The different types of propulsion

In this document, I am going to present the different types of propulsion, their characteristics and some examples of use.

Solid Propulsion:

As its name suggests, solid propulsion uses solid propellants. The principle is to ignite a grain (propellant block) that will burn and so generate hot gases. There is a hole that goes through the grain, this hole defines the spot where the grain is ignited and defines the combustion surface at every instant of the combustion. Indeed, the combustion surface evolves with time because the combustion digs the grain and so enlarge the hole as illustrated below:

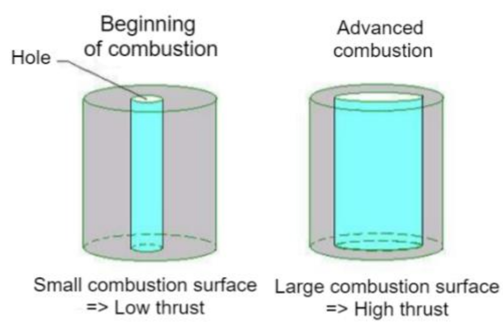

Figure 1 Evolution of combustion surface with time

We can easily see the evolution of the combustion surface between the beginning and an advanced state of combustion. This evolution of combustion surface generates an evolution of the thrust induced by this combustion. Indeed, the bigger the combustion surface is, the more propellant quantity burns simultaneously, the more gases are generated, and so the higher the thrust is. This evolution defines the thrust law (evolution of thrust in time). It is possible to target a thrust law by changing the shape of the hole. For example, if we choose to use a star-shaped hole, we will obtain a constant thrust during the flight (that is why this shape is frequently used) as shown below:

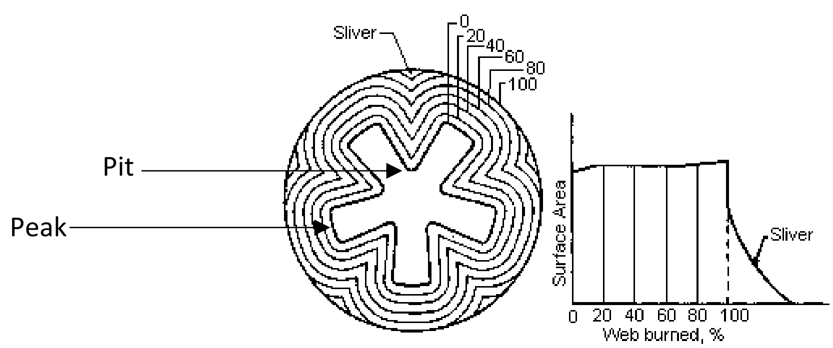

Figure 2 Evolution of thrust with a star-shaped hole

The pits of the star are consumed faster than the peaks (because there is combustion on each part of the pits), the surface generated by these pits lower with time, this compensates the augmentation of the hole diameter.

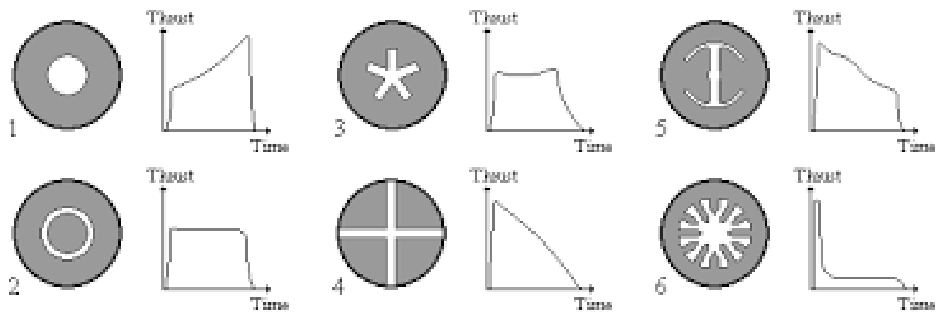

Figure 3 Some shape and thrust law examples

The principal advantages of solid propulsion are its simplicity, its compactness, and its reliability.

The main inconvenient of solid propulsion is that you can't stop the combustion so you can't use the same motor several times.

This kind of propulsion is mostly used for the rocket's boosters. Indeed, when the rocket is launched, the first phase consists in taking speed and leaving the atmosphere. Solid propulsion is adapted to this mission as it is efficient and compact. Moreover, there is no need to use the motor several times in this phase.

