Introduction to Aerospace Propulsion

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Lecture No - 36

Rockets,
Missiles,
and
Spacecrafts

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- Chinese used rockets in the 12th century AD against the Mongol attacks.
- In India Tipu Sultan used rockets against the British army in the 18th century.
- The modern rocket scientists, : Contantin Tsiolkovosky of Russia,, Hans Oberth and Fritz Opel of Germany, and Robert Goddard and Werner Von Braun of USA.
- They and many others help develop the fundamental scientific principles of rockets, including multi-stage rockets, for launching satellites and space vehicles.

- The operation of a rocket is not dependent on atmosphere or forward speed.
- This is an advantage as the rocket is the method of propelling vehicles beyond earth's atmosphere.
- And a disadvantage, as both the fuel and the oxidizer must be carried in the body of the rocket.
- The basic rocket devise is a thermal rocket motor, which is a heat engine.
- It converts chemical energy into heat by burning of propellant and oxidizer
- The heat creates high energy of the burnt gases which is accelerated through a shaped nozzle.
- The large momentum of the exhaust gas creates the reaction force, by Newton's laws of motion, and acts as ***Thrust*** for propelling it forward.

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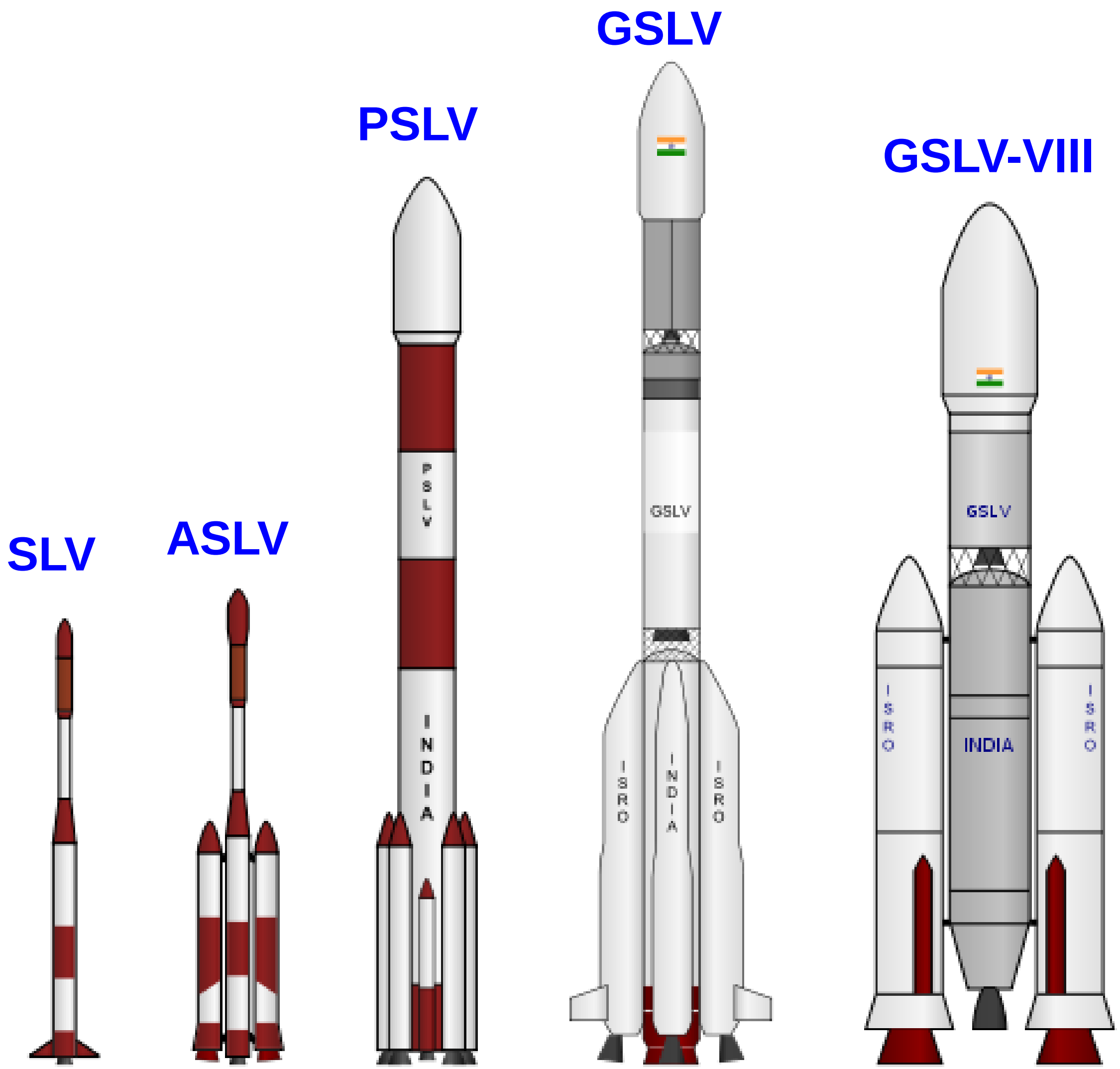
Indian Satellite Launch Vehicles



