Jet Aircraft Propulsion

Prof. Bhaskar Roy, Prof. A M Pradeep
Department of Aerospace Engineering,
IIT Bombay

Lect-39

In this lecture...

- Components of ramjets and pulsejets
- Ramjet combustors
- Types of pulsejets: valved and valveless, Pulse detonation engines

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Ramjet engines

- Ramjet engines consist of intakes, combustors and nozzles.
- The entire compression process is accomplished in the intake of the ramjet.
- Intakes therefore form a very important component of ramjets.
- After the intake, the compressed air goes into the combustor.
- The combustion products are then expanded through the nozzle to generate thrust.

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Ramjet intakes

- Ramjet intakes are usually of the supersonic, variable ramp geometry.
- The ramp position will be adjusted depending upon the operating condition.
- The intake usually employs 2-3 oblique shocks followed by a normal shock for decelerating the flow.
- After the normal shock, the flow that is subsonic is further decelerated using a diffuser.

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Ramjet combustors

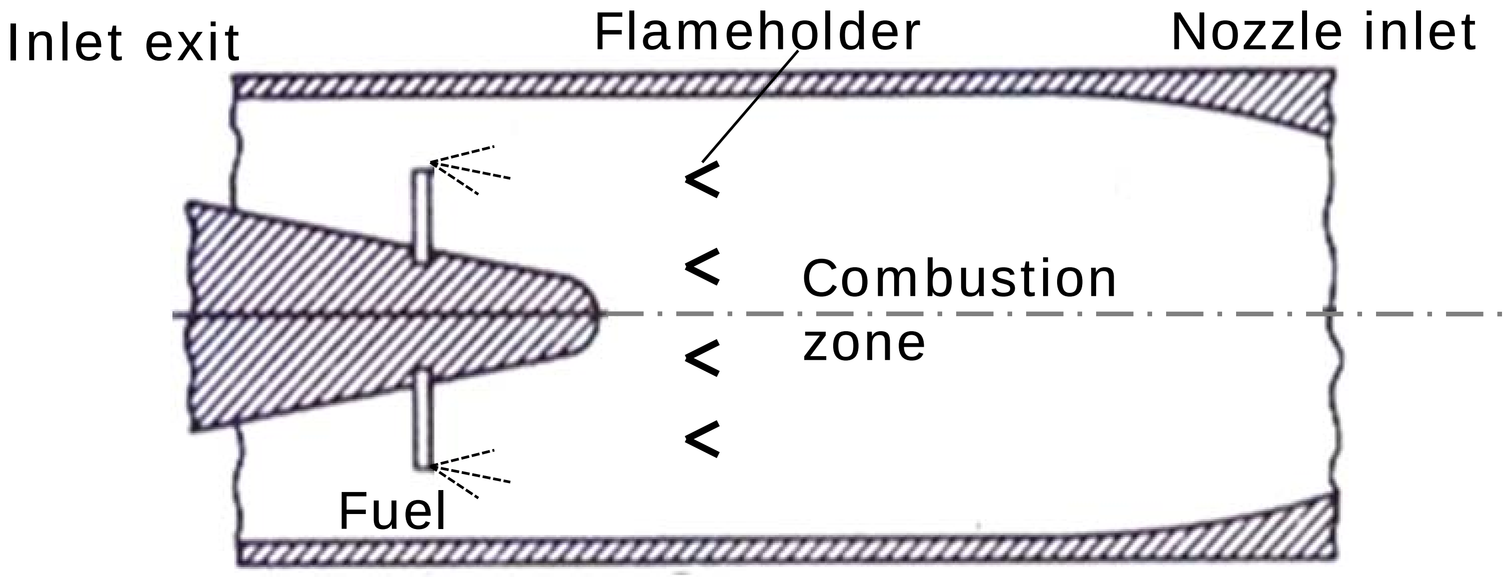
- Unlike other jet engines like turbojets, turbofans etc, there are no rotating components in ramjets.
- The temperatures in the combustion chamber are therefore much higher than the conventional jet engines.
- Maximum temperatures as high as 3000K are common in ramjets.
- Ramjet combustors are similar to the afterburners used in turbojet engines.