Figure 4 Solid Propulsion on JAXA H3

Liquid Propulsion:

As its name suggests, liquid propulsion uses liquid propellants. The principle is to put together two liquid propellants that will react on contact and generate hot gases. The two propellants are stored in two different tanks, then they are introduced into the combustion chamber in which they react together and generate hot gases and so a thrust. It is possible to control the combustion and so the thrust by modifying the propellant flow rate into the combustion chamber during the flight. The principle of this kind of combustion is pretty simple, but realizing it is much more complex as shown in the illustration and the picture below:

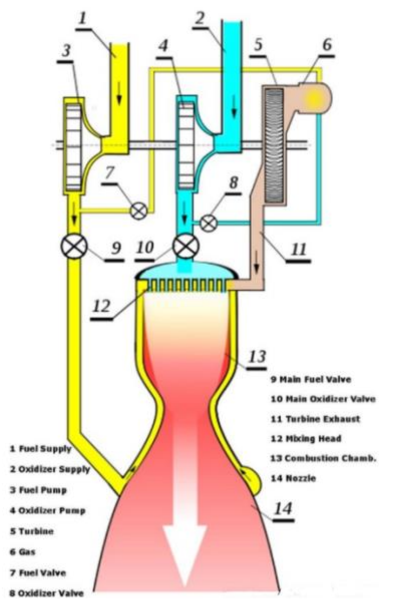

Figure 6 Scheme of a liquid propulsion system

Figure 5 Example of a liquid propulsion motor

To realize a liquid propulsion motor, it is necessary to use valves and turbopumps to ensure a sufficient and controlled propellant flow rate inside the combustion chamber. This kind of system consumes a lot of energy, it is not possible to supply it with an external source (electricity is rare on board). Therefore, we need to use a gas generator and a propeller supplied by the propellants to furnish the necessary energy to the turbopumps (gases generated by this generator are injected inside the combustion chamber to minimize the energy losses). We can also see in the scheme that a part of the propellants is used as a cooling liquid before being introduced inside the combustion chamber. Indeed, liquid propellants are stored at low temperature, it is coherent to use them as a cooling liquid (as an example, hydrogen is commonly used in liquid propulsion, its condensation temperature at ambient pressure is 20.28 Kelvins, we must store it at -253 °C to keep it liquid).

The principal vantages of liquid propulsion are the better ISP obtained with it which is far better than the one obtained with solid propulsion (ISP means specific impulse, it characterizes the thrust as a function of the quantity of propellant used per unit of time) and the simplicity of thrust control.

The principal disadvantages of liquid propulsion are the complexity of realization and the propellant storage difficulties (bigger tanks and necessity of low temperatures and high pressures).

This kind of propulsion is mostly used on upper stages. Indeed, these stages are used in the last phase, so it is important to control the thrust and to have the ability to use the motor several times (during maneuvers for example).

Figure 7 Liquid Propulsion on Ariane 6

Hybrid Propulsion:

Hybrid propulsion uses solid and liquid propellants. The principle is to use a propellant couple that will react together and generate hot gases. The grain is placed inside the combustion chamber. The grain is pierced by one or several hole(s) (with several holes you can increase the initial combustion surface). The liquid propellant, stored in a tank upstream from the combustion chamber, is injected inside the hole(s) to make a contact between the two propellants and obtain hot gases generating reaction.

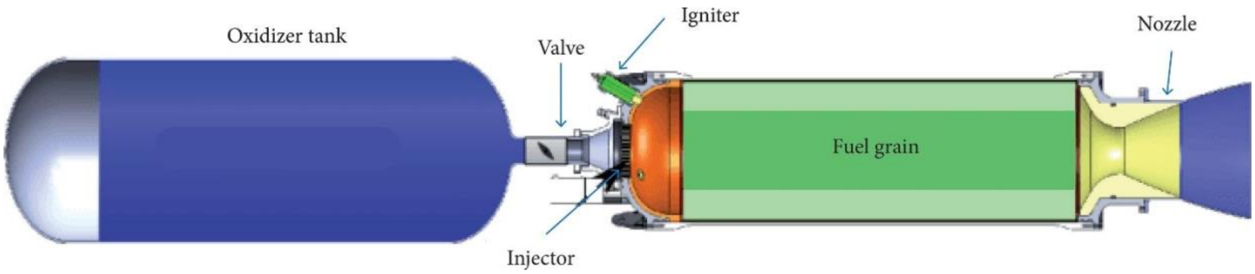

Figure 8 Hybrid propulsion system

As for solid propulsion, it is possible to choose a particular hole shape to modulate the thrust. It is also possible to regulate the combustion by using the valves which are controlling the quantity of liquid propellant introduced inside the combustion chamber.

The principal advantages of hybrid propulsion are higher ISP obtained, the conception simplicity, the good thrust control, and lower risk of explosion than for the other types of propulsion.

The principal disadvantages are the low regression speed (consumption of propellant speed) and so the low thrust, the high pressure needed for propellant injection (needs to be higher than the pressure inside the combustion chamber) which include great efforts through the tank and so the necessity to have a more resistant tank which means a heavier tank, finally, at the end of combustion, the chamber is bigger (the grain has almost been totally consumed), the propulsion is then less efficient (it is harder to cover all the available surface).

At the moment, hybrid propulsion is still under development as it offers poor performances. However, this technology could be the most efficient one in a few years as some companies are collecting funds to develop it.

Figure 9 Baguette-One, an HyprSpace project