Introduction to Aerospace Propulsion

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Lecture No - 37

Rockets, Missiles --- continued

In the last lecture fundamental parameters were introduced :

$$\mathbf{F_J}$$

$$V_{e\text{-max}}$$

$$\mathrm{I}_{\mathrm{sp}}$$

Another parameter is weight flow $\dot{\mathrm{W}} = \dot{m}.g$

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rocket thrust in the atmosphere.

If the exit area is A_{ex}, the exit pressure p_{ex}, and the altitude ambient pressure p_a (p_{SL-a} at sea level), then the altitude thrust is less than the thrust in a vacuum by the amount p_a .

sea level thrust of the rocket,

$$F_{SL-J} = \dot{m}V_{ex} + A_{ex}(p_{ex} - p_{SL-a})$$

at *altitude*,

$$F_j = \dot{m}V_{ex} + A_{ex}\left(p_{ex} - p_a\right)$$

Thus, thrust at any altitude

$$F_j = F_{SL-j} + A_{ex}(p_{SL-a} - p_a) = F_{SL-j} + p_{SL-a}.A_{ex}.(1-\delta)$$

Where, $\delta = \dfrac{p_a}{p_{SL-a}}$ Pr. drop with altitude

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Thrust in vacuum is : $$F_j = \dot{m}.V_{ex} + P_{ex}.A_{ex}$$

or, $$F_j = \frac{\dot{W}}{g}.V_{ex} + P_{ex}.A_{ex}$$

From these equations the *specific impulse (at S.L.)* is given as

$$I_{sp} = \frac{F_{SL-j} + p_{SL-a}(A_{ex})(1-\delta)}{g.\dot{m}}$$

Where,

$$\boxed{\delta = p_a / p_{0a}}$$

In vacuum this becomes

$$I_{sp} = \frac{V_{ex}}{g}$$

The characteristics of a rocket is also signified by a parameter called *characteristics velocity*,

$$V^* = V_e / C_F$$

where, C_F is the Thrust coefficient = $F_j / p_c A_t$
p_c is combustion chamber pressure and
A_t nozzle throat area

Now, if *weight flow rate* of propellant is given as one can define a *specific propellant consumption rate* as

$$\dot{W}_{sp} = \dot{W}/F = 1/I_{sp} = g/I_{sp}$$

and a *weight flow coefficient* as $C_w = \dot{W}/ p_c A_t$

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Thus, based on the above definitions one can write *characteristic velocity*

$$V^* = \frac{g}{\dot{W}_{sp} \cdot C_F} = \frac{g \cdot I}{C_F} = \frac{g}{C_w} = \frac{g \cdot p_c \cdot A_t}{\dot{W}}$$

- The combustion chamber pressure p_c is dependant on the chemical and the ignition properties of the propellants.
- These characteristics parameters vary with the propellant used.

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The ideal characteristic velocity may also be written as :

$$V^* = \frac{a_c}{\sqrt{\left[2\left(\frac{2}{k+1}\right)^{\frac{2}{k-1}}\left(\frac{k^2}{k+1}\right)\right]}}$$

a_c is the *acoustic velocity* of the gas in the combustion chamber and is decided by the thermodynamic state of the gas as specified in the value of specific heat ratio k≠γ , prevalent there. Thus V* is dependant only on the two parameters.

