Introduction to Aerospace Propulsion

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Lecture No - 35

Ramjets
and
Pulsejets

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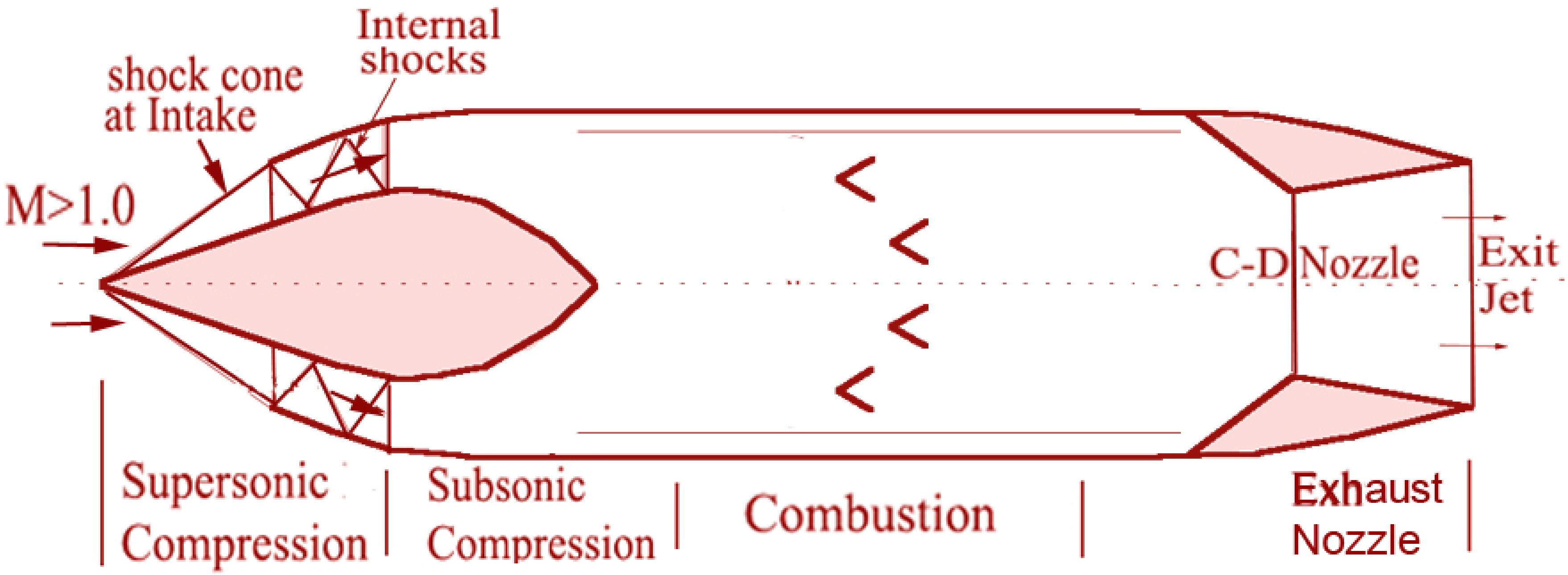
Ramjet Schematic



- The ramjet engine produces power by increasing the momentum of the working fluid, i.e. air.
- In contrast to the other air-breathing engines, the working cycle is done without compressor and turbine, and also without any need for enclosed combustion.
- Ramjet engine is mechanically the least complicated air-breathing jet engine for thrust production --- for flying vehicles.

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- Ramjets apply compression to the air by ram compression at very high speeds (M>2.0).
- All the compression is done in the diffusing (ram) process.
- This restricts the use of ramjet to only supersonic speeds. No Take off, Landing possible.
- At very high Mach numbers (>5.0) the shocks in the intake produce large losses that restricts the actual performance of the engine.

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- After the diffusion in Intake, fuel is injected into the stream in the combustion zone.
- The high temperature and high pressure gas is expanded through a nozzle, - to a supersonic flow at the exit.
- The mixture of air and burned fuel is exhausted through a <u>convergent-divergent (C-D) nozzle</u>.
- Exit pressure (P_e) is same as or nearly same as the ambient pressure. Thus the chocking pressure (P_c) at the throat is higher than the ambient pressure (P_a).

