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* Rocket propellant is a material used by a rocket as, or to produce in a chemical reaction, the reaction mass (propulsive mass) that is ejected, typically with very high speed, from a rocket engine to produce thrust, and thus provide spacecraft propulsion. * In a chemical rocket propellants undergo exothermic chemical reactions to produce hot gas. There may be a single propellant, or multiple propellants; in the latter case one can distinguish fuel and oxidizer. The gases produced expand and push on a nozzle, which accelerates them until they rush out of the back of the rocket at extremely high speed. * For smaller attitude control thrusters, a compressed gas escapes the spacecraft through a propelling nozzle. * A potential other method is that the propellant is not burned but just heated. * In ion propulsion, the propellant is made of electrically charged atoms (ions), which are electromagnetically pushed out of the back of the spacecraft. Magnetically accelerated ion drives are not usually considered to be rockets however, but a similar class of thrusters use electrical heating and magnetic nozzles. * Contents *

* The Space Shuttle Atlantis during ascent.

* Rockets create thrust by expelling mass backwards in a high speed jet (see Newton's Third Law). Chemical rockets, the subject of this article, create thrust by reacting propellants within a combustion chamber into a very hot gas at high pressure, which is then expanded and accelerated by passage through a nozzle at the rear of the rocket. The amount of the resulting forward force, known as thrust, that is produced is the mass flow rate of the propellants multiplied by their exhaust velocity (relative to the rocket), as specified by Newton's third law of motion. Thrust is therefore the equal and

opposite reaction that moves the rocket, and not by interaction of the exhaust stream with air around the rocket. Equivalently, one can think of a rocket being accelerated upwards by the pressure of the combusting gases against the combustion chamber and nozzle.

This operational principle stands in contrast to the commonly-held assumption that a rocket “ pushes” against the air behind or below it. Rockets in fact perform better in outer space (where there is nothing behind or beneath them to push against), because there is a reduction in air pressure on the outside of the engine, and because it is possible to fit a longer nozzle without suffering from flow separation, in addition to the lack of air drag. * The maximum velocity that a rocket can attain in the absence of any external forces is primarily a function of its mass ratio and its exhaust velocity. The relationship is described by the rocket equation: . The mass ratio is just a way to express what proportion of the rocket is propellant (fuel/oxidizer combination) prior to engine ignition. Typically, a single-stage rocket might have a mass fraction of 90% propellant, 10% structure, and hence a mass ratio of 10: 1 .

The impulse delivered by the motor to the rocket vehicle per weight of fuel consumed is often reported as the rocket propellant’s specific impulse. A propellant with a higher specific impulse is said to be more efficient because more thrust is produced while consuming a given amount of propellant. * Lower stages will usually use high-density (low volume) propellants because of their lighter tankage to propellant weight ratios and because higher performance propellants require higher expansion ratios for maximum performance than can be attained in atmosphere. Thus, the Apollo-Saturn V

first stage used kerosene-liquid oxygen rather than the liquid hydrogen-liquid oxygen used on its upper stages. Similarly, the Space Shuttle uses high-thrust, high-density solid rocket boosters for its lift-off with the liquid hydrogen-liquid oxygen Space Shuttle Main Engines used partly for lift-off but primarily for orbital insertion.

Chemical propellants

* There are four main types of chemical rocket propellants: solid, storable liquid, cryogenic liquid and liquid monopropellant. Hybrid solid/liquid bi-propellant rocket engines are starting to see limited use as well. Solid propellants

* Main article: Solid-fuel rocket

* [edit]Description

* Solid propellants are either “ composites” composed mostly of large, distinct macroscopic particles or “ ____-bases” which are a homogeneous mixture of one or more primary ingredients. Composites typically consist of a mixture of granules of solid oxidizer (examples: ammonium nitrate, ammonium perchlorate, potassium nitrate) in a polymer binder with flakes or powders of: energetic compounds (examples: RDX, HMX), metallic additives (examples: Aluminum, Beryllium), plasticizers, stabilizers, and/or burn rate modifiers (iron oxide, copper oxide). ____-bases (single, double or triple base depending on the number of primary ingredients) are mixtures with the fuel, oxidizer and binders and plasticizers that are macroscopically indistinguishable and often blended as liquids and cured in a single batch. Often, the ingredients of a double base propellant have multiple roles such

as RDX which is both a fuel and oxidizer or nitrocellulose which is a fuel, oxidizer and plasticizer.