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PSLV launch from Sriharikota Launch base

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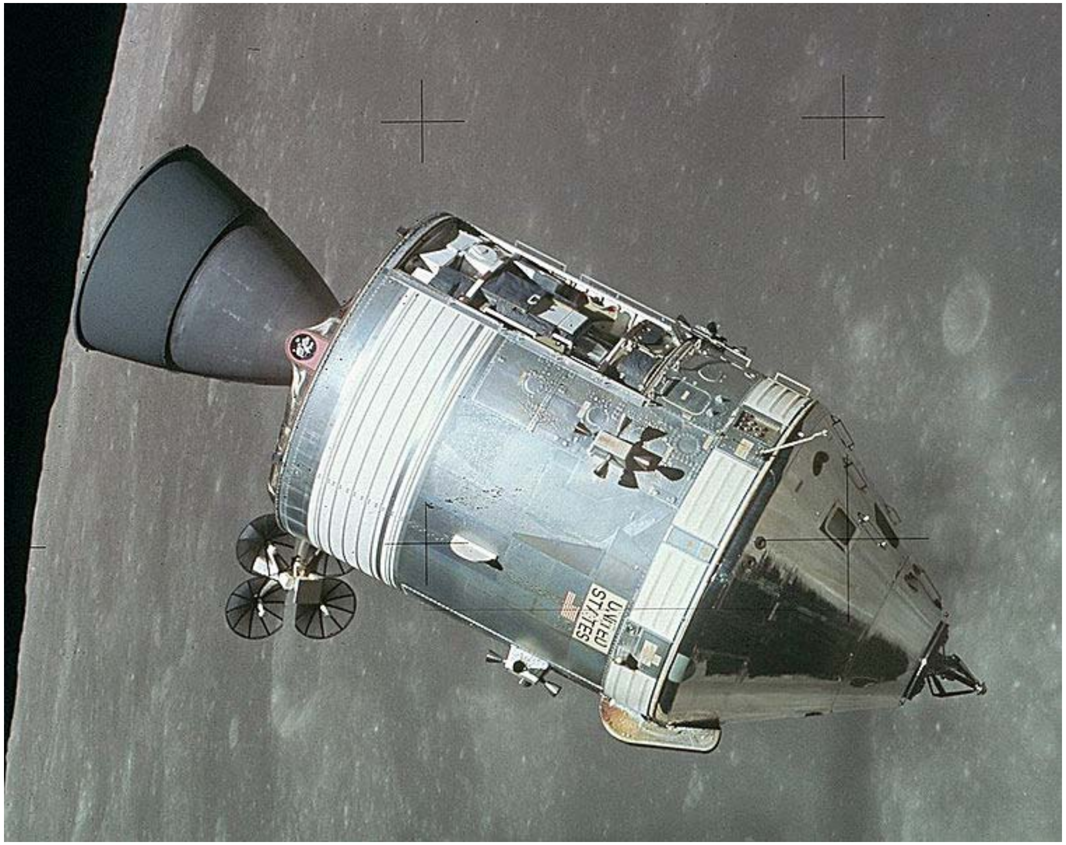
Proton Rocket - Russia