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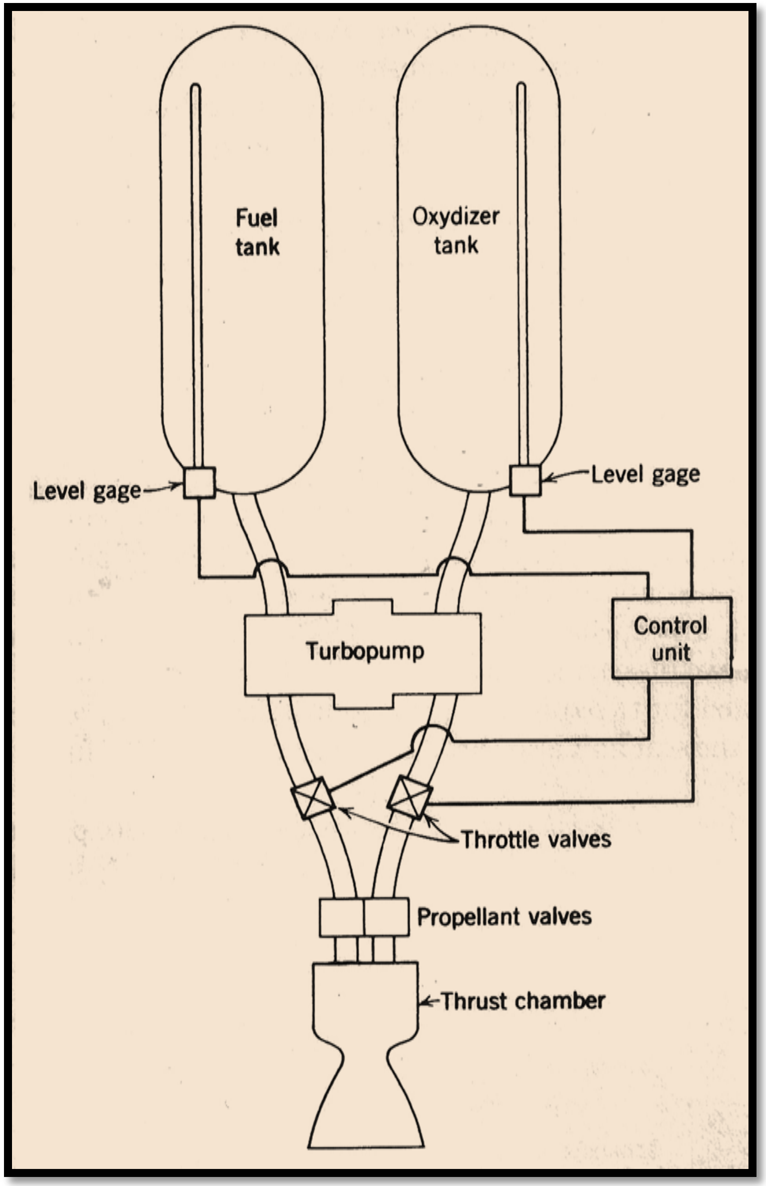

Liquid Rocket Motor

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A liquid rocket combustion chamber is designed to accommodate and allow sufficient resident time for the following job :

- Injection, atomization, vaporization and even mixing of liquid fuel and liquid oxidiser

- Thermal decomposition of the oxidizer to enable chemical reaction with fuel

- Ignition, flame stabilization and combustion of fuel, oxidizer mixture

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- Even dispersion of combustion products towards the exhaust nozzle
- The volume, length and shape of the combustion chamber needs to be selected to complete all the above steps. Various fuel-oxidizer combination provides for various characteristics length, $\mathbf{L^*}$ for rocket.

$$\mathbf{L^*} = \text{CC Volume/Throat Area} = \mathbf{V_{cc}} / \mathbf{A_t}$$

- The values of $\mathbf{L^*}$ are found experimentally.

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Some of the common liquid propellant fuel and oxidizer combinations are as follows:

Oxidiser	***Fuels***
Liquid Oxygen (O_2)	Liquid Hydrogen; Kerosene, Fluorine, Hydrazine, Ethanol, Methanol, Liquid ammonia,
Nitric Acid (HNO_3)	Hydrazine, Kerosene , Liquid Ammonia, Aniline, Turpentine
Hydrogen Peroxide (H_2O_2)	Ethanol, Methanol, Hydrazine, Kerosene, Ethylene Diamine

The highest specific impulse values are obtained by using hydrogen as a fuel and burning it either with oxygen or fluorine. At sea level, using a combustion chamber operating as 35 kN/m^2 absolute pressure, one can achieve

Hydrogen + Fluorine = 375 seconds;
Hydrogen + Oxygen = 362 seconds.

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Desirable properties of liquid propellants:

- Low Freezing point
- High specific gravity
- Good chemical stability during storage
- High specific heat, High thermal conductivity, and high decomposition temperatures
- Pumping properties – flowability (under Cryogenic condition)
- Temperature stability of physical properties e.g. viscosity, vapor pressure etc.(e.g. under cryogenic conditions)

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Solid Propellant Rockets

- The solid rocket motor are pre-fitted with the propellants inside them.
- Total absence of pumps, valves, pipelines, injectors and the control system makes solid rockets simpler devices.
- The shape and the size of the combustion chamber is decided by the shape and the size of the propellant.
- Which in turn is decided by its burning characteristics and the desired combustion characteristics, required thrust and specific impulse.
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- Various grain sizes shown in fig. are the designed for controlled burning in a desired manner to achieve required specific impulse.
- The fabrication, handling, storage and fitting inside the rocket motor of these grains are engineering problem, often quite expensive.
- Due to the shape / sizes of the propellants (*Fig*.) some of the propellants are designed for *restricted burning*, - others undergo *unrestricted burning*.
- Once the propellant is ignited it should burn smoothly along its exposed surfaces without detonations.

