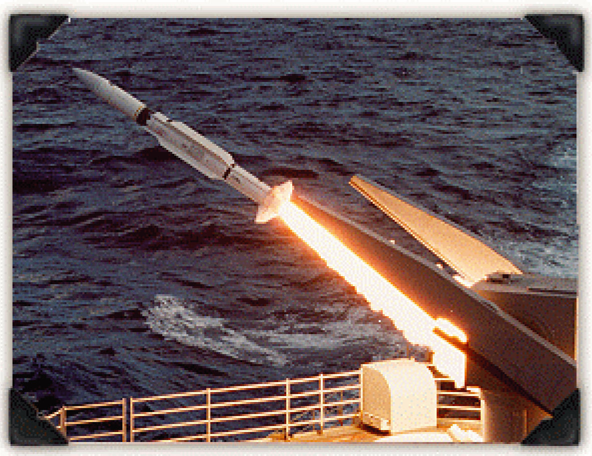


PROPELLANT COMPONENTS

The major ingredients of modern military propellants are actually few. They consist of fuels, oxidizers and binders (polymers), and are fairly basic in their chemical nature and structure. The minor ingredients, used to assist or tie together the major ingredients, are more numerous and sometimes more complex.

The interactions of these major and minor ingredients, when combined into a practical solid propellant, are especially complex. These interactions can take place at all stages of manufacture, storage, and use.

Controlling such interactions makes solid-propellant technology difficult, expensive and, therefore, important to understand. The ingredients themselves represent output of the conventional chemical and explosive industries (although a few, like nitroglycerin, are produced locally); however, the combination of these ingredients into a propellant is still thought of by some as a "black art." Making it into a science is what has justified the expenditure of so many millions of dollars over the past 50 years.

We will review briefly the development of modern propellants, touch on the basic ingredients that are used in the manufacture of propellants, and then describe the various types of propellants and their comparative properties.

BACKGROUND OF PROPELLANT DEVELOPMENT

The history of truly efficient military propellants is a fairly short one in this country, dating from 1900 for guns and from 1942 for rockets. However, the chemistry of propellant ingredients, has a long history.

For example, the use of black powder dates back more than 700 years in Europe and probably 1000 years in the Orient. These facts emphasize the point that mastering the really difficult science of propellants comes in understanding the complex interactions that take place in their preparation, storage and use.

Progress toward developing truly efficient propellants was necessarily slow until these interactions were defined and controlled; the problem is a continuing one as new ingredients are developed and introduced into improved propellants.

Solid rocket propellants have considerably greater complexity than most gun propellants and all liquid propellants. This is so because solid rockets are mechanically much simpler in principle than either guns or liquid-fueled rockets. Therefore, a solid rocket propellant must perform by chemical means many of the jobs that are performed by the hardware in guns and liquid rockets.

The success of military solid rockets since 1943 attests to the competence of the interdisciplinary teams assigned to their development, more than to any supposed greater simplicity of the task. Certain other components of missile systems, such as guidance and control, are at a lower stage of maturity only partly because of their great technical difficulty.

Because weapons propulsion is viewed by top DOD officials as a very mature technology, less money each year is available for its improvement. This is regrettable because a long cycle is still required to bring a new propellant or propulsion concept from the idea phase to full production.

Even such a simple device as the 2.75-inch folding-fin aircraft rocket required a five-year cycle of development (1949 to 1954) largely because of propellant problems. Six to eight years is a more realistic time scale for modern rocket propulsion systems, although with plenty of money, technical talent, and highest priority, complete weapon systems, have been developed in a somewhat shorter time. Such a wealth of resources cannot be made available, obviously, for every military development. Thus, plans must be made for an extended cycle of development for any new weapon propulsion system and already established technology must be used as much as possible. The environmental performance requirements for a new weapon system must be defined and limited as much as possible before embarking on the program.

PROPELLANT TYPES

Nitrocellulose deserves special attention because it has served as the major ingredient of military propellants since about 1900 in the U.S. and a few years longer in Europe.

Experiments leading to the development of nitrocellulose began in Europe prior to 1840, but the German, Schoenbein, gets the most credit for developing a reasonably practical process by about 1845. The Englishman, **Frederic Abel**, a Frenchman named **Vieille**, and Sweden's Alfred Nobel are credited with later discoveries which made the use of nitrocellulose fully practical by about 1890. This half century span of research and development from 1840 to 1890 is indicative of the many problems encountered. Indian Head's own Dr. George W. Patterson, was largely responsible in the U.S. for developing fully practical, colloided or gelatinized nitrocellulose propellants for guns, basing his work primarily on the discoveries of Vieille with ether and alcohol solvents.

Practical gun propellants, based on uniform mixture of nitrocellulose and nitroglycerin (double-base), a actually older than Vieille's and Patterson's single-base powders. **Alfred Nobel** deserves much of the credit for such double-base propellants because of his amazing discovery that these two notoriously treacherous materials could be combined even without solvents into a safe substance, which he called Ballistite. The Nobel process of combining them was neither obvious nor very safe for many years; but once intimately combined into a thoroughly colloided or gelatinized mass, nitrocellulose and nitroglycerin became a remarkably tractable, homogeneous material. By far the greatest part of Indian Head's present production of propellants is based on this invention of Alfred Nobel, with additional newer ones.

LIQUID PROPELLANTS

Although of lesser recent interest militarily compared to solid propellants, liquid propellants were chosen over solids by the U.S. rocket pioneer, **Robert Goddard**, in his experiments between the two World Wars. Dr. Goddard's explanation was that no suitable solid propellants were available. Currently, solid propellants predominate over liquids in military weapons because of their greater storability and volumetric efficiency. Solid propellants also offer lower life cycle costs and system simplicity. Conversely, liquid propellants, principally oxygen and kerosene-like fuels, have tended to dominate the space propulsion scene until recently. For military applications liquid oxygen is considered unacceptable. Red fuming nitric acid or nitrogen tetroxide tends to be the oxidizer of choice where a military rocket can benefit from a liquid propellant design. Fuels are mixed organic amines or hydrazine and its various alkyl derivatives, such as monomethyl and dimethyl hydrazine (UDMH). Hybrid systems, generally based on nitric acid oxidizer and a low oxidizer-content, rubber-fuel grain, are of some interest, but have not yet reached full operational status.

DOUBLE-BASE PROPELLANTS

Although **Ballistite** for guns can (and in Italy for some years did) consist of nothing more than a 50:50 intimate (colloided) mixture of carefully purified nitrocellulose and nitroglycerin, such a combination is not adequately stable for military use and would not perform well in rockets for numerous reasons. Nevertheless, the U.S. rocket propellant in World War II, "JPN" (Jet Propulsion/Navy), did consist mainly of nitrocellulose (51 percent) and nitroglycerin (43 percent) and it was based on long-used gun propellants. A fuel-type plasticizer, a new stabilizer, a wax, a blackening agent, and a potassium salt were used in minor proportions to improve processing, storability, and combustion properties respectively, but all the energy, or specific impulse (Isp), was derived from the nitrocellulose and nitroglycerin. In other words, all the necessary minor ingredients detracted from the basic ballistic performance or Isp. The JPN Ballistite served the U.S. for almost all military rocket needs during World War II in spite of its far-from-ideal internal ballistic properties.

Double-base propellants generally require careful application of low flammability inhibitors if one desires to protect the internal motor walls from flame. Such materials represent an important field of study because satisfactory inhibitor materials must absorb a minimum of nitroglycerin, must be fully compatible with the propellant, and must not impose a severe increase in system cost. Ethyl cellulose and cellulose acetate are typical inhibitor materials for free-standing cartridge grains. Satisfactory case bonding liner-inhibitors generally involve a rubber substrate, impervious to nitroglycerin, and an intermediate film with excellent adhesive properties to propellant and liner.

Other components of a rocket motor include the case and nozzle, fins, the igniter, mechanical devices to stabilize burning, and rubber seals to prevent leakage of gas or flow of hot gases between inhibitor and motor.

COMPOSITE PROPELLANTS

A feature of ammonium perchlorate, rubber-based, composite propellants is a natural tendency toward low pressure. True plateau burning is seldom achieved in high performance composite systems, but slopes ("n") of 0.3 or 0.4 are very common and are adequate to ensure operability over a wide range of temperatures.

A twenty-year, multimillion-dollar effort on binders for ammonium perchlorate oxidizer, aluminum fuel, and energetic gas producers, such as nitroguanidine and HMX, has produced an array of composite propellants that provide the base for most of our present-day guided missiles. By now, most composite-filled missiles use a polybutadiene "backbone" as the propellant binder. However, polyglycol-based polyurethanes, polyvinyl chloride, polysulfide, and even nitrocellulose binders are still in the inventories.