Apollo Spacecraft for Moon mission – USA (Saturn Rocket)



Space Shuttle Columbia launch

Types of missiles

Conventional guided missiles (targetted)

- Air-to-air missile
- Air-to-surface missile
- Anti-ballistic missile
- Anti-satellite weapon
- Anti-ship missile
- Land-attack missile
- Anti-tank guided missile
- Surface-to-air missile (list)
- Surface-to-surface missile
- Wire-guided missile

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Types of missiles

Cruise missiles (has a long cruise flight)

Ballistic missiles (Aim and Shoot)

- Tactical ballistic missile
- Short-range ballistic missile
- Theatre Ballistic Missiles
- Medium-range ballistic missile
- Intermediate-range ballistic missile
- Intercontinental ballistic missile
- Submarine-launched ballistic missile
- Air-launched ballistic missile

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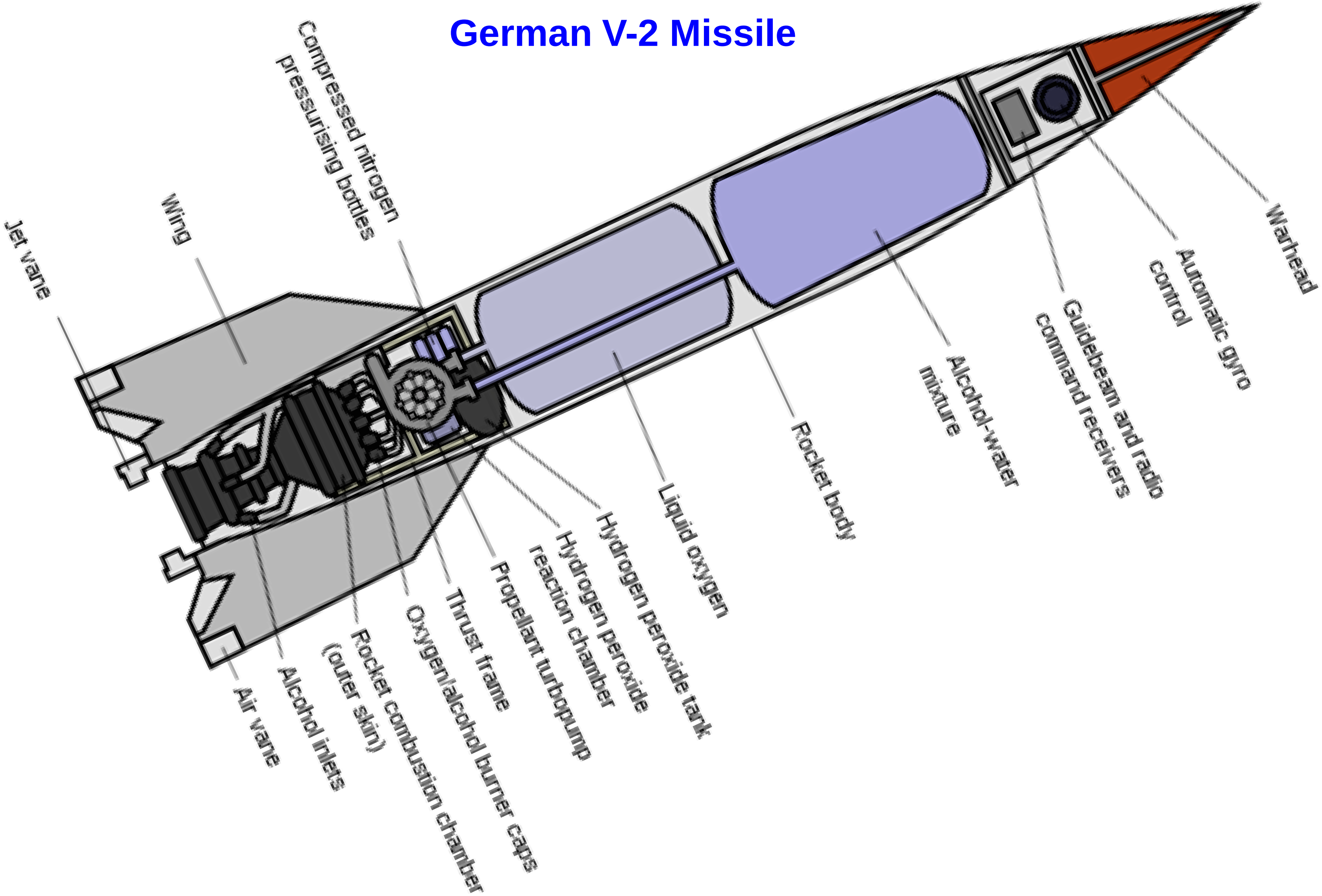
German V-2 Missile