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Ramjet combustors

- Combustors have flameholders for stabilizing the flame within the combustor.
- The length of the combustor depends upon the fuel used, the injector characteristics and the flame holders.
- Though flameholders are essential to ensure stable combustion, they also lead to total pressure losses.
- Designers would need to optimize the blockage due to flameholders.

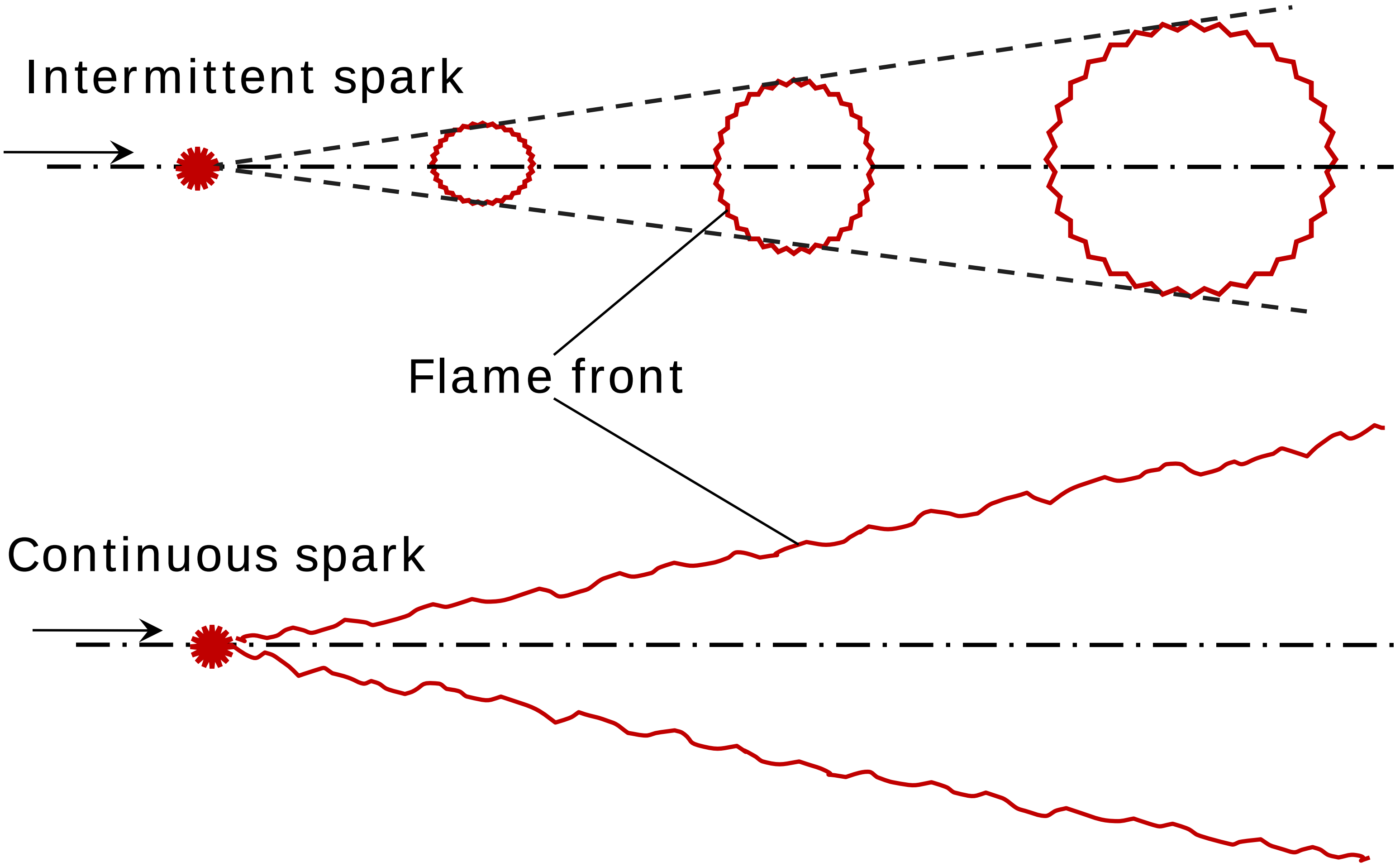
Ramjet combustors



Schematic of a typical ramjet combustion chamber

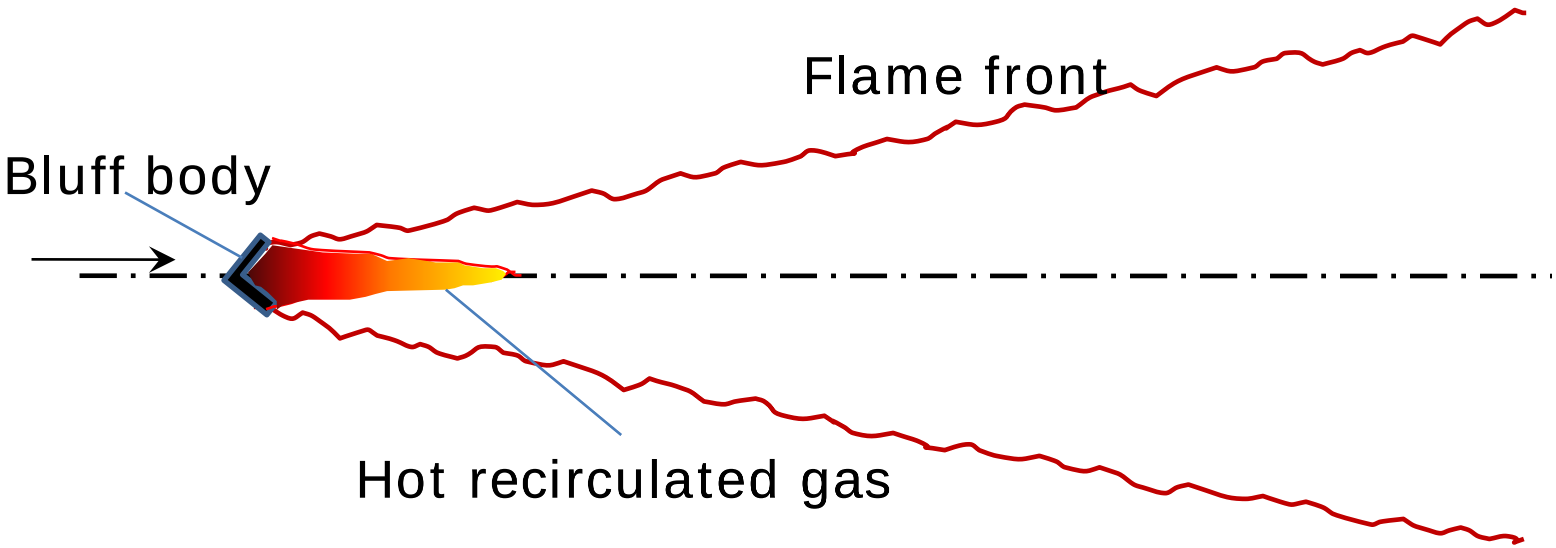
Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Ramjet combustors



Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Ramjet combustors



Operation of a flameholder in a ramjet combustor

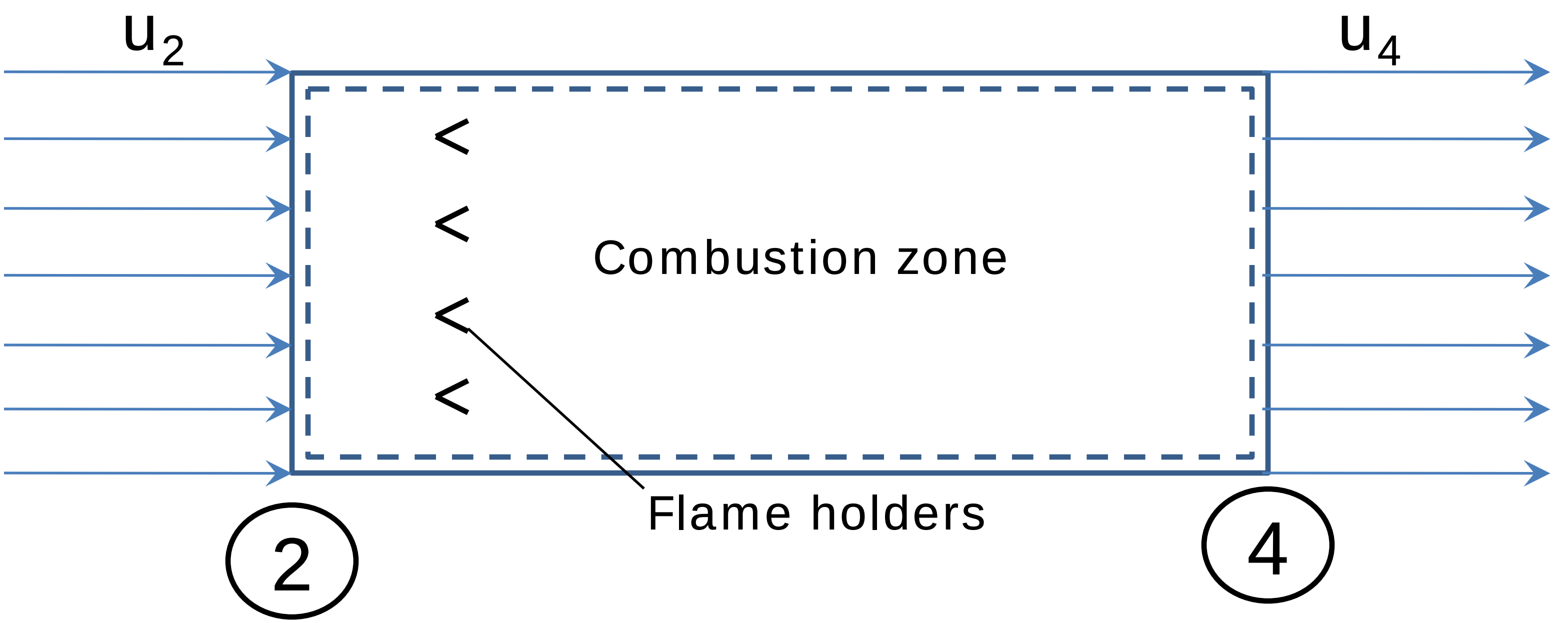
Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Ramjet combustors

- Even in the absence of frictional drag due to the flameholders, the heating process in a constant area duct will lead to stagnation pressure loss.
- Let us consider a one-dimensional flow in an afterburner.
- The flow entering and leaving the combustor are assumed to be uniform.
- The flameholders exert a total leftward drag, *D*, on the flow.

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Ramjet combustors



Simplified combustion chamber flow

Ramjet combustors

$$(P_2 - P_4)A - D = \dot{m}_4 u_4 - \dot{m}_2 u_2$$

or, $P_2 - P_4 = \rho_4 u_4^2 - \rho_2 u_2^2 + K(\tfrac{1}{2}\rho_2 u_2^2)$

where, K is the ratio of pressure drop due to friction.

Since, $M^2 = u^2 / \left(\dfrac{\gamma P}{\rho}\right)$

We can express $\dfrac{P_2}{P_4} = 1 + \gamma M_4^2 - \gamma M_2^2 \dfrac{P_2}{P_4} + K\dfrac{\gamma M_2^2}{2}\dfrac{P_2}{P_4}$

or, $\dfrac{P_2}{P_4} = \dfrac{1 + \gamma M_4^2}{1 + \gamma M_2^2 (1 - \dfrac{K}{2})}$

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Ramjet combustors

In terms of the total pressure ratio :

$$\frac{P_{04}}{P_{02}} = \frac{1+\gamma M_2^2\left(1-\frac{K}{2}\right)}{1+\gamma M_4^2}\left[\frac{1+\frac{\gamma-1}{2}\gamma M_4^2}{1+\frac{\gamma-1}{2}\gamma M_2^2}\right]^{\gamma/(\gamma-1)}$$