Because of the need for maximum volumetric propulsive efficiency and motor performance index (defined as total impulse divided by total weight of the propulsion system) in modern guided missiles, so as to minimize volume, it is customary for composite propellants to be bonded to the inside wall of the rocket chamber. Such a practice is not common with most double-base propellants for a variety of reasons, including cost. In a guided missile, propulsion cost is generally a small fraction of total system cost, especially in proportion to its relatively high weight and volume, so that the added expense of case bonding the propellant by means of an intermediate rubbery liner is almost always justified to obtain maximum volumetric efficiency. It is this normally accepted requirement for case bonding that has justified such an enormous effort in developing binders and liners for composite propellants. It is indeed a major accomplishment for a modern composite propellant, which consists of 85 to 90 percent granular solids (typically ammonium perchlorate, aluminum and burning rate modifiers) and only 10 to 15 percent rubbery binder, to perform properly from -65 degrees to +165 degrees F, after being subjected to the rigors of vibration and temperature cycling. The propellant is under stress at all times yet must not develop cracks, large voids, or unbonded regions at any location, at any time in its useful life. This single requirement for perfect structural integrity forms the principal basis for much of the difficult effort in developing composite propellants. Such stringent requirements for explosives do not exist, and requirements for cartridge-loaded propellant grains place a less severe demand on mechanical properties.

Complex minor ingredients for composite propellants include the following:

Crosslinking chemicals, which have been assigned various trivial names and acronyms, such as epoxies, MAPO (a trifunctional aziridinyl phosphine oxide), MT-4, various isocyanates, such as TDI, HDI, IPDI, and polyols such as trimethylol propane
Burning rate catalysts, such as copper chromite (or chromate), ferrocene, and several less migratory derivatives of this organic iron compound
A variety of processing aids to improve the wetting and adhesion between binders and fillers (AP, HMX, and aluminum)
Anticaking agents for the AP such as tricalcium phosphate.
As mentioned previously, the potential interaction of all these ingredients in the propellants must be determined, fully understood, and rechecked for each new source, if not for each new lot of each material. When the number of ingredients exceeds 15, the potential for variable interaction of these ingredients is truly staggering and has indeed caused continual problems in manufacture, storage, and use of the propellant.

PROPELLANT TYPES AND PROPERTIES

Solid propellants are made up of three basic ingredients:

- oxidizer,
- fuel, and
- binder.

Two, or even three, of these may be contained in the same material. Nitrocellulose is an example of all three, when colloided. A convenient way to divide solid propellants into classes is according to physical state; i.e., homogeneous (single-base or double-base) and composite. Double-base propellants are further subdivided according to manufacturing method extruded or cast.

Homogeneous Propellants

Homogeneous propellants are those propellants using nitrocellulose as the basic ingredient in order to give them the structural characteristics of a plastic.
This is because nitrocellulose, when properly compounded, forms a colloid which can be processed into many shapes.
Whether the compositions contain only nitrocellulose or have nitroglycerin as a second combustible ingredient determines whether these propellants are single- or double-base.

Single-Base Propellants

Single-base propellants contain nitrocellulose as the main ingredient with diphenylamine, or similar compound, as a stabilizer and with other additives depending on the application.
These are used primarily in gun applications and cartridge-actuated devices.

Double-Base Propellants

Double-base propellants have two principal ingredients-nitrocellulose and nitroglycerin-and certain additives such as the following:
Plasticizers
phthalates - triacetin
Stabilizers
2-nitrodiphenylamine - tertiary butylcatechol
ethyl centralite - N-methyl - p-nitroanaline
Burning-rate modifiers
lead salts - copper salts
Extrusion lubricants
stearates - soaps - waxes
Flash suppressors
potassium salts.
Recently, additional oxidizers have been added, such as ammonium perchlorate and HMX, which make a modified type of double-base propellant, terme. composite-modified double-base.
Aluminum is also becoming more commonly included to increase energy and tn stabilize combustion.

Extruded Double-Base Propellants (EDB).

Briefly, propellant ingredients are mixed under water to homogenize the material and then rolled on a rubber mill to form a carpet roll sheet. This is warmed and extruded under vacuum in a ram press through an appropriate die. The propellant grain is then cut to length and machined to the proper outside (and sometimes inside) diameter.

The advantages of extruded double-base propellants are that they are inexpensive, reliable, easily ignited and inspected, and all ingredients are readily available. This type of propellant also enables fine control over the burning rate versus pressure function and some control over temperature sensitivity of burning rate. The disadvantages of extruded double-base propellants are that they have limited shapes and sizes (up to 12 inches in diameter) and a specific impulse limit of 240 seconds; they require inhibitors and cartridge loading; and they require auxiliary motor parts to support the grain so as to prevent gas flow in the grain motor annulus.

Cast Double-Base Propellants (CDB).