Further complicating categorization, there are many propellants that contain elements of double base and composite propellants often a composite with some amount of energetic additives homogeneously mixed into the binder. In the case of gunpowder (a pressed composite without a polymeric binder) the fuel is charcoal, the oxidizer is potassium nitrate, and sulphur serves as a catalyst. (Note: sulphur is not a true catalyst in gunpowder as it is consumed to a great extent into a variety of reaction products such as K_2S . During the 1950s and 60s researchers in the United States developed Ammonium Perchlorate Composite Propellant (APCP).

This mixture is typically 69-70% finely ground ammonium perchlorate (an oxidizer), combined with 16-20% fine aluminium powder (a fuel), held together in a base of 11-14% PBAN or HTPB (polybutadiene rubber fuel). The mixture is formed as a thickened liquid and then cast into the correct shape and cured into a firm but flexible load-bearing solid. APCP solid propellants are the most widely used in spaceflight launch vehicles and are also used in many military missiles. The military, however, uses a wide variety of different types of solid propellants some of which exceed the performance of APCP. A comparison of the highest specific impulses achieved with the various solid and liquid propellant combinations used in current launch vehicles is given in the Wiki article Solid-fuel rocket.[1] * [edit]Advantages

* Solid propellant rockets are much easier to store and handle than liquid propellant rockets. High propellant density makes for compact size as well.

These features plus simplicity and low cost make solid propellant rockets ideal for military applications. In the 1970s and 1980s the U. S. switched entirely to solid-fueled ICBMs: the LGM-30 Minuteman and LG-118A Peacekeeper (MX). In the 1980s and 1990s, the USSR/Russia also deployed solid-fueled ICBMs (RT-23, RT-2PM, and RT-2UTTH), but retains two liquid-fueled ICBMs (R-36 and UR-100N). All solid-fueled ICBMs on both sides had three initial solid stages, and those with multiple independently targeted warheads had a precision maneuverable bus used to fine tune the trajectory of the re-entry vehicles. U. S. Minuteman III ICBMs were reduced to a single warhead by 2011 in accordance with the START treaty leaving only the Navy's Trident sub-launched ICBMs with multiple warheads. * Their simplicity also makes solid rockets a good choice whenever large amounts of thrust are needed and cost is an issue. The Space Shuttle and many other orbital launch vehicles use solid-fueled rockets in their boost stages (solid rocket boosters) for this reason. * [edit]Disadvantages

* Relative to liquid fuel rockets, solid fuel rockets have lower specific impulse. The propellant mass ratios of solid propellant upper stages is usually in the . 91 to . 93 range which is as good or better than that of most liquid propellant upper stages but overall performance is less than for liquid stages because of the solids' lower exhaust velocities. The high mass ratios possible with (unsegmented) solids is a result of high propellant density and very high strength-to-weight ratio filament-wound motor casings. A drawback to solid rockets is that they cannot be throttled in real time, although a programmed thrust schedule can be created by adjusting the interior propellant geometry. Solid rockets can be vented to extinguish

combustion or reverse thrust as a means of controlling range or accommodating warhead separation.

Casting large amounts of propellant requires consistency and repeatability which is assured by computer control. Casting voids in propellant can adversely affect burn rate so the blending and casting takes place under vacuum and the propellant blend is spread thin and scanned to assure no large gas bubbles are introduced into the motor. Solid fuel rockets are intolerant to cracks and voids and often require post-processing such as x-ray scans to identify faults. Since the combustion process is dependent on the surface area of the fuel; voids and cracks represent local increases in burning surface area. This increases the local temperature, system pressure and radiative heat flux to the surface. This positive feedback loop further increases burn rate and can easily lead to catastrophic failure typically due to case failure or nozzle system damage. * [edit]Liquid propellants

* The most common liquid propellants in use today:

* LOX and kerosene (RP-1). Used for the first stages of the Saturn V, Atlas V and Falcon, the Russian Soyuz, Ukrainian Zenit, and developmental rockets like Angara and Long March 6. Very similar to Robert Goddard's first rocket. This combination is widely regarded as the most practical for boosters that lift off at ground level and therefore must operate at full atmospheric pressure. * LOX and liquid hydrogen, used in the Space Shuttle orbiter, the Centaur upper stage of the Atlas V, Saturn V upper stages, the newer Delta IV rocket, the H-IIA rocket, and most stages of the European Ariane 5 rocket. * Nitrogen tetroxide (N₂O₄) and hydrazine (N₂H₄), MMH, or UDMH. Used in

military, orbital, and deep space rockets because both liquids are storable for long periods at reasonable temperatures and pressures.