If we assume that $\dot{m}_4 = \dot{m}_2$ and that $P = \rho RT$

$$\frac{P_2}{P_4} = \frac{u_4}{u_2}\frac{T_2}{T_4} = \frac{M_4}{M_2}\sqrt{\frac{T_2}{T_4}} = \frac{M_4}{M_2}\sqrt{\frac{T_{02}}{T_{04}}\frac{1+\frac{\gamma-1}{2}\gamma M_4^2}{1+\frac{\gamma-1}{2}\gamma M_2^2}}$$

The stagnation temperature ratio can be expressed as,

$$\frac{T_{04}}{T_{02}} = \frac{{M_4}^2}{{M_2}^2}\frac{1+\frac{\gamma-1}{2}\gamma M_4^2}{1+\frac{\gamma-1}{2}\gamma M_2^2}\frac{\left[1+\gamma M_2^2\left(1-\frac{K}{2}\right)\right]^2}{[1+\gamma M_4^2]^2}$$

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Ramjet nozzles

- Nozzles expand the combustion products coming from the combustor and generate thrust.
- Nozzles in ramjets are usually of the converging-diverging type.
- They are normally axisymmetric with or without provision for geometry variation.
- Variable geometry is required for optimum operation under various operating conditions.

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Variants of ramjet engines

- Ramjets can be designed in a variety of configurations.
- Conventional ramjets: Can type ramjets (CRJ)
- Solid fuelled ramjets (SFRJ), Liquid fuelled ramjets (LFRJ) and Gaseous fuelled ramjets (GFRJ).
- Integral rocket-ramjets (IRR): SFIRR, LFIRR and GFIRR
- Combined cycle: Air-turboramjet (ATR)
- Ejector Ramjets (ERJ)

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Pulsejet engines

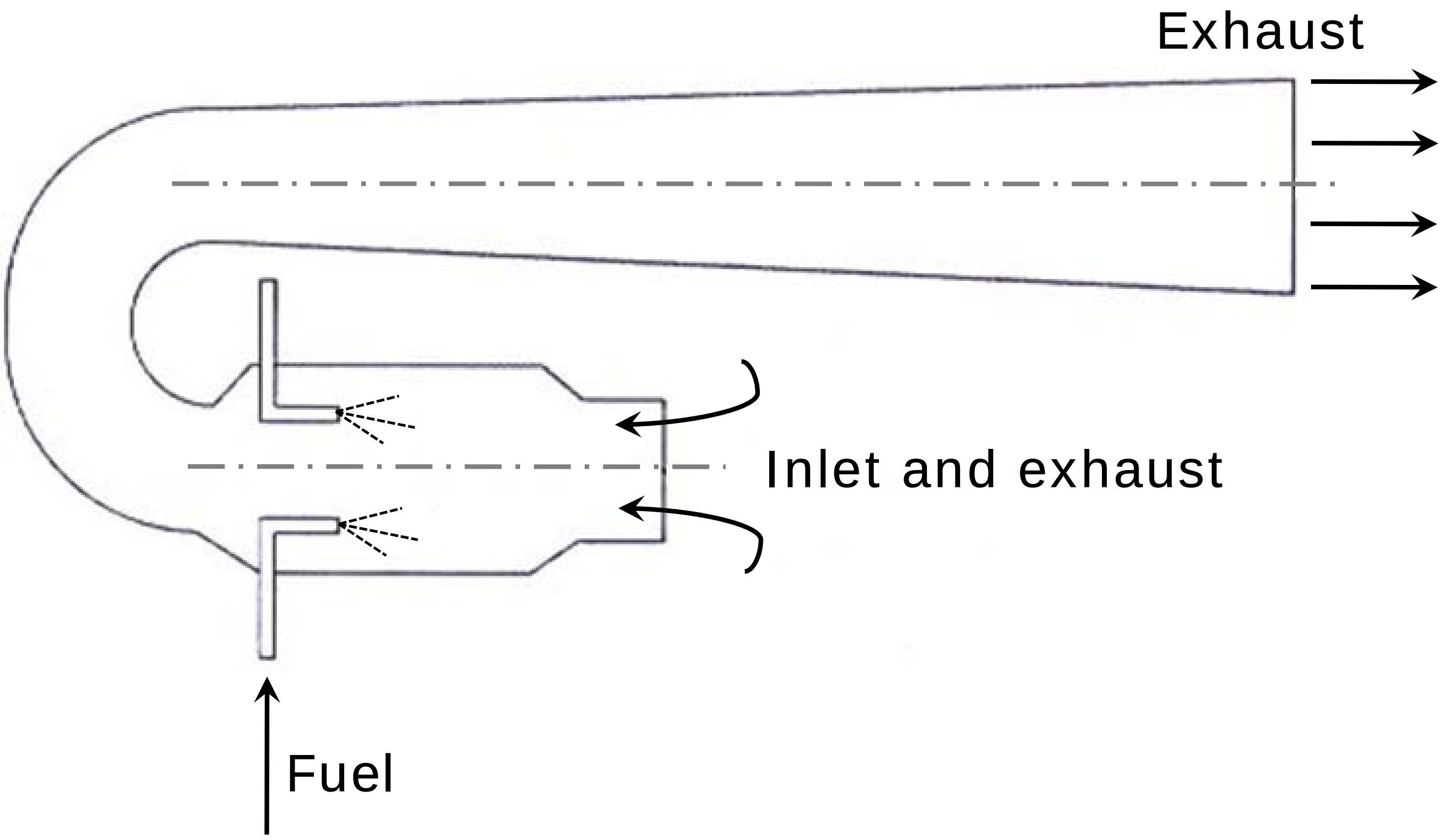
- There are two types of pulsejet engines: valved-type and valve-less type.
- Valved-type pulsejet have been the more popularly used versions.
- In valved type engines, the pulsing is accomplished using a set of valves.
- The combustion in the engine is self-sustaining.
- The valves operate when the fuel-air mixture ignites in the combustor.
- The combustion products are expelled through the tailpipe to create thrust.

