DEPARTMENT OF AEROSPACE ENGINEERING

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UNIT V - PERFORMANCE OF AEROSPACE VEHICLES

Performance Characteristics of Solid, Liquid, and Hybrid Rockets

Hybrid Rocket Propulsion

Hybrid rocket propulsion is a rocket propulsion system where the rocket motor uses propellants in two different states of matter – one solid and the other either gas or liquid.

Hybrid rockets avoid some of the disadvantages of solid rockets like the dangers of propellant handling, while also avoiding some disadvantages of liquid rockets like their mechanical complexity. Because it is difficult for the fuel and oxidizer to be mixed intimately (being different states of matter), hybrid rockets tend to fail more benignly than liquids or solids. Like liquid rocket engines, hybrid rocket motors can be shut down easily and the thrust is throttleable.

The theoretical specific impulse (Isp) performance of hybrids is generally higher than solid motors and lower than liquid engines. Isp as high as 400 s has been measured in a hybrid rocket using metalized fuels. Hybrid systems are more complex than solid ones, but they avoid significant hazards of manufacturing, shipping, and handling solid rocket motors by storing the oxidizer and the fuel separately.

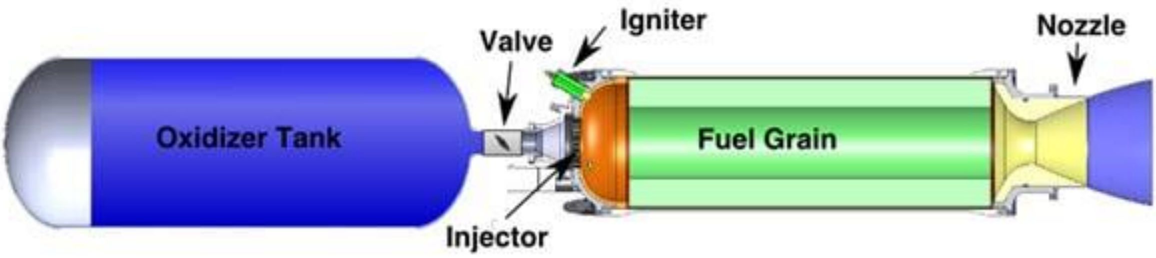
Basic Concepts Of Hybrid Rocket Propulsion:

In its simplest form, a hybrid rocket consists of a pressure vessel (tank) containing the liquid propellant, the combustion chamber containing the solid propellant, and a valve isolating the two. When thrust is desired, a suitable ignition source is introduced in the combustion chamber and the valve is opened. The liquid propellant (or gas) flows into the combustion chamber where it is vaporized and then reacted with the solid propellant. Combustion occurs in a boundary layer diffusion flame adjacent to the surface of the solid propellant.

Generally, the liquid propellant is the oxidizer and the solid propellant is the fuel because solid oxidizers are problematic and lower performing than liquid oxidizers. Furthermore, using solid fuels such as Hydroxyl-Terminated Polybutadiene (HTPB) or paraffin wax allows for the incorporation of high-energy fuel additives such as aluminium, lithium, or metal hydrides.

Common oxidizers include gaseous or liquid oxygen or nitrous oxide. Common fuels include polymers such as polyethylene, cross-linked rubber such as HTPB, or liquefying fuels such as paraffin wax. Hybrid rocket propulsion is a rocket propulsion system where the rocket motor uses propellants in two different states of matter.

Hybrid Rocket Propulsion System Conceptual Overview



Advantages of Hybrid Rocket Propulsion Compared with Liquid Rockets:

1. **Mechanically simpler** – requires only a single liquid propellant resulting in less plumbing, fewer valves, and simpler operations.

2. **Denser fuel** – fuels in the solid phase generally have a higher density than those in the liquid phase, reducing overall system volume.

3. **Metal additives** – reactive metals such as aluminium, magnesium, lithium, or beryllium can be easily included in the fuel grain increasing specific impulse (Isp), density, or both.

4. **Combustion instabilities** – Hybrid rockets do not typically exhibit high-frequency combustion instabilities that plague liquid rockets due to the solid fuel grain breaking up acoustic waves that would otherwise reflect in an open liquid engine combustion chamber.

5. **Propellant pressurization** – One of the most difficult-to-design portions of a liquid rocket system is the turbopumps. Turbopump design is complex as it has to precisely and efficiently pump and keep separated two fluids of different properties in precise ratios at very high volumetric flow rates, often cryogenic temperatures, and highly volatile chemicals while combusting those same fluids to power itself. Hybrids have far less fluid to move and can often be pressurized by a blow-down system (which would be prohibitively heavy in a liquid rocket) or self-pressurized oxidizers (such as N2O).

6. **Cooling** – Liquid rockets often depend on one of the propellants, typically the fuel, to cool the combustion chamber and nozzle due to the very high heat fluxes and vulnerability of the metal walls to oxidation and stress cracking. Hybrid rockets have combustion chambers that are lined with solid propellant which shields them from the product gases. Their nozzles are often graphite or coated in ablative materials similar to solid rocket motors. The design, construction, and testing of liquid cooling flows is complex, making the system more prone to failure.

Advantages of Hybrid Rocket Propulsion Compared with Solid Rockets:

1. **Higher theoretical Isp** – Possible due to limits of known solid oxidizers compared to often used liquid oxidizers.

2. **Less explosion hazard** – Propellant grain is more tolerant of processing errors such as cracks since the burn rate is dependent on the oxidizer mass flux rate. Propellant grain cannot be ignited by stray electrical charge and is very insensitive to auto-igniting due to heat. Hybrid rocket motors can be transported to the launch site with the oxidizer and fuel stored separately, improving safety.