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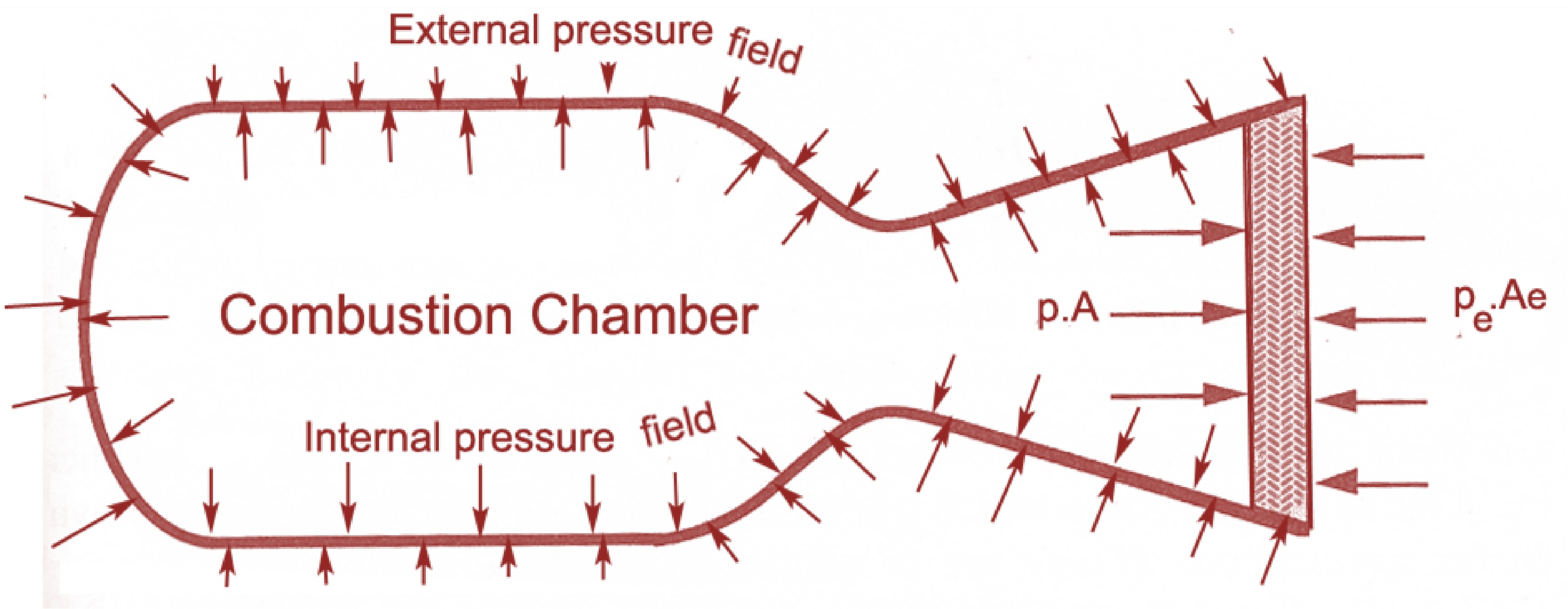