N₂O₄/UDMH is the main fuel for the Proton rocket, Long March rockets, PSLV, and Fregat and Briz-M upper stages. This combination is hypergolic, making for attractively simple ignition sequences. The major inconvenience is that these propellants are highly toxic, hence they require careful handling. * Monopropellants such as hydrogen peroxide, hydrazine, and nitrous oxide are primarily used for attitude control and spacecraft station-keeping where their long-term storability, simplicity of use, and ability to provide the tiny impulses needed, outweighs their lower specific impulse as compared to bipropellants. Hydrogen peroxide is also used to drive the turbopumps on the first stage of the Soyuz launch vehicle. * [edit]Historical propellants

* These include propellants such as the letter-coded rocket propellants used by Nazi Germany in World War II used for the Messerschmitt Me 163 Komet's Walter HWK 109-509 motor and the V-2 pioneer SRBM missile, and the Soviet/Russian utilized syntin, which is synthetic cyclopropane, C₃H₆ which was used on Soyuz U2 until 1995.[citation needed] Syntin develops about 10 seconds greater specific impulse than kerosene. * [edit]Advantages

* Liquid fueled rockets have higher specific impulse than solid rockets and are capable of being throttled, shut down, and restarted. Only the combustion chamber of a liquid fueled rocket needs to withstand high combustion pressures and temperatures and they can be regeneratively cooled by the liquid propellant. On vehicles employing turbopumps, the propellant tanks are at very much less pressure than the combustion

chamber. For these reasons, most orbital launch vehicles use liquid propellants. * The primary performance advantage of liquid propellants is due to the oxidizer. Several practical liquid oxidizers (liquid oxygen, nitrogen tetroxide, and hydrogen peroxide) are available which have better specific impulse than the ammonium perchlorate used in most solid rockets, when paired with comparable fuels.

These facts have led to the use of hybrid propellants: a storable oxidizer used with a solid fuel, which retain most virtues of both liquids (high ISP) and solids (simplicity).[citation needed] (The newest nitramine solid propellants based on CL-20 (HNIW) can match the performance of NTO/UDMH storable liquid propellants, but cannot be controlled as can the storable liquids.) * While liquid propellants are cheaper than solid propellants, for orbital launchers, the cost savings do not, and historically have not mattered; the cost of the propellant is a very small portion of the overall cost of the rocket. [citation needed] Some propellants, notably Oxygen and Nitrogen, may be able to be collected from the upper atmosphere, and transferred up to low-Earth orbit for use in propellant depots at substantially reduced cost.[2] * [edit]Disadvantages

* The main difficulties with liquid propellants are also with the oxidizers. These are generally at least moderately difficult to store and handle due to their high reactivity with common materials, may have extreme toxicity (nitric acids), moderately cryogenic (liquid oxygen), or both (liquid fluorine, FLOX- a fluorine/LOX mix). Several exotic oxidizers have been proposed: liquid ozone (O₃), ClF₃, and ClF₅, all of which are unstable, energetic, and toxic. * Liquid fueled rockets also require potentially troublesome valves and

seals and thermally stressed combustion chambers, which increase the cost of the rocket. Many employ specially designed turbopumps which raise the cost enormously due to difficult fluid flow patterns that exist within the casings. * [edit]Gas propellants

* A gas propellant usually involves some sort of compressed gas. However, due to the low density and high weight of the pressure vessel, gases see little current use, but are sometimes used for vernier engines, particularly with inert propellants. * GOX (gaseous oxygen) was used as one of the propellants for the Buran program for the orbital maneuvering system.

Hybrid propellants

* Main article: hybrid rocket

* A hybrid rocket usually has a solid fuel and a liquid or gas oxidizer. The fluid oxidizer can make it possible to throttle and restart the motor just like a liquid fueled rocket. Hybrid rockets can also be environmentally safer than solid rockets since some high-performance solid-phase oxidizers contain chlorine (specifically composites with ammonium perchlorate), versus the more benign liquid oxygen or nitrous oxide often used in hybrids. This is only true for specific hybrid systems. There have been hybrids which have used chlorine or fluorine compounds as oxidizers and hazardous materials such as beryllium compounds mixed into the solid fuel grain. Because just one constituent is a fluid, hybrids can be simpler than liquid rockets depending on the motive force used to transport the fluid into the combustion chamber. Fewer fluids typically means fewer and smaller piping systems, valves and pumps (if utilized). * Hybrid motors suffer two major drawbacks. The first, shared with solid rocket motors, is that the casing around the fuel grain must be

built to withstand full combustion pressure and often extreme temperatures as well.