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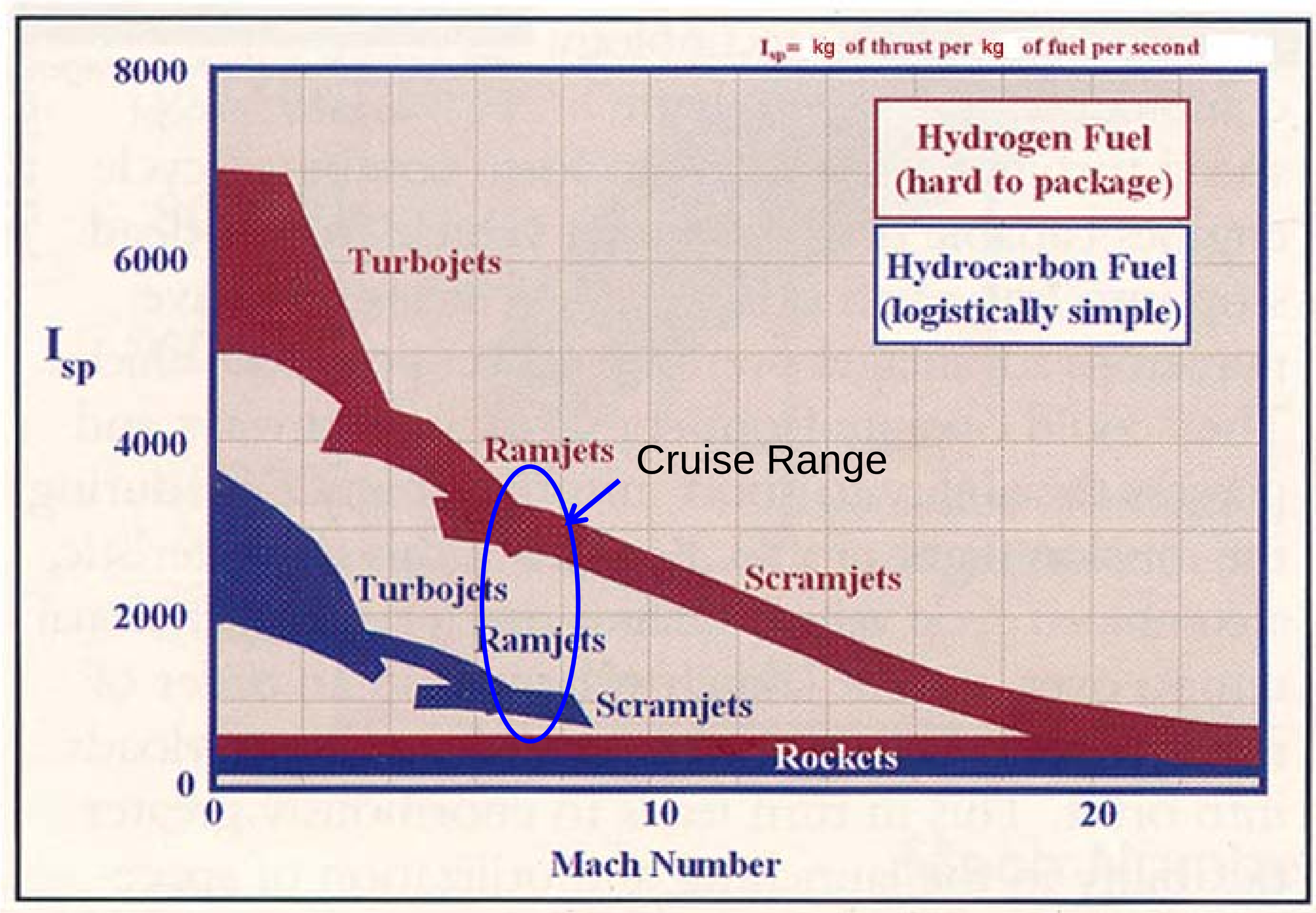