3. **Fewer handling and storage issues** – Ingredients in solid rockets are often incompatible chemically and thermally. Repeated changes in temperature can distort the grain. Antioxidants and coatings are used to keep the grain from breaking down or decomposing.

4. **More controllable** – Stop/restart and throttling are all easily incorporated into most designs. Solid rockets rarely can be shut down easily and rarely have throttling or restart capabilities.

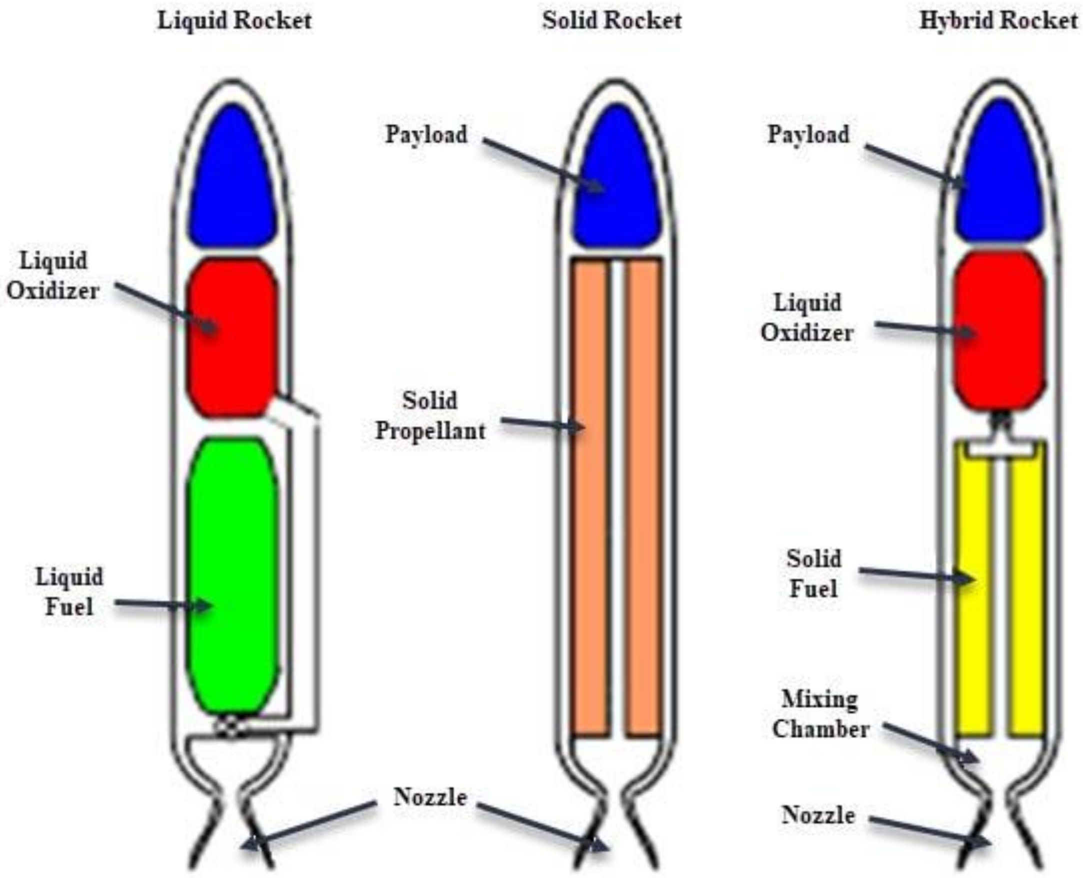
<u>Disadvantages Of Hybrid Rocket Propulsion</u>:

1. **Oxidizer-to-fuel ratio shift ("O/F shift")** – with a constant oxidizer flow rate, the ratio of fuel production rate to oxidizer flow rate will change as a grain regresses. This leads to off-peak operation from a chemical performance point of view. However, for a well-designed hybrid, the O/F shift has a very small impact on performance because I_{sp} is insensitive to the O/F shift near the peak.

2. **Low regression rate** (the rate at which the solid phase recedes) fuels often drive multi-port fuel grains. Multi-port fuel grains have poor volumetric efficiency and, often, structural deficiencies. High regression rate liquefying fuels developed in the late 1990s offer a potential solution to this problem.

3. Compared with liquid-based propulsion, re-fueling a partially or depleted hybrid rocket would present significant challenges, as the solid propellant cannot simply be pumped into a fuel tank. This may or may not be an issue, depending on how the rocket is planned to be used.

Liquid Rocket vs Solid Rocket vs Hybrid Rocket



Hybrid Rocket Propulsion Safety:

1. **Pressure vessel failures** – Chamber insulation failure may allow hot combustion gases near the chamber walls leading to a “burn-through” in which the vessel ruptures.

2. **Blowback** – For oxidizers that decompose exothermically such as nitrous oxide or hydrogen peroxide, flame or hot gasses from the combustion chamber can propagate back through the injector, igniting the oxidizer and leading to a tank explosion. Blow-back requires gases to flow back through the injector due to insufficient pressure drop which can occur during periods of unstable combustion. Blowback is inherent to specific oxidizers and is not possible with oxidizers such as oxygen, or nitrogen tetroxide unless fuel is present in the oxidizer tank.

3. **Hard starts** – An excess of oxidizer in the combustion chamber before ignition, particularly for monopropellants such as nitrous oxide, can result in a temporary over-pressure or “spike” at ignition.