However, modern composite structures handle this problem well, and when used with nitrous oxide and a solid rubber propellant (HTPB), relatively small percentage of fuel is needed anyway, so the combustion chamber is not especially large. * The primary remaining difficulty with hybrids is with mixing the propellants during the combustion process. In solid propellants, the oxidizer and fuel are mixed in a factory in carefully controlled conditions. Liquid propellants are generally mixed by the injector at the top of the combustion chamber, which directs many small swift-moving streams of fuel and oxidizer into one another. Liquid fueled rocket injector design has been studied at great length and still resists reliable performance prediction. In a hybrid motor, the mixing happens at the melting or evaporating surface of the fuel. The mixing is not a well-controlled process and generally quite a lot of propellant is left unburned,[3] which limits the efficiency of the motor. The combustion rate of the fuel is largely determined by the oxidizer flux and exposed fuel surface area. This combustion rate is not usually sufficient for high power operations such as boost stages unless the surface area or oxidizer flux is high.

Too high of oxidizer flux can lead to flooding and loss of flame holding that locally extinguishes the combustion. Surface area can be increased, typically by longer grains or multiple ports, but this can increase combustion chamber size, reduce grain strength and/or reduce volumetric loading. Additionally, as the burn continues, the hole down the center of the grain (the 'port') widens and the mixture ratio tends to become more oxidizer rich. * There has been

much less development of hybrid motors than solid and liquid motors. For military use, ease of handling and maintenance have driven the use of solid rockets. For orbital work, liquid fuels are more efficient than hybrids and most development has concentrated there. There has recently been an increase in hybrid motor development for nonmilitary suborbital work: * Several universities have recently experimented with hybrid rockets.

Brigham Young University, the University of Utah and Utah State University launched a student-designed rocket called Unity IV in 1995 which burned the solid fuel hydroxy-terminated polybutadiene (HTPB) with an oxidizer of gaseous oxygen, and in 2003 launched a larger version which burned HTPB with nitrous oxide.. Stanford Universityresearches nitrous-oxide/paraffin hybrid motors. * The Rochester Institute of Technology was building a HTPB hybrid rocket to launch small payloads into space and to several near Earth objects. Its first launch was scheduled forSummer2007. * Scaled Composites SpaceShipOne, the first private manned spacecraft, is powered by a hybrid rocket burning HTPB with nitrous oxide. The hybrid rocket engine was manufactured by SpaceDev. SpaceDev partially based its motors on experimental data collected from the testing of AMROC's (American Rocket Company) motors at NASA's Stennis Space Center's E1 test stand. * The Dream Chaser crewed spaceplane intends to use twin hybrid engines of similar design to SpaceShipOne for orbit raising, deorbiting, and emergency escape system. * [edit]Gel propellant

* Some work has been done on gelling liquid propellants to give a propellant with low vapor pressure to reduce the risk of an accidental fireball. Gelled

propellant behaves like a solid propellant in storage and like a liquid propellant in use.

Inert propellants

* Some rocket designs have their propellants obtain their energy from non chemical or even external sources. For example water rockets use the compressed gas, typically air, to force the water out of the rocket. * Solar thermal rockets and Nuclear thermal rockets typically propose to use liquid hydrogen for an Isp (Specific Impulse) of around 600–900 seconds, or in some cases water that is exhausted as steam for an Isp of about 190 seconds. * Additionally for low performance requirements such as attitude jets, inert gases such as nitrogen have been employed.

* The theoretical exhaust velocity of a given propellant chemistry is a function of the energy released per unit of propellant mass (specific energy). Unburned fuel or oxidizer drags down the specific energy. However, most rockets run fuel-rich.[citation needed] * The usual explanation for fuel-rich mixtures is that fuel-rich mixtures have lower molecular weight exhaust, which by reducing increases the ratio which is approximately equal to the theoretical exhaust velocity. This explanation, though found in some textbooks, is wrong. Fuel-rich mixtures actually have lower theoretical exhaust velocities, because decreases as fast or faster than .[citation needed] * The nozzle of the rocket converts the thermal energy of the propellants into directed kinetic energy. This conversion happens in a short time, on the order of one millisecond. During the conversion, energy must transfer very quickly from the rotational and vibrational states of the exhaust molecules into translation. Molecules with fewer atoms (like CO and H₂)

store less energy in vibration and rotation than molecules with more atoms (like CO₂ and H₂O).

These smaller molecules transfer more of their rotational and vibrational energy to translation energy than larger molecules, and the resulting improvement in nozzle efficiency is large enough that real rocket engines improve their actual exhaust velocity by running rich mixtures with somewhat lower theoretical exhaust velocities.[citation needed] * The effect of exhaust molecular weight on nozzle efficiency is most important for nozzles operating near sea level. High expansion rockets operating in a vacuum see a much smaller effect, and so are run less rich. The Saturn-II stage (a LOX/LH₂ rocket) varied its mixture ratio during flight to optimize performance. * LOX/hydrocarbon rockets are run only somewhat rich (O/F mass ratio of 3 rather than stoichiometric of 3.4 to 4), because the energy release per unit mass drops off quickly as the mixture ratio deviates from stoichiometric. LOX/LH₂ rockets are run very rich (O/F mass ratio of 4 rather than stoichiometric 8) because hydrogen is so light that the energy release per unit mass of propellant drops very slowly with extra hydrogen.

In fact, LOX/LH₂ rockets are generally limited in how rich they run by the performance penalty of the mass of the extra hydrogen tankage, rather than the mass of the hydrogen itself.[citation needed] * Another reason for running rich is that off-stoichiometric mixtures burn cooler than stoichiometric mixtures, which makes engine cooling easier. Because fuel-rich combustion products are less chemically reactive (corrosive) than oxygenated products, vast majority of rocket engines are designed to run

fuel-rich, with at least one exception for the Russian RD-180 preburner, which burns LOX and RP-1 at a ratio of 2. 72.

* Additionally, mixture ratios can be dynamic during launch. This can be exploited with designs that adjust the oxidizer to fuel ratio (along with overall thrust) during the flight to maximize overall system performance. For instance, during lift-off thrust is a premium while specific impulse is less so. As such, the system can be optimized by carefully adjusting the O/F ratio so the engine runs cooler at higher thrust levels. This also allows for the engine to be designed slightly more compactly, improving its overall thrust to weight performance.

Propellant density

* Although liquid hydrogen gives a high Isp, its low density is a significant disadvantage: hydrogen occupies about 7x more volume per kilogram than dense fuels such as kerosene. This not only penalises the tankage, but also the pipes and fuel pumps leading from the tank, which need to be 7x bigger and heavier. (The oxidiser side of the engine and tankage is of course unaffected.) This makes the vehicle's dry mass much higher, so the use of liquid hydrogen is not such a big win as might be expected. Indeed, some dense hydrocarbon/LOX propellant combinations have higher performance when the dry mass penalties are included. * Due to lower Isp, dense propellant launch vehicles have a higher takeoff mass, but this does not mean a proportionately high cost; on the contrary, the vehicle may well end up cheaper. Liquid hydrogen is quite an expensive fuel to produce and store, and causes many practical difficulties with design and manufacture of the vehicle. * Because of the higher overall weight, a dense-fuelled launch

vehicle necessarily requires higher takeoff thrust, but it carries this thrust capability all the way to orbit.

This, in combination with the better thrust/weight ratios, means that dense-fuelled vehicles reach orbit earlier, thereby minimizing losses due to gravity drag. Thus, the effective delta-v requirement for these vehicles are reduced.

* However, liquid hydrogen does give clear advantages when the overall mass needs to be minimised; for example the Saturn V vehicle used it on the upper stages; this reduced weight meant that the dense-fuelled first stage could be made significantly smaller, saving quite a lot of money. *

Tripropellant rockets designs often try to use an optimum mix of propellants for launch vehicles. These use mainly dense fuel while at low altitude and switch across to hydrogen at higher altitude. Studies by Robert Salkeld in the 1960s proposed SSTO using this technique.[4] The Space Shuttle approximated this by using dense solid rocket boosters for the majority of the thrust for the first 120 seconds, the main engines, burning a fuel-rich hydrogen and oxygen mixture operate continuously throughout the launch but only provide the majority of thrust at higher altitudes after SRB burnout.