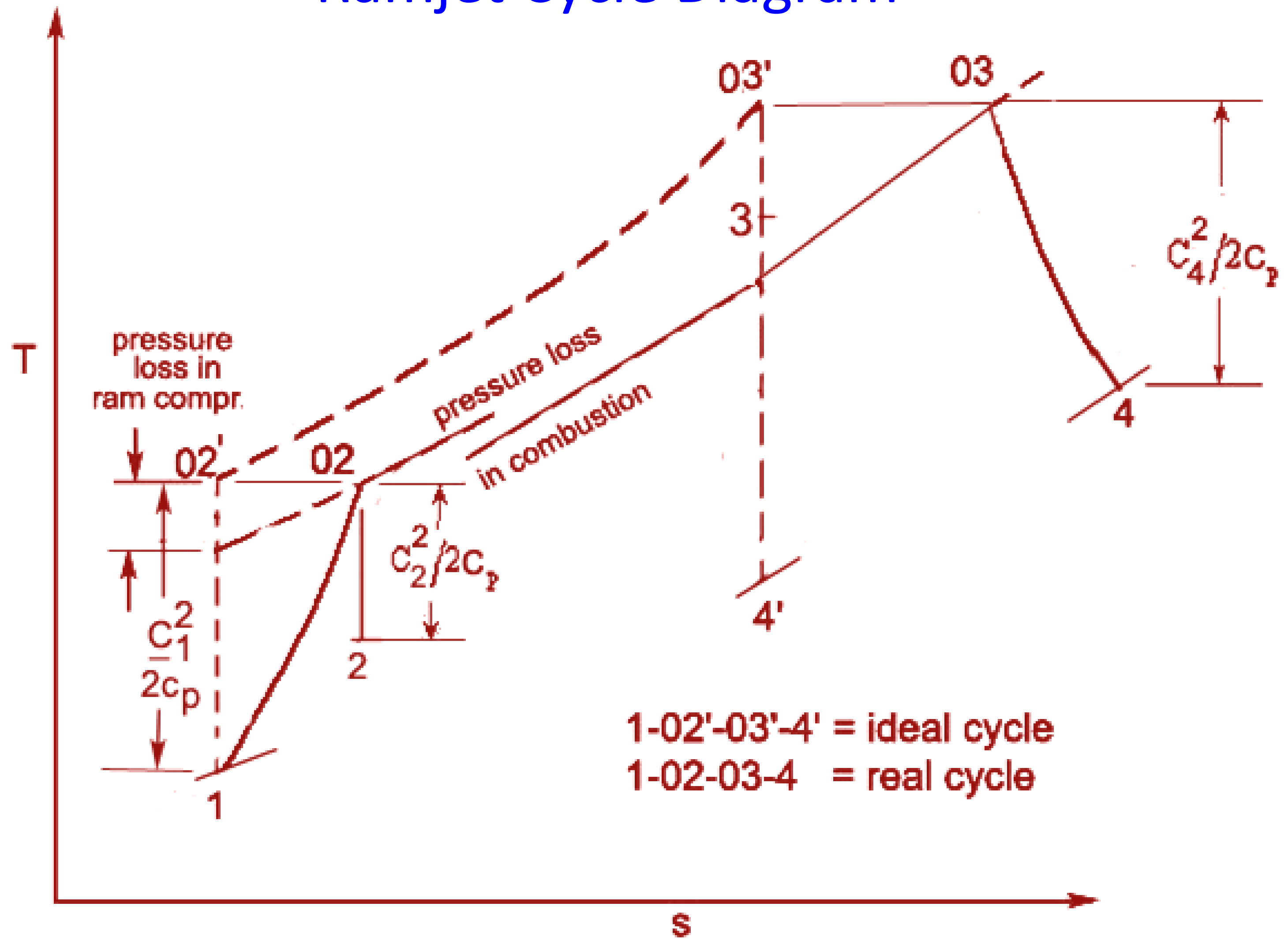
I_{sp} = Specific Impulse