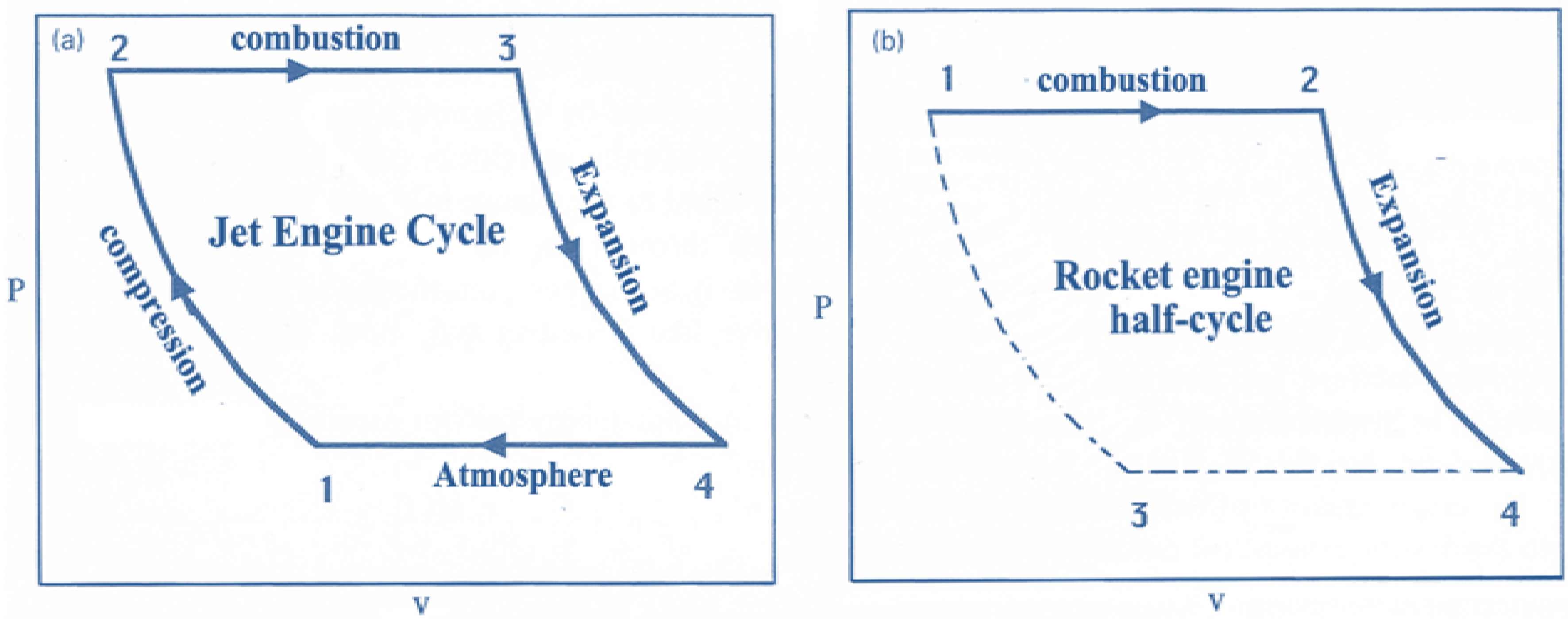
Pressure distributions contributing to thrust



Net thrust created, $$F_{net} = \oint p.dA$$

As heat engine the rocket works the same way as the other heat engines do. However, since it does not use the atmospheric air it does not complete a cycle.



Heat engine as a (a) Jet Engines, (b) Rocket

- There are two basic kinds of fuel and oxidizer used in rocket engines.
- One in which the fuel and the oxidizer are both liquid and are separately pumped into the rocket motor combustion chamber.
- In the other variety the fuel and the oxidizer are both solids, often in mixtures, are already positioned inside the combustion chamber in suitable shapes and sizes.
- In both the cases the burnt mixture of gases is released through nozzles for thrust creation.

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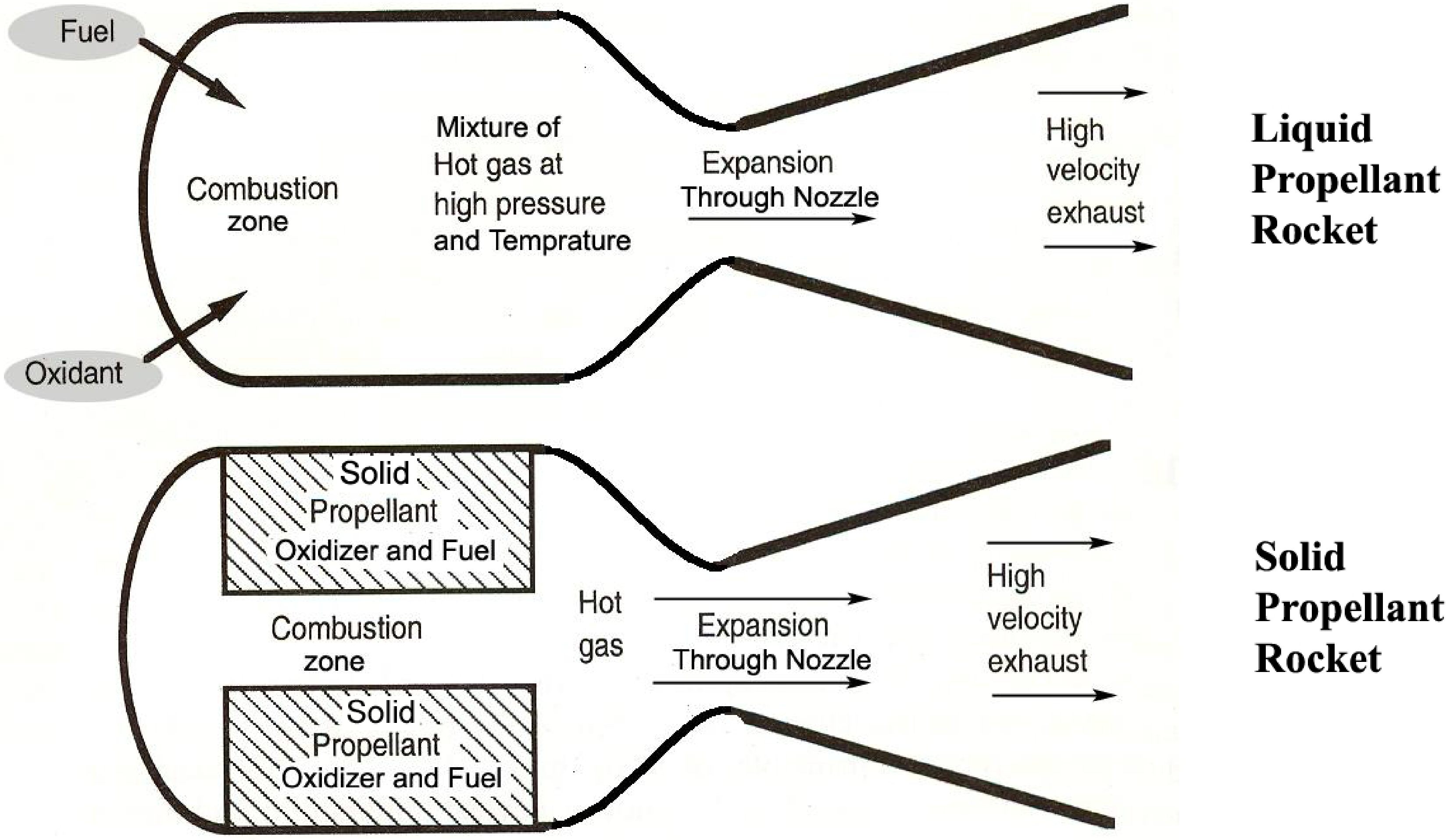
Schematic of Liquid and Solid Propellant Rocket Engines