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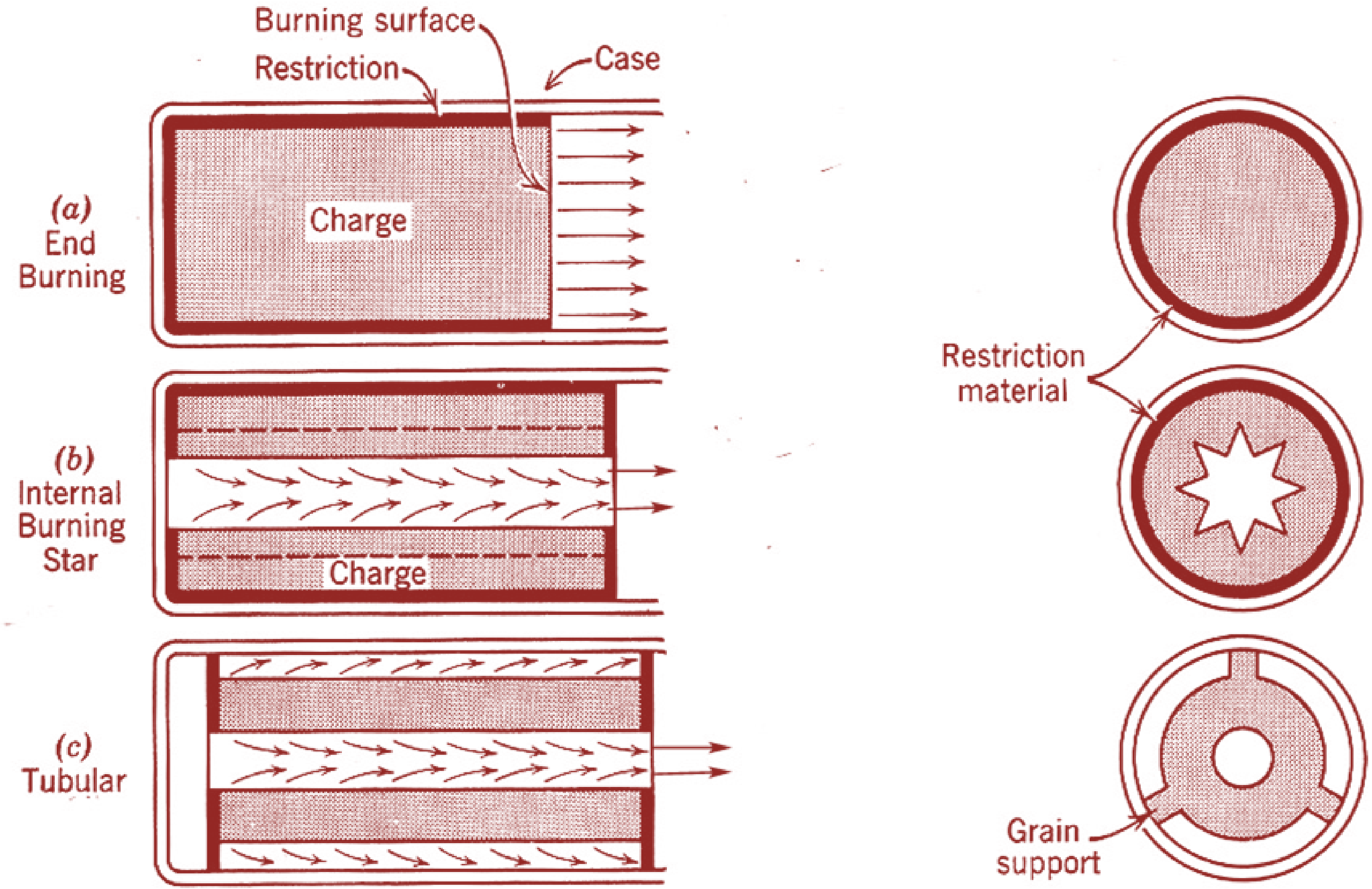
Designs (a) (b), (d) and (e) are ***restricted burning*** types; (c) (f) and (g) are ***unrestricted burning*** types