Ramjet Cycle Diagram



- The ideal ramjet operates on a Jule-Brayton cycle.
- The actual cycle, has strong irreversibilities in the form of large pressure losses, practically at every step of the flow processes. (Fig.).
- As shown in the diagram the diffusion process is adiabatic but irreversible (large total pressure losses).
- The heat addition in the combustion chamber is accompanied (total) pressure loss.

- Through a multiplication of (total) pressure losses the exhaust nozzle entry pressure reached is substantially lower than that of an ideal engine

- As a result the pressure ratio (i.e. total-to-static) available across the nozzle, is significantly reduced compared to an ideal engine. Additional losses occur inside the exit nozzle.

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The general thrust equation can be written to include fuel addition. And by substituting the mass flow term from continuity condition, Thrust of the engine is :

$$F = \rho . V_a . A_1 \left(\overline{m} . V_e - V_a \right) + A_e . p_a . \left(\frac{p_e}{p_a} - 1 \right)$$

where, $\overline{m} = 1 + f$, **and** ***f*=fuel/air ratio, and A_1, A_e = Area of flow enttry and exit, and p_a , p_e are the ambient and the exit pressures**

Hence, *specific thrust*

$$C_F = \frac{F}{\dot{m}} = V_a . \left(\overline{m} \frac{V_e}{V_a} - 1 \right) + \frac{A_e}{A_1} . \frac{p_a}{\rho_a V_a} . \left(\frac{p_e}{p_a} - 1 \right)$$

For a reasonable value of specific thrust to be achieved, $V_e >> V_a$ i.e. substantial acceleration across the engine, or $p_e >> p_a$ i.e. a substantial pressure (static) increment inside the engine are required to be achieved.

Specific fuel consumption : The efficiency of an engine is often defined by its specific fuel consumption, which is defined under a specific operating condition, as :

$$sfc = \frac{\dot{m}_f}{F} = \frac{f}{F/\dot{m}_a} = \frac{f}{C_F}$$

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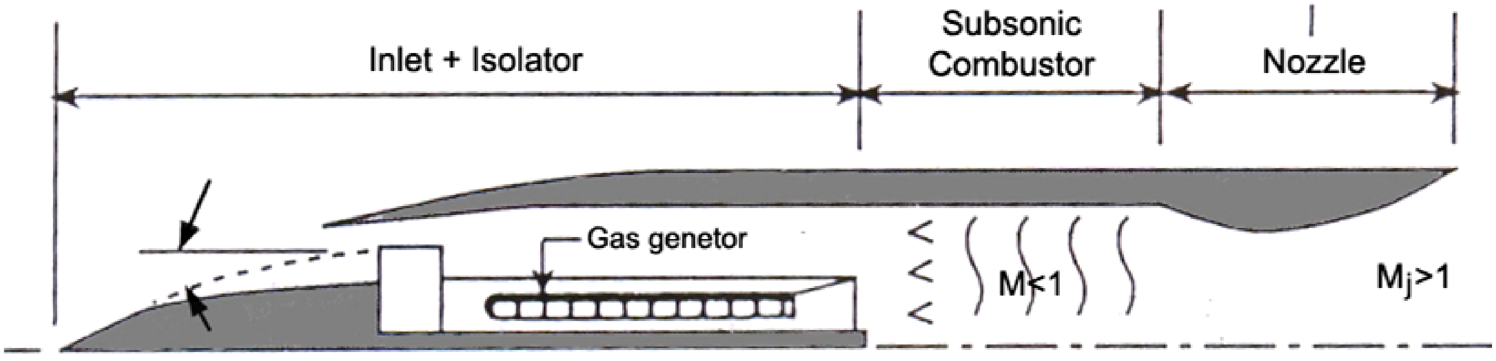
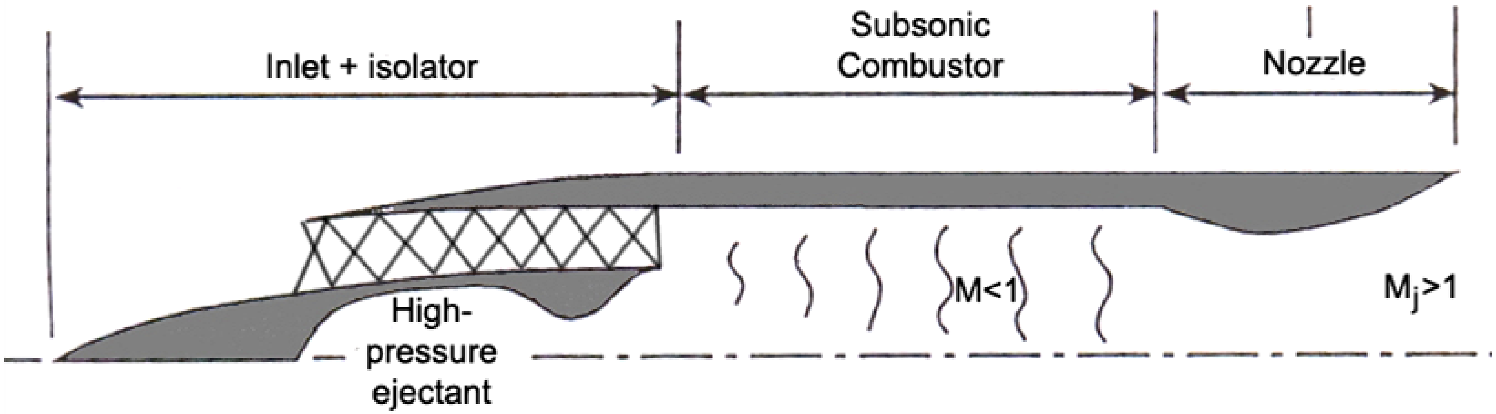
Efficiency : The *thermal efficiency* of an engine represents the fraction of heat released in the combustion process that is converted to work (in this case thrust work), and is a useful parameter for comparing various engine designs under standard operating conditions.