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Basic Rocket Science : Thrust generation

An equation for rocket thrust is obtained from simple momentum analysis. If the mass of the rocket at time ***t + dt*** is ***m*** and ***dm*** is expended in time ***dt***, accompanied by a velocity change ***dV***, then conservation of momentum requires that

$$(m+dm)V = m(V+dV)+dm(V-V_{e\text{-max}})$$

Where, $V_{e\text{-max}}$ is the velocity of the exhaust gas relative to the rocket after full expansion to the atmosphere

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From which, we can derive that

$$0 = m\,dV - V_{e\text{-max}}\,dm$$

differentiating with respect to time

$$\frac{mdv}{dt} = V_{e\text{-max}} \frac{dm}{dt}$$

$\frac{\mathrm{mdv}}{\mathrm{dt}}$ is the propulsive force or thrust, F_j and

$\frac{\mathrm{dm}}{\mathrm{dt}}$ is the mass flux of fuel and oxidizer together, Hence the jet thrust may be written as :

$$F_j = V_{e-\max} \frac{dm}{dt}$$

- The exhaust velocity $V_{e\text{-max}}$ depends on the design of the exhaust nozzle and on the local ambient conditions of flight.
- In a well designed convergent-divergent nozzle, the exhaust velocity is known approx. for flights within the atmosphere.
- The value of γ is determined by the internal temperature and chemical composition of the exhaust, and is normally less than the value for ordinary air.

$$V_e = \sqrt{2.c_p.(T_{0cc} - T_e)} = \sqrt{\frac{2.\gamma.(T_{0cc} - T_e)}{\gamma - 1}}$$

$$= \sqrt{\frac{2.\gamma.T_{cc}.(1 - T_e/T_{0cc})}{\gamma - 1}}$$

The ideal exhaust velocity is obtained -

$$= \sqrt{\frac{2.\gamma.T_{0cc}.\left[1 - \left(P_a / P_{0cc}\right)^{\frac{\gamma-1}{\gamma}}\right]}{\gamma - 1}}$$

$$= \sqrt{\frac{2.\gamma.T_{0cc}.\eta_{cycle}}{\gamma - 1}}$$

$$\approx \sqrt{\frac{2.\gamma.T_{0cc}}{\gamma - 1}} = \boldsymbol{V_{e-max}} \text{ (for limiting case - vaccuum)}$$

T_{0cc} – Comb. Chamber temp
T_e - Exhaust face temp.
P_a - Atm. Pressure
P_{0cc} - Comb Chamber Pr.
η_{cycle} - Ideal Cycle efficiency

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The Thrust Specific Fuel (Propellant) Consumption (TSFC) of a rocket is : $\frac{g.\dot{m}}{F} = \frac{g}{V_{ex}}$

The *reciprocal of Thrust per unit fuel weight* and is used as a measure of propulsive efficiency, and is called ***specific impulse***.

$$\text{Specific impulse} = I_{sp} = \frac{F_j}{g.\dot{m}}$$

- The specific impulse values at sea level and at altitude are not the same (for same propellant and nozzle), in terms of the measured thrust.

------- To be continued

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