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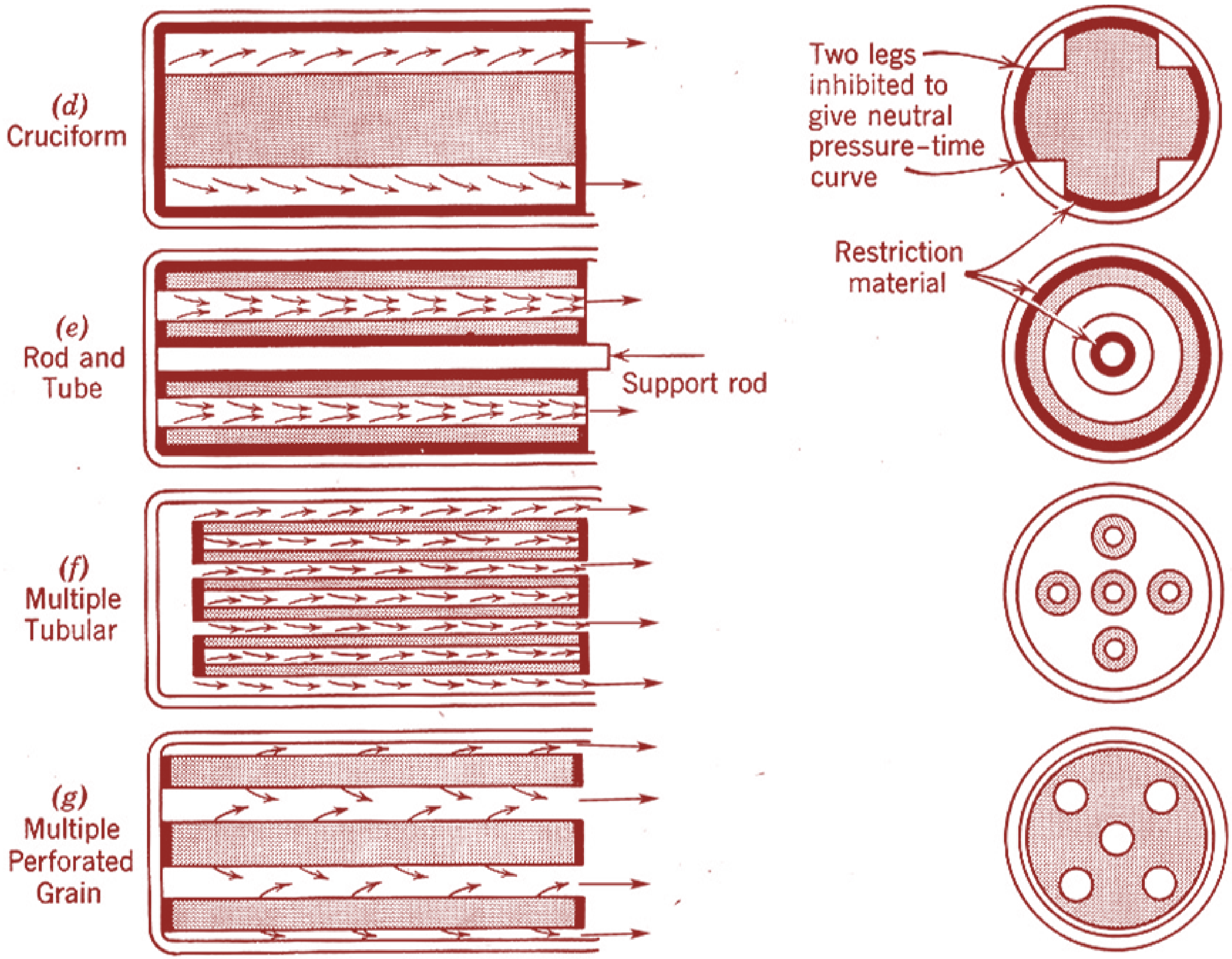
(d)
Cruciform
(e)
Rod and
Tube
Support rod
(f)
Multiple
Tubular
(g)
Multiple
Perforated
Grain
Two legs
inhibited to
give neutral
pressure-time
curve
Restriction
material

A solid propellant usually includes two or more of the following components :

- Oxidizer
- Fuel
- Chemical compound as binder
- Additives – to control burning and facilitate fabrication
- Inhibiters

<u>The fuel and the oxidizer are both solids and need to be mixed in correct proportion to get the best burning behavior.</u>

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By their chemical composition / fabrication method solid propellants are of 3 types :

(a) Double base propellants,
(b) Composite propellants,
(c) Multiple base propellant (4 to 8 chemicals).

Double base propellants have been used for many years in artillery rockets, missiles up to weight of about 10,000 kg and can produce specific impulse up to about 250 s. However most of the bigger rocket propellants are made of *composite propellants*.

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Desirable Properties for Solid Rockets

- High release of chemical energy
- Lower molecule weight
- No deterioration of mechanical and chemical properties during storage
- High density
- Relatively unaffected by atmospheric conditions
- High Temperature and Pressure for combustion initiation

--- Rockets and Nozzles---- to be Continued

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