$$\eta = \frac{T.V_a}{f.\dot{m}_a.\dot{Q}_f}$$

where , $\dot{Q}_f$ = heating value of fuel, kJ/kg



Air-turbo rocket ramjet



Ejector ramjet

Schematics of generic hybrid ramjet engines that produce static thrust

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- At flight Mach 5 and above the unit becomes a **Supersonic Combustion Ramjet** (SCRAMJET) in which the combustion is done in supersonic flow.
- An isolator is inserted before the combustor to diffuse further through a shock train, producing a low supersonic flow in to the scramjet combustors.
- Scramjet produces useful thrust at higher flight Mach numbers

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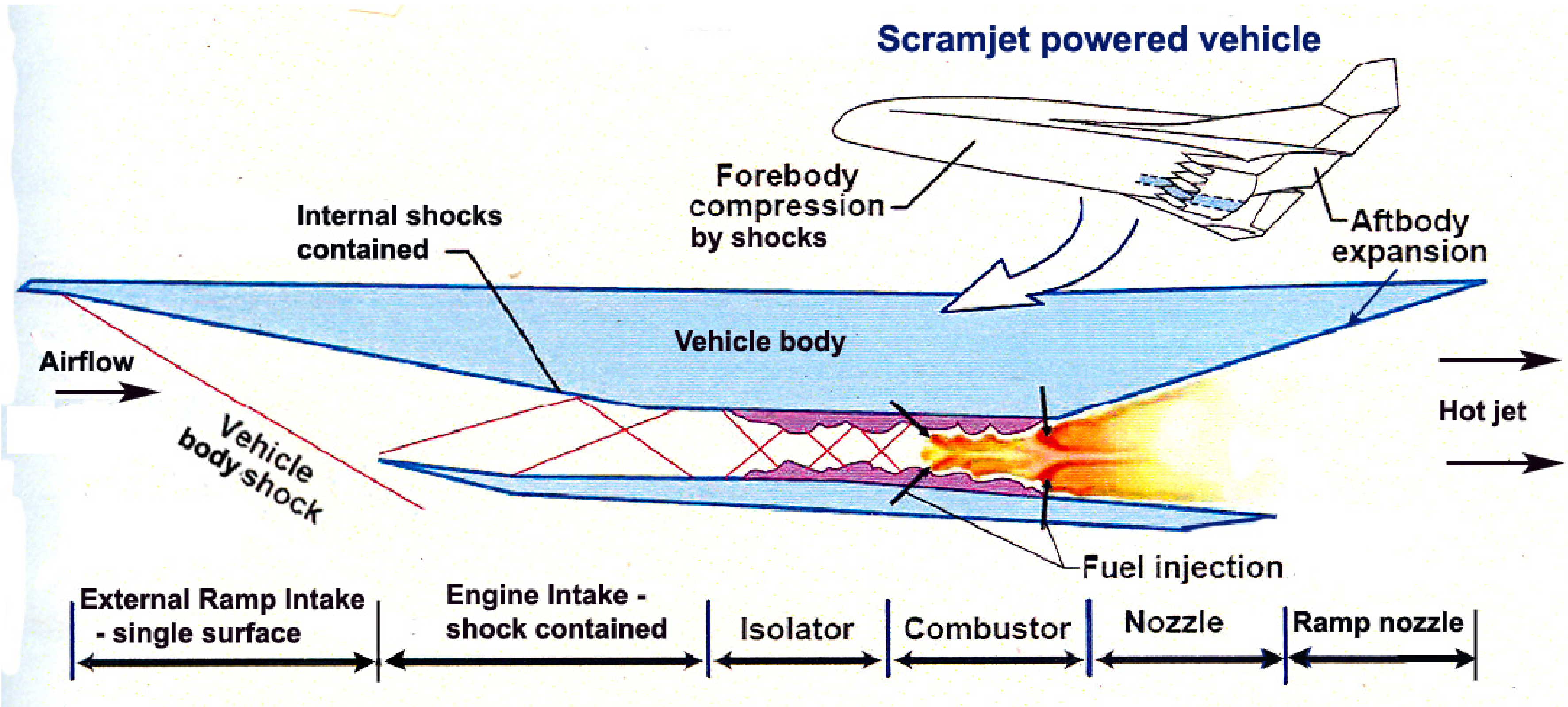
Scramjet Engine



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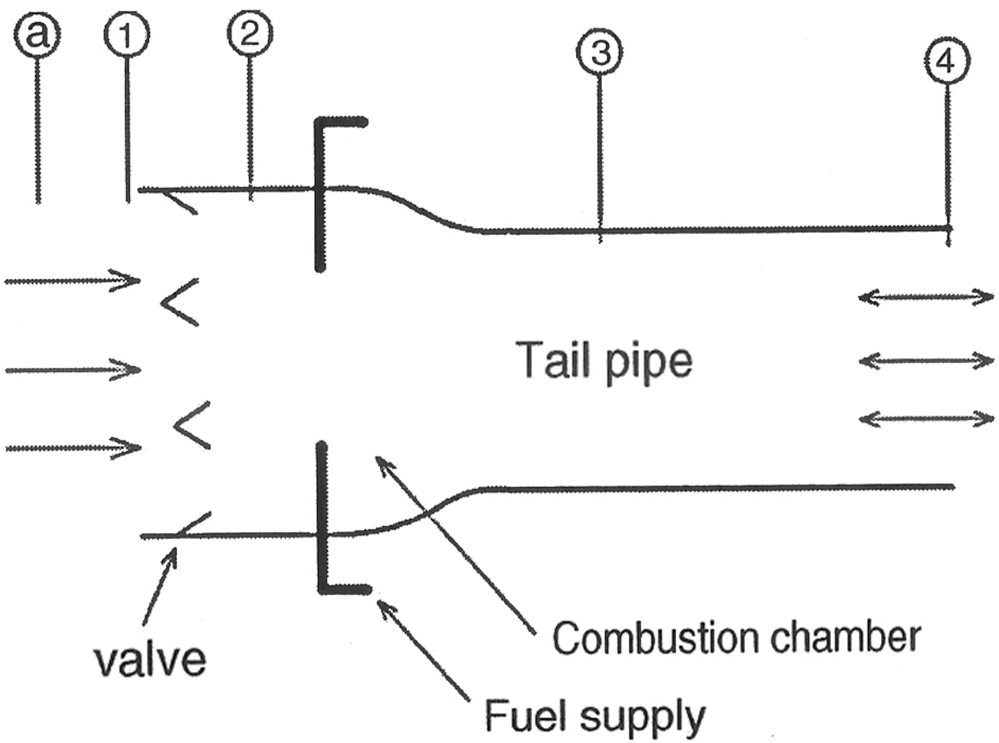
Pulsejets