This type of propellant was developed to eliminate the size and shape limitations of extruded propellants. The mold, or chamber, is filled with casting powder (single- base or double-base powder) and then the chamber is "cast," i.e., filled with nitroglycerin casting solvent (nitroglycerin, plasticizer, and stabilizer). The advantages that applied to the extruded double-base propellants also apply to the cast double-base propellants. However, the cast double-base propellants have no size or shape limitation and the heat effects during curing are small since no chemical reactions are involved in solution effects. Excluding the size and shape limitations, the disadvantages of the cast double-base propellants are the same as those for the extruded double-base propellants. Some success has been achieved recently with case-bonding of softer CDB compositions.

Nonhomogeneous (Composite) Propellants

Composite propellants consist of suspensions of crystalline oxidizers and metallic fuels in a resinous binder. Ammonium perchlorate is commonly used as an oxidizer (up to 80 percent) and polyurethane, polybutadiene, polysulfide, polyvinyl chloride, and polyesters are used as binders, depending on the application. Plasticizers, curing agents, stabilizers, burning-rate additives, catalysts, and other additives, are also components of the formulation.

Composite propellants offer the following advantages:

- cost of processing in large motors is relatively low;
- higher energy oxidizers give higher specific impulse;
- cartridge loading or case-bonded systems are possible;
- and burning rates are unaffected by high accelerations.

On the other hand they offer the following problems: mechanical properties are very different from double-base formulations but allow case bonding; energy is limited by solids loading limitations; moisture usually must be excluded during processing and storing; casting is complicated by gassing and high viscosity; they are smoky in humid atmospheres; and their exhaust is corrosive and, hence, somewhat more toxic than that of double-base.

GUN PROPULSION

Guns have been in active service by military forces throughout the centuries. However, it has only been in recent years that any significant new developments have been obtained. This has been mainly through efforts of the German experiments during World War II and Army and Navy developments since World War II. New developments and applications of guns have dictated the need for an increased understanding of the mechanism of the firing cycle. Indian Head has played an increasing role in the expanding field of gun technology, particularly in the area of ammunition development.

Guns are generally classified according to use, size, and tradition. This varies among the military services. The basic distinction is between small arms and artillery. Any gun below a 20-millimeter bore size is generally classified as a small arm.

The Army distinguishes among mortars, howitzers, and guns. Mortars give high trajectories with short range and are usually loaded from the muzzle. Howitzers give medium-to-high trajectories, and guns provide flat-to-medium trajectories of longer range. Bore size is usually given in millimeters.

Naval artillery is divided among small (20 millimeters to 3 inches), medium (3 to 6 inches), and major (above 6 inches) calibers. With medium caliber guns and larger, the length of the barrel is also specified in caliber lengths; for example, a 3-inch, 50-caliber gun. The "3" signifies the bore size in inches, and the "50" signifies that the barrel (breech to muzzle) is 50 x 3 = 150 inches long.

DESCRIPTION OF OPERATION

A gun can be considered as a particular kind of heat engine. In operation, the propellant charge located in the gun chamber is ignited by the primer. Gases produced by combustion of the propellant grains cause a rapid buildup of pressure. When a certain pressure is reached (shot-start pressure) which overcomes the forces of projectile weight and engraving of the projectile in the rifling, the projectile begins to move toward the muzzle which causes an increase in chamber volume. A maximum pressure is reached a few inches from the origin of rifling followed by a decrease in pressure all the way to the muzzle. At the muzzle, the pressure is 10 percent to 30 percent of the maximum pressure, depending on the geometry of the propellant grains.

The energy utilized to accelerate the projectile and the gun in the form of recoil. Proper balancing of the energies involved yields a recoil system of sufficient propellant gases toward the muzzle is counteracted by capacity to hold the gun on its mount.

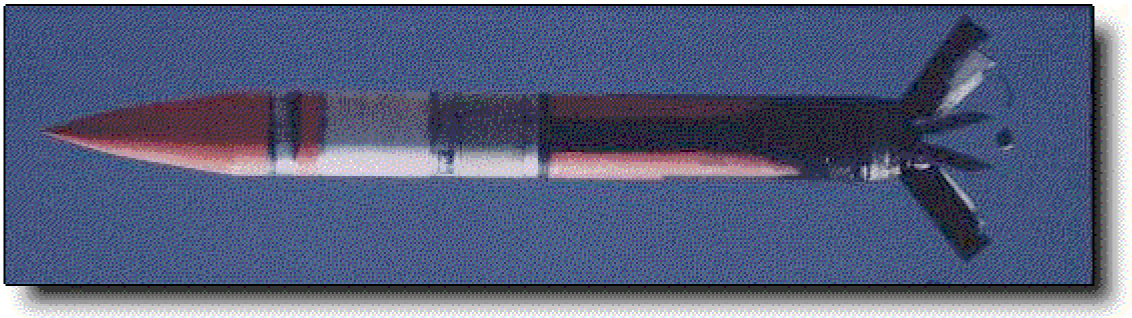
PROJECTILES

Projectiles can be broadly classified according to three main types: spin-stabilized, fin-stabilized, and rocket assisted (both fin- and spin-stabilized). Formal military classification is based on the intended use of the projectile and the composition of the explosive charge (i.e., antipersonnel, antitank, and incendiary). Some very significant progress in projectile design has been made in the past few years.

SPIN-STABILIZED PROJECTILES

Most guns in use today and all Navy guns use spin-stabilized projectiles. Spinning a projectile promotes flight stability. Spinning is obtained by firing the projectiles through a rifled tube. The projectile engages the rifling by means of a rotating band normally made of copper. The rotating band is engaged by the lands and grooves. At a nominal muzzle velocity of 2800 feet per second, spin rates on the order of 250 revolutions per second are encountered.

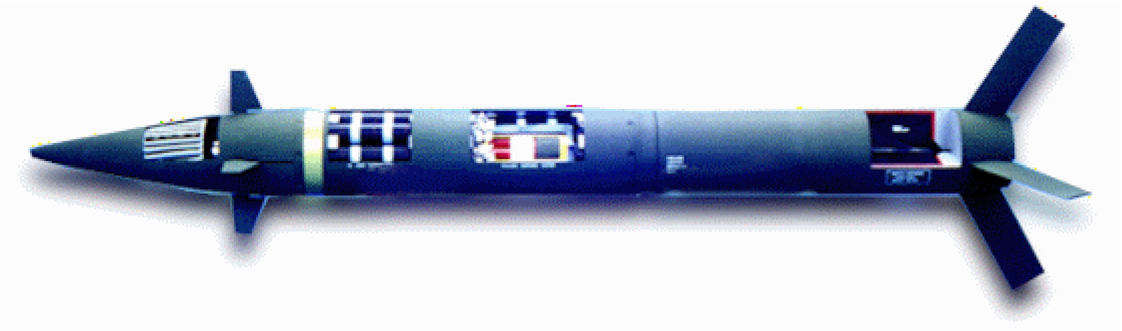
Spin-stabilized projectiles are full bore (flush with the bore walls) and are limited approximately to a 5:1 length-to-diameter ratio. They perform very well at relatively low trajectories (less than 45° quadrant elevation). In high trajectory applications they tend to overstabilize (maintain the angle at which they were fired) and, therefore, do not follow the trajectory satisfactorily.



FIN-STABILIZED PROJECTILES

These projectiles obtain stability through the use of fins located at the aft end of the projectile. Normally, four to six fins are employed. Additional stability is obtained by imparting some spin (approximately 20 revolutions/second) to the projectile by canting the leading edge of the fins. Fin-stabilized projectiles are very often subcaliber. A sabot, wood or metal fitted around the projectile, is used to center the projectile in the bore and provide a gas seal. Such projectiles vary from 10:1 to 15:1 in length-to-diameter ratio.

Fin-stabilized projectiles are advantageous because they follow the trajectory very well at high-launch angles, and they can be designed with very low drag thereby increasing range and/or terminal velocity. However, fin-stabilized projectiles are disadvantageous because the extra length of the projectile must be accommodated and the payload volume is comparatively low in relation to the projectile length.



ROCKET-ASSISTED PROJECTILES

There are two main reasons for developing rocket-assisted projectiles: (1) to extend the range over standard gun systems, and (2) to allow for lighter mount and barrel design and reduce excessive muzzle flash and smoke by reducing the recoil and setback forces of standard gun systems.

Since the ranges are different, the above two objectives represent opposite approaches in the development of rocket-assisted projectiles. Normally, one or the other establishes the performance of the rocket-assisted projectile under development although some compromise in the two approaches may be established by the design objectives.

CARTRIDGE-ACTUATED DEVICES

Cartridges and cartridge-actuated devices (CADs) are small, self-contained energy sources that are used to do mechanical work. The energy is generated by the burning of a propellant or pyrotechnic material and is used often to push a piston or initiate an explosive train.

This differentiates cartridges from similar devices, such as rocket igniters, where heat energy, not mechanical work, is the desired output. Cartridge-actuated devices are simply devices that utilize cartridges as mechanical power sources. Although guns and explosive destruct devices might meet this definition, they are not generally regarded as cartridges or cartridge-actuated devices.

CAD's are used throughout the military services and in private industry. Non-aircraft CAD applications have included emergency systems for deep diving submersibles and submarines, propulsion units for mine field markers, release mechanisms for allowing separation of missile stages, timing systems for hand grenade fuzes, inflation systems for marking locations of buoys, and "soft" recovery systems for reentry space vehicles. In the private sector many of the proposed air bag approaches to passive driver restraint systems are CAD's because of the quick response required and space/weight restrictions. The emergency aerial flare kit carried by many larger pleasure boats is, in fact, a cartridge actuated device.

The two principal types of cartridges are those that respond instantaneously to the initiation stimulus and those that provide a delayed response. "Instantaneous" cartridges (delay of less than 50 milliseconds) are referred to as impulse cartridges. Impulse cartridges are used primarily in stores release applications; i.e., pushing a bomb or missile away from an aircraft.

Several attributes of cartridges and associated devices (CAD's) have led to the proliferation of applications in recent years. First, as previously mentioned, cartridges are physically small, lightweight sources of energy. Theoretical energy densities of cartridges approach that of the propellants used in the cartridge (ranging to almost 400,000 foot-pounds of energy per pound of propellant). Cartridges and cartridge-actuated devices require no maintenance once installed, are in relation to the value of their mission, inexpensive and, perhaps most important, exhibit a high degree of reliability. Furthermore, they are very versatile, allowing initiation by many sources, among which are the following:

*Initiation Energy	*Initiating Mechanism

*	*
*Mechanical	*Firing pin
*Ballistic hot gas	*Pneumatic hose
*Electrical (high and low voltage)	*Electrical cable
*Explosive	*Explosive cord
*Laser	*Fiber optics

PROPELLANT-ACTUATED SYSTEMS

Propellant-actuated systems include such devices as catapults, rocket catapults, and rocket motors which are used in military aircrew escape systems. These devices, in conjunction with various cartridge-actuated devices and other life-support equipment, provide the capability to eject aircrew men safely from disabled aircraft. All catapults, rocket catapults, and rocket motors currently in use are solid-propellant devices. The design and function of these devices vary widely in complexity; however, the purpose of each is to enhance the safe-ejection envelope.

Ejection envelope is a concept that involves the configuration, velocity, altitude and orientation of an aircraft upon initiation of the ejection sequence. A safe-ejection envelope includes the various combinations of these factors under which aircrew men can safely eject. High tail surfaces, exceptionally high speeds, and the advent of multi seat aircraft are developments which have generated the need for propellant-actuated systems to perform a variety of functions during the ejection sequence.

Military requirements govern such factors as aircraft configuration and velocity. Therefore, the escape-system, including its propellant-actuated systems, must be designed in response to increased aircraft performance capabilities in order to continuously provide the military aircrew man with an optimum means of emergency egress under all conditions of operation.

ROCKETS AND MISSILE SYSTEMS

SURFACE WEAPON SYSTEMS

The Navy's surface missile fleet is equipped with Standard Missile systems air attack. They can be used against one or a group of attacking aircraft or missiles.

Surface-launched missiles are carried by the following types of ships: cruisers, destroyers, destroyer escorts, aircraft carriers, patrol gunboats, and ammunition ships.

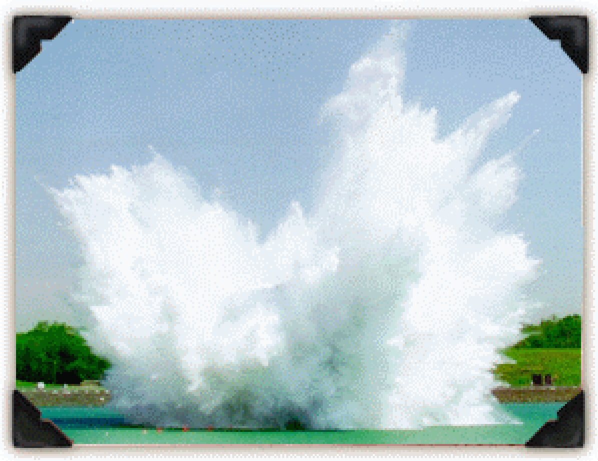
JATO

The JATO (jet assisted takeoff) is a rocket motor used for launching target drones, for providing auxiliary thrust for heavily loaded aircraft, and for providing the means of propulsion for test vehicles and sleds.

The Mk 23 is a cast-composite propellant. It is used to launch target drones/threat simulators and to propel test sleds. The Mk 23 is the bigger JATO with a 24,200 lb-sec impulse. This rocket motor is placed on the underside of the target drone or test sled and fired at the nominal temperature (70° F) for 2.2 seconds with I 1,000 pounds of thrust. The Mk 23 is also used Tri-service.

The Mk 23 is attached to the underside of a surface aircraft and burns for 5 seconds at 4,500 pounds of thrust equalling 22,500 lb-sec impulse. Two or more of these rockets can be attached to the aircraft.

The JATO rocket motors separate from the target drones or aircraft after firing. The igniter for these rocket motors are separate and must be installed in the rocket motor prior to firing, with the exception of the Mk 34, which have the igniter built into the rocket.



UNDERWATER WEAPONS SYSTEMS

ASROC

The ASROC missile is a dual-purpose, solid-fuel, rocket-propelled weapon that is launched from surface ships to destroy high-performance submarines. The missile is available in rocket-thrown torpedo and rocket-thrown depth charge configurations. Each of these configurations consists of the payload connected to the rocket motor by an airframe.

Otto Fuel II

Otto Fuel II is the propellant for the torpedo Mk 46 Mod I and Mk 48 Mod 1. Otto Fuel II, named after its developer, the late Dr. Otto Reitlinger, is nonexplosive, shock-insensitive, liquid monopropellant designed for torpedo application. In most liquid monopropellants, the combination of fuel and oxidizer produces a potential explosive hazard. Otto Fuel, however, offers outstanding safety characteristics while meeting temperature, shock stability, and energy requirements. In use, Otto Fuel II is first sprayed under pressure into a combustion chamber and then ignited. The exhaust gases from the burning fuel are utilized to drive the torpedo engine.

EXPLOSIVES AND WARHEADS

EXPLOSIVES APPLICATION AND PROCESSING

Much of Indian Head explosives work has evolved from propellant technology. Other interests in explosives have come about through development of techniques in formulation of modern explosives and methods of processing.

It is the purpose of an explosive to decompose extremely rapidly throughout its mass and to produce hot expanding gases at a violent rate. On initiation, explosives produce a special form of combustion in which fuel, in intimate contact with oxidizer materials, burns so rapidly that the developed heat of combustion cannot escape before it has ignited an adjacent zone and expanded the gaseous products. This causes a violent chain of product reactant interactions, proceeding in microseconds to a point where a shock wave is produced and propagated. The energy of expansion appears primarily in the form of heat and light. Therefore, an explosion is a rapid chemical interaction of materials resulting in the release of energy in the form of heat, light, and shock wave (or overpressure). An explosion is a special (rapid) form of combustion.

EVOLUTION

The use of explosives in the form of saltpeter-type gun powder, or black powder, dates back (on record) to the 12th Century. Its discovery has been variously attributed to the Chinese, the Asian Indians, and the Arabs.

From the writings of Roger Bacon, it is known that the knowledge of gun powder existed in England in 1242. It is interesting to note that he chose to conceal his knowledge because, as he explained, "the crown is unable to digest scientific facts, which it scorns and misuses to its own detriment and that of the wise. Let not pearls, then, be thrown before swine."

Perhaps partly because of that attitude, some 100 years were to pass before records appeared in 1346 in England alluding to the use of gun powder and by the early 16th Century, numerous powder mills were in operation there.

In this country, it is known that black powder was manufactured in Massachusetts in 1675. Over the years, many other plants were built. Perhaps the best known is that of the mill on the Brandywine built by E.I. duPont in the early 1800's. It is interesting to note that their formula was the same as was called for in England in the 18th Century, and the same basic formula as is in use today.

From these crude beginnings other explosive materials evolved while the use of black powder declined until it was used only for some pyrotechnics, igniters, and delay systems. Alchemists spearheaded technical development in the 17th and 18th Centuries, with the discovery and use of sulfuric and nitric acids, and with the development of theory on structures of chemicals by the 18th and 19th Centuries. This work led to the materialization and definition of that series of nitrated chemicals which provide the bulwark of chemical explosive technology today.

TYPES OF EXPLOSIVES

Rates of combustion for the materials covered by this text can vary widely from a few centimeters per minute to over 9000 meters per second. The rate of reaction depends on many factors, including composition, degree of confinement, and mode of initiation. When the rate of reaction (progression) exceeds the speed of sound in that material, a detonation is said to have occurred. Many explosives are capable of reacting at several velocities (according to the prevailing conditions) greater than the speed of sound. When an explosive detonates at well below its maximum rate it is said to be a low-order detonation. When near its maximum, it is called a high-order detonation.

Sometimes a high-efficiency explosion (high-order detonation) can only be achieved through initiation by ignition and shock. Explosives that must have this type of initiation in order to function are called **high (or secondary) explosives**. Explosives that provide this type of initiation are called **primary (or initiator) explosives**. The former are rather safe and insensitive to normal handling hazards; although their function is to explode, they are capable of burning passively. The latter are relatively less stable, easy to initiate, and more sensitive to normal handling hazards. Their normal mode of decomposition is detonation.

A third type of explosive is called **pyrotechnics**. As powdered mixtures of solid fuels and oxidizer materials, pyrotechnics are generally quite sensitive to heat and friction and must be handled with great care. The classification "pyrotechnics" covers a wide range of materials and uses include intense flares and signal rockets, smoke signal compositions, propellant ignition systems, and time-delay systems.

HANDLING

Because of the close proximity of fuel and oxidizer in an explosive material, little stimulus is normally required to cause an explosive to function. Consequently, explosion hazards are latent within these compositions and must be guarded against by constant precautions. One must always handle an explosive with respect, remembering that it is the ultimate purpose of the explosive to explode.

SELECTION

High explosives of primary concern to the military are usually solids like TNT compositions and plastic bonded explosive compositions; but they are sometimes liquids like nitroglycerin. In all cases, the basis for functioning remains the same - fuels in intimate contact with oxidizer. Obviously, of all such possible combinations, some are more desirable for military use than others. The principal factors considered in the decision to adopt a particular explosive for military use are the following:

Low cost and high availability
High stability or resistance to natural decomposition
Resistance to water or nonhygroscopicity
Good compatibility with materials of contact
Low toxicity
High density
Low sensitivity to accidental initiation
Low volatility
Functional melting point (low exudation probability).
Since full compliance with all requirements is rarely achieved and shifts in relative requirements (such as availability and toxicity) occur, the best balance of properties is determined through testing, evaluation, and rating methods.

CHARACTERIZATION

Today, in addition to the determination of adequacy of physical properties and explosive performance, a fuller characterization is performed of explosives being considered for general field use. Before large-scale we, the explosive must first be subjected to a series of tests to ascertain the safe usability of the compositions. This series of tests always includes tests for impact, friction, and electrostatic discharge sensitivity to initiation; physical stability (resistance to growth and exudation); and chemical stability (resistance to decomposition when subjected to vacuum, age acceleration, or self-heat inducing conditions). Other tests generally applied include durability, resistance to hostile environment (humidity and temperature cycling) and negligent handling, and long-term stability (storability in terms of years or decades).

Other tests often center on the suitability of a composition to perform the designed mission application. These tests include such factors as ability to survive shock of impact (Susan test) to enable initiation by command stimuli), resistance to high temperatures or fires increasing temperatures (differential thermal analysis or cook-off. and resistance to initiation or explosion by bullet impact.

PROCESSING

In all cases, explosive ingredients are combined in such manner that the synergistic effect of the combination will enhance the explodability of the resulting composition. As a result of this tailoring, PBX formulations may sometimes be more sensitive to shock or thermal stimuli) than the propellant counterparts. However, since safety is the prime consideration in the formulation of Navy requirements for shipboard storage of explosives accepted for service, this synergistic vulnerability is, of necessity, carefully tailored. Processing in terms of ingredient pretreatment, coating, or mixing extends to propellant techniques as well and include such things as vertical mixing, glazing, pneumatic mixing, inert diluent processing, standard chemical synthesis, and in some cases, even rolling. Emphasis at Indian Head has been on vertical mixing and casting of PBX formulations, pneumatic methods of ingredient pretreatment, and coating and batch chemical synthesis of ingredients through established techniques.

WARHEAD

Warheads vary in size and shape depending on the mission of the weapon, design constraints imposed by other components in the weapon system, and the environmental exposure anticipated. Configurations vary from ogive shapes employed in projectiles to simple rectangular boxes. Although intricate geometric designs are occasionally called for and spheres and modified conical sections are not uncommon, slightly modified right circular cylinders are probably the most commonly encountered shape in Navy missile and torpedo applications. Ogives for bombs, projectiles, and some missiles are probably the next most frequently ncountered. At Indian Head, warhead filling interests are usually confined to castable PBX processing.

The configuration of the warhead as well as the fill access port size are important factors with regard to processing. These aspects, together with the properties of the uncured explosive matrix, exert the most significant influence on the processing methods used and probability of early success in manufacture.

In most warhead processing situations, a primary concern is loading the maximum amount (weight) of explosive possible within the given volume provided by the warhead envelope. This practice usually adds to the physical integrity of the explosive by precluding voids, fissures, or porosity. The integrity is usually not essential to reliable weapon performance except where projectile fills are concerned. When physical integrity is essential to a slurry cast composition, special processing steps must be taken to assure elimination of entrapped gases within the mix when cast. This is accomplished through a variety of techniques including special: pretreatment of ingredients and application of heat, vacuum, and other stimuli) in various ways during casting. Most processing is done by remote control, and high-shear, close-tolerance propellant-type mixers are usually employed to assure uniform mixing. This is especially true with high-viscosity castable PBX mixing The predominant configurations of processing concern at IHDIV are associated with torpedo warheads or projectiles.

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