

## **INTRODUCING PROPELLANT INTO A COMBUSTION CHAMBER**

Rocket propellant is mass that is stored, usually in some form of propellant tank, prior to being ejected from a rocket engine in the form of a fluid jet to produce thrust.

Chemical rocket propellants are most commonly used, which undergo exothermic chemical reactions which produce hot gas which is used by a rocket for propulsive purposes. Alternatively, a chemically inert reaction mass can be heated using a high-energy power source via a heat exchanger, and then no combustion chamber is used.

### **A solid rocket motor:**

Solid rocket propellants are prepared as a mixture of fuel and oxidizing components called 'grain' and the propellant storage casing effectively becomes the combustion chamber. Liquid-fueled rockets typically pump separate fuel and oxidiser components into the combustion chamber, where they mix and burn. Hybrid rocket engines use a combination of solid and liquid or gaseous propellants. Both liquid and hybrid rockets use *injectors* to introduce the propellant into the chamber. These are often an array of simple jets- holes through which the propellant escapes under pressure; but sometimes may be more complex spray nozzles. When two or more propellants are injected the jets usually deliberately collide the propellants as this breaks up the flow into smaller droplets that burn more easily.

### **Rocket Ignition :**

Rocket fuels, hypergolic or otherwise, must be mixed in the right quantities to have a controlled rate of production of hot gas. A hard start indicates that the quantity of combustible propellant that entered the combustion chamber prior to ignition was too large. The result is an excessive spike of pressure, possibly leading to structural failure or even an explosion (sometimes facetiously referred to as "spontaneous disassembly").

Avoiding hard starts involves careful timing of the ignition relative to valve timing or varying the mixture ratio so as to limit the maximum pressure that can occur or simply ensuring an adequate ignition source is present well prior to propellant entering the chamber.

Explosions from hard starts often cannot happen with purely gaseous propellants, since the amount of the gas present in the chamber is limited by the injector area relative to the throat area, and for practical designs propellant mass escapes too quickly to be an issue.

A famous example of a hard start was the explosion of Wernher von Braun's "1W" engine during a demonstration to General Dornberger on December 21, 1932. Delayed ignition allowed the chamber to fill with alcohol and liquid oxygen, which exploded violently. Shrapnel was embedded in the walls, but nobody was hit.

### **Rocket Combustion:**

#### **Combustion chamber**

For chemical rockets the combustion chamber is typically just a cylinder, and flame holders are rarely used. The dimensions of the cylinder are such that the propellant is able to combust thoroughly; different propellants require different combustion chamber sizes for this to occur. This leads to a number called  $L^*$  :

$$L^* = V_c/A_t$$

where:

- $V_c$  is the volume of the chamber
- $A_t$  is the area of the throat

$L^*$  is typically in the range of 25–60 inches (0.63–1.5 m).

The combination of temperatures and pressures typically reached in a combustion chamber is usually extreme by any standards. Unlike in air-breathing jet engines, no atmospheric nitrogen is present to dilute and cool the combustion, and the temperature can reach true stoichiometric. This, in combination with the high pressures, means that the rate of heat conduction through the walls is very high.

## Rocket nozzles

Typical temperatures (T) and pressures (p) and speeds (v) in a De Laval Nozzle

The large bell or cone shaped expansion nozzle gives a rocket engine its characteristic shape.

In rockets the hot gas produced in the combustion chamber is permitted to escape from the combustion chamber through an opening (the "throat"), within a high expansion-ratio 'de Laval' nozzle.

Provided sufficient pressure is provided to the nozzle (about 2.5-3x above ambient pressure) the nozzle *chokes* and a supersonic jet is formed, dramatically accelerating the gas, converting most of the thermal energy into kinetic energy.

The exhaust speeds vary, depending on the expansion ratio the nozzle is designed to give, but exhaust speeds as high as ten times the speed of sound of sea level air are not uncommon.

Rocket thrust is caused by pressures acting in the combustion chamber and nozzle. From Newton's third law, equal and opposite pressures act on the exhaust, and this accelerates it to high speeds.

About half of the rocket engine's thrust comes from the unbalanced pressures inside the combustion chamber and the rest comes from the pressures acting against the inside of the nozzle (see diagram). As the gas expands (adiabatically) the pressure against the nozzle's walls forces the rocket engine in one direction while accelerating the gas in the other.

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