Pulsejets - operation

1) A spark plug initiates the combustion process inside the combustion chamber when the inlet valves are closed
2) Combustion occurs in an enclosed chamber and is approximately a constant volume process
3) Combustion is nearly an explosion in that enclosed volume and raises the pressure and temperature to high values

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4) The high pressure and temperature forces the gases to flow out of the tail pipe and nozzle

5) Evacuation of the combustion chamber results in pressure drop – that opens the spring loaded inlet valve and air comes in from the intake

6) The spring loaded inlet valves are normally closed and open only when the pressure difference across it is attained.

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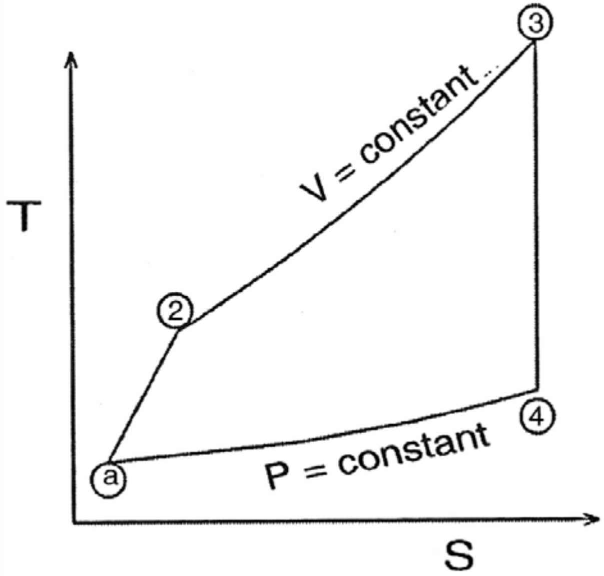

$$P_{01} = P_{0a} = P_a.\left(1+\frac{\gamma_{air}-1}{2}.M_a^2\right)^{\left[\frac{\gamma}{\gamma-1}\right]_{air}}$$

$$T_{01} = T_{0a} = T_a.\left(1+\frac{\gamma_{air}-1}{2}.M_a^2\right) = T_{02}$$

$$P_{02} = P_a.\left(1+\eta_I.\frac{\gamma_{air}-1}{2}.M_a^2\right)^{\left[\frac{\gamma}{\gamma-1}\right]_{air}}$$

$$P_{03} = P_{02}(T_{03}/T_{02})$$

$$\dot{m}_a.c_{p\text{-air}}.T_{02} + \dot{m}_f.Q_f.\eta_{cc} = (\dot{m}_a + \dot{m}_f).c_{gas}.T_{03}$$

$$\text{whereby, } f = \frac{\left(c_{gas}.T_{03} - c_{p\text{-air}}.T_{02}\right)}{\left(\eta_{cc}.Q_f\right) - \left(c_{gas}.T_{03}\right)}$$

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$$\frac{T_{04}}{T_4} = \left(\frac{P_{04}}{P_e}\right)^{\left[\frac{\gamma}{\gamma-1}\right]_{gas}} \quad ; \quad \text{and}, V_e = \sqrt{2.c_{p-gas}.T_{04}\left[1-\left(\frac{P_a}{P_{03}}\right)^{\left(\frac{\gamma-1}{\gamma}\right)_{gas}}\right]}$$

In a real cycle $P_e \neq P_a$; in an ideal cycle, $P_e = P_a$

Thrust, $$F = \dot{m}_a.(1+f).V_e - \dot{m}_a.V_a + (P_e - P_a).A_e$$

Specific Thrust $$\frac{F}{\dot{m}_a} = (1+f).V_e - V_a + \frac{1}{\dot{m}}(P_e - P_a).A_e$$

Thrust Specific fuel consumption may be written as

TSFC: $$\frac{\dot{m}_f}{F} = \frac{f}{F/\dot{m}_a}$$

Next

Rocket Propulsion