Valveless pulsejet engines

- The main disadvantage of valved pulsejet engines is the use of mechanical valves.
- Wear and tear, reliability and noise problems can be partly overcome by valveless pulsejets.
- These engines do not have mechanical valves, but have aerodynamic valves.
- One of the most successful valveless pulsejet engines, Lockwood-Hiller engines, have a “U” bend.
- The intake and exhaust pipes face the same direction.

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Valveless pulsejet engines



Schematic of a valveless pulsejet engine

Valveless pulsejet engines

- Combustion process generates two shock wave fronts.
- By appropriately tuning the system, a stable, resonating combustion leading to be considerable thrust generation, can be achieved.
- Because of the deflagrating nature of the combustion, valveless pulsejet have a rather clean combustion.
- Valveless pulsejets have been successfully demonstrated for powering small sized as well as very large sized aircraft.

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Valveless pulsejet engines

An aircraft with a valveless pulsejet engine

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Pulse Detonation Engines

- Pulse detonation engines (PDE) have been demonstrated conceptually.
- It is expected to deliver efficiencies higher than conventional gas turbine engines.
- Pulse detonation engines also have no moving parts like a ramjet.
- PDE detonate rather than deflagrate their fuel.
- Detonation involves supersonic combustion of the fuel.

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Pulse Detonation Engines

- PDE are envisaged to be used for supersonic flights.
- PDEs use intermittent detonation waves to generate thrust.
- PDE operation is not governed by the acoustics of the system.
- This renders better control of the engine unlike conventional pulsejets.
- PDE generate higher specific thrust than a comparable ramjet even at lower subsonic speeds.

Pulse Detonation Engines

- PDE may be used as a stand-alone engine, combined cycle or as a hybrid engine.
- Pure PDE simply have an array of detonation tubes to generate thrust.
- Combined cycle PDE involve adding a PDE to the flow path of a ramjet or scramjet enabling operation from subsonic to hypersonic speeds.
- Hybrid engines involve use of PDE along with a conventional jet engine.

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

In this lecture...

- Components of ramjets and pulsejets
- Ramjet combustors
- Types of pulsejets: valved and valveless, Pulse detonation engines

Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay