Jet Aircraft Propulsion

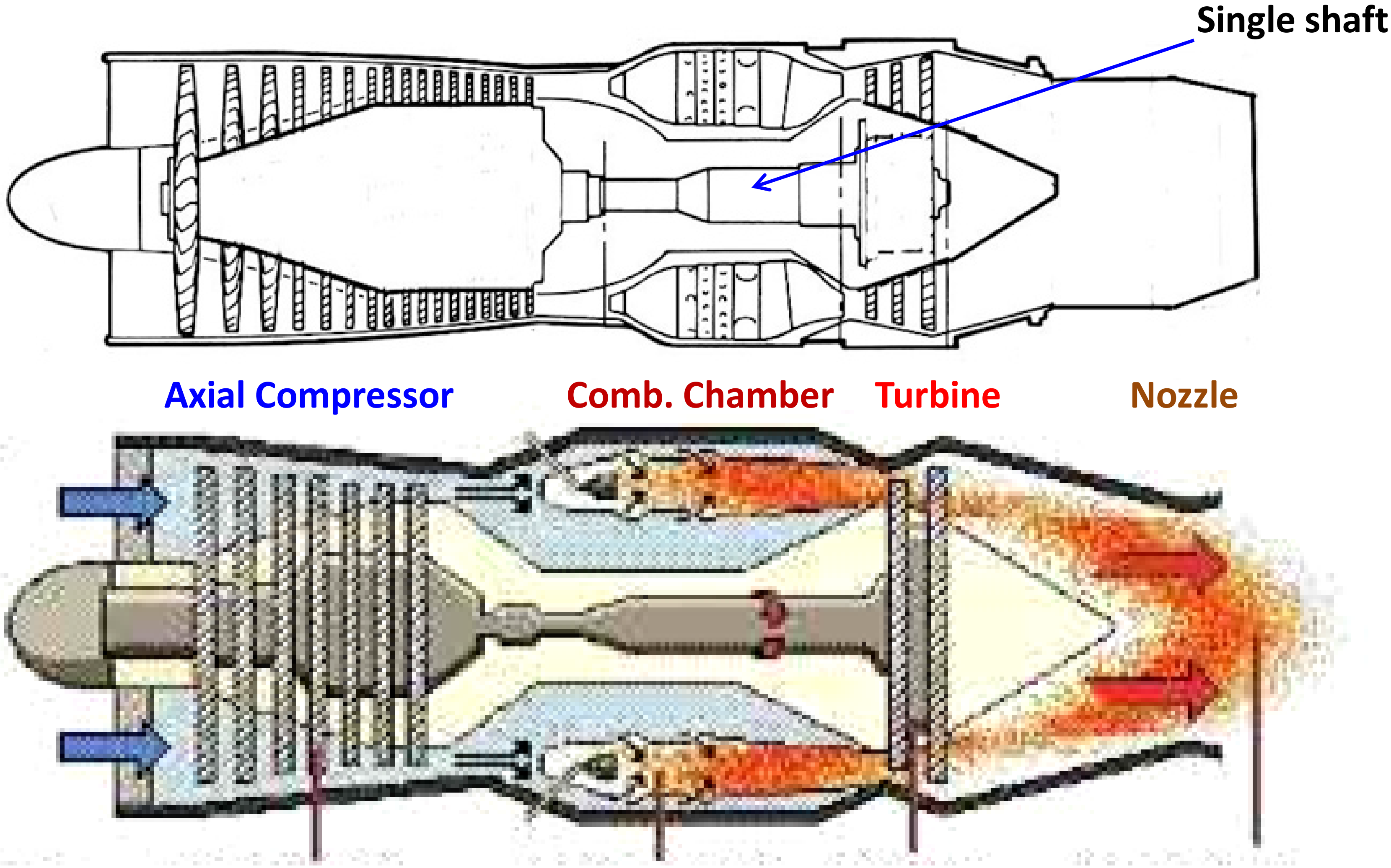
Prof. Bhaskar Roy, Prof. A M Pradeep
Department of Aerospace Engineering,
IIT Bombay

Lecture 4

Performance of a basic Jet engine

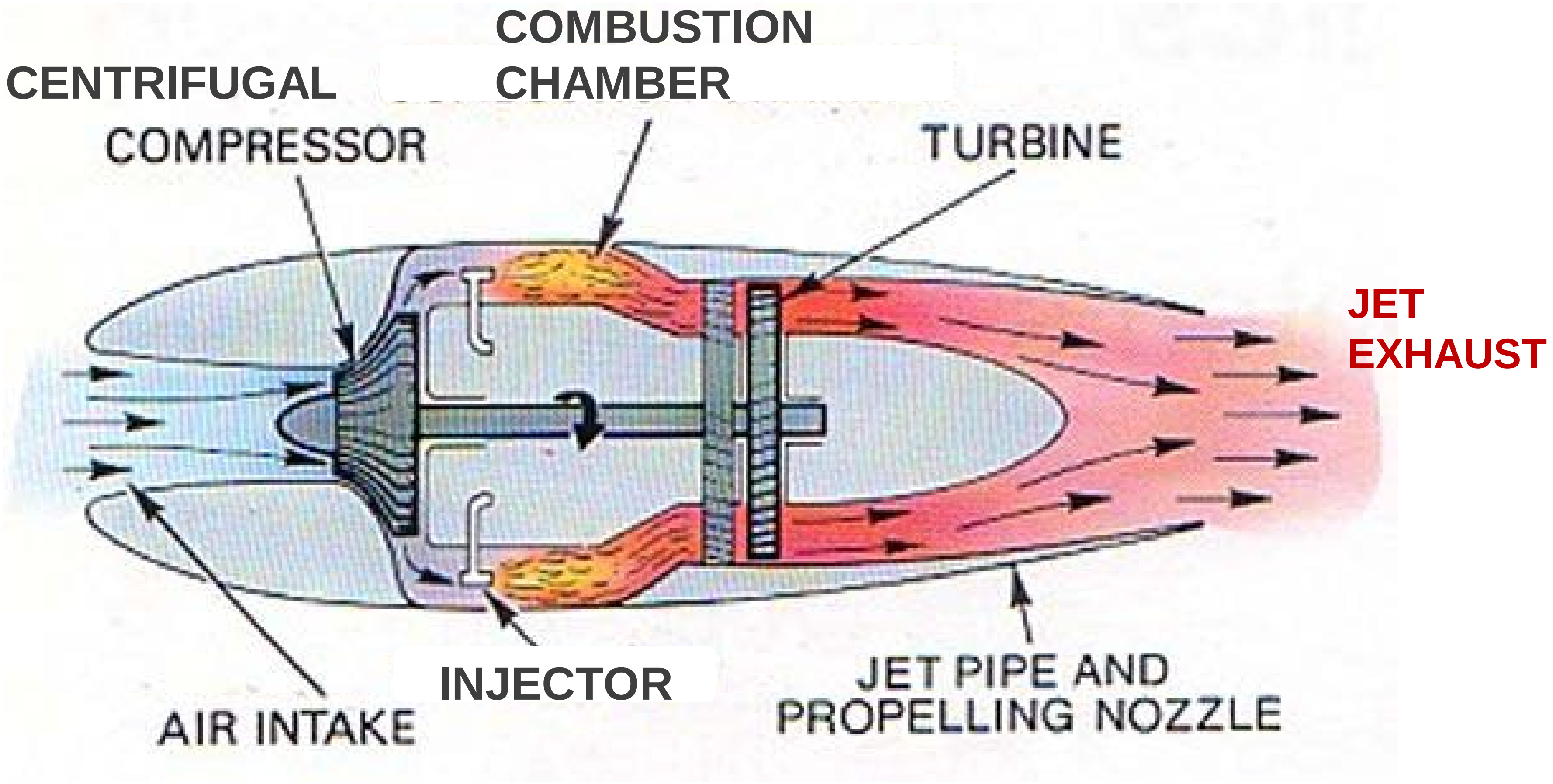
Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Simple single spool turbojet engine

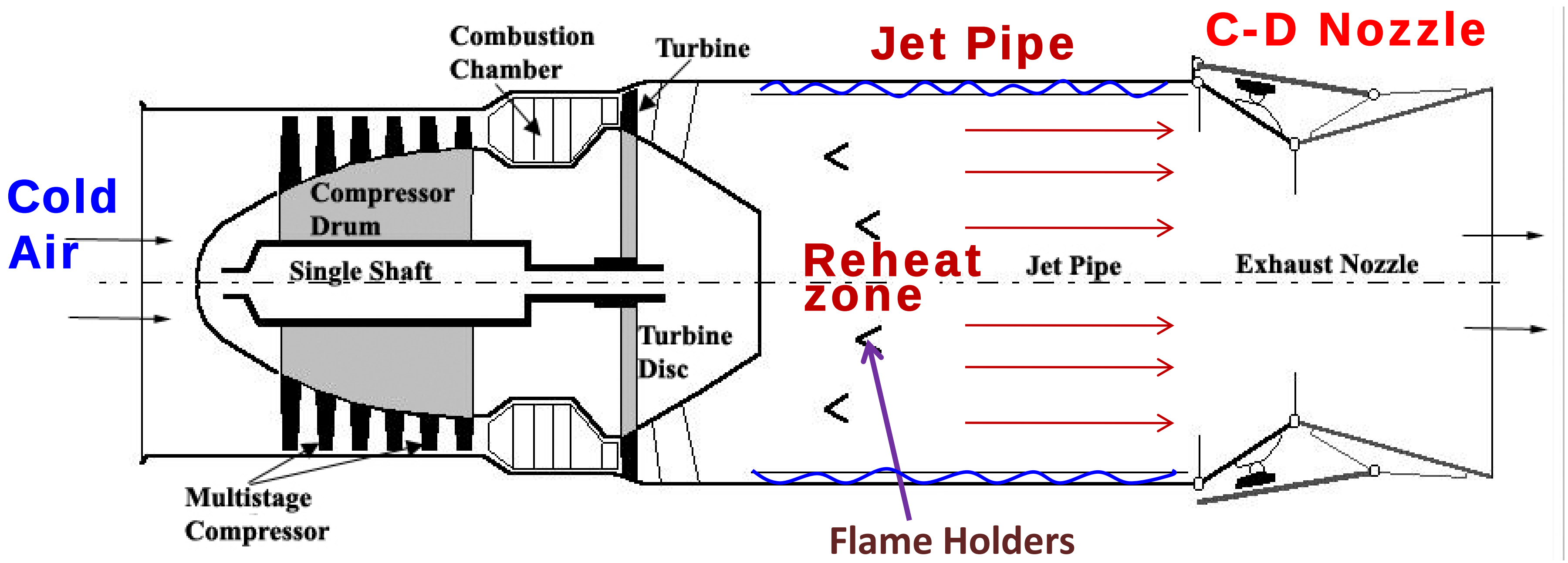


Prof. Bhaskar Roy, Prof. A M Pradeep, Department of Aerospace, IIT Bombay

Single Spool Turbojet Engine



Single Spool Turbojet Engine with Reheat



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

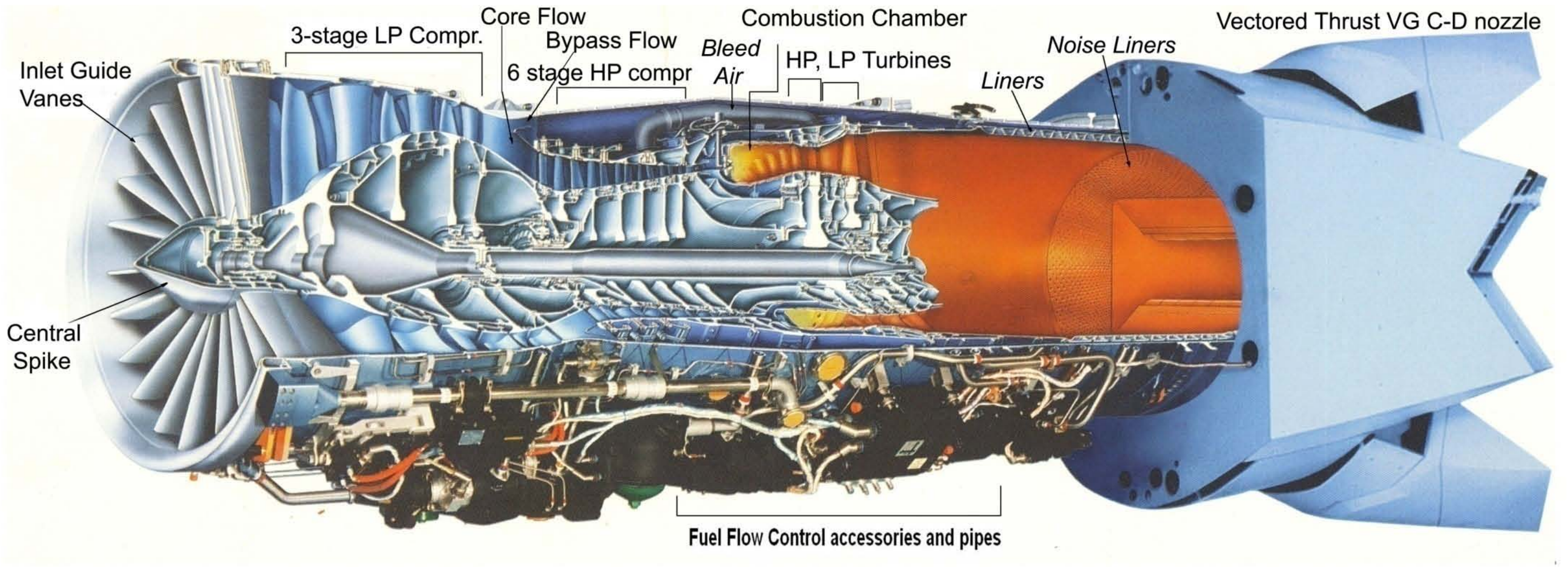
Consider the Thrust Equation

$$F_n = \dot{m}.V_e - \dot{m}.V_a + A_{e.}(P_e - P_a)$$

- By Reheating it is intended to increase magnitude of the exit velocity **V_e by** employing Convergent-Divergent nozzle which can produce supersonic exit velocity
- Increased V_e would decrease P_e and take it below P_a
- This would result in a negative pressure thrust
- Hence, it is necessary that a reheat engine has sufficient pressure after the turbine to create high velocity jet. For this a larger compressor is required.

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

Compressors 9 stages **Jet Pipe** **Nozzle system**



A modern afterburning very low bypass turbofan engine

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

Thrust of a basic turbojet engine (momentum thrust)

$$F_n = (\dot{m}_a + \dot{m}_f) V_e - \dot{m}_a . V_a$$

Where, $\dot{m}_a$ is the air mass flow through the engine

$\dot{m}_f$ is the fuel mass flow injected in to the engine

V_e , V_a are the air velocity into the engine and the same exiting the engine

V_e is dependant on η_{energy}

V_e is also dependant on $\eta_{propulsive}$

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

Thrust of a reheat turbojet engine (momentum thrust)

$$F_n = (\dot{m}_a + \dot{m}_{f\text{-}CC} + \dot{m}_{f\text{-}Rht})V_e - \dot{m}_a . V_a$$

Where $\dot{m}_{f\text{-}Reheat}$ is the fuel input during the reheat or afterburning process

V_e is dependant on η_{energy}, and $\eta_{propulsive}$

Hence unless the fuel is burn efficiently and then energy is converted efficiently to V_e thrust production will not be efficient

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

The overall engine efficiencies are given by

$$\eta_o = \frac{\dot{m}.V_a.(V_e - V_a)}{\dot{m}_f.\dot{Q}_{fuel}} = \eta_p.\eta_e$$

$$\eta_{o\text{-}reheat} = \frac{\dot{m}.V_a.(V_e - V_a)}{[\dot{m}_{f\text{-}cc} + m_{f\text{-}rht}].\dot{Q}_{fuel}} = \eta_{p\text{-}AB}.\eta_{e\text{-}AB}$$

Specific fuel consumptions

$$SFC = \frac{\dot{m}_{f-cc}}{F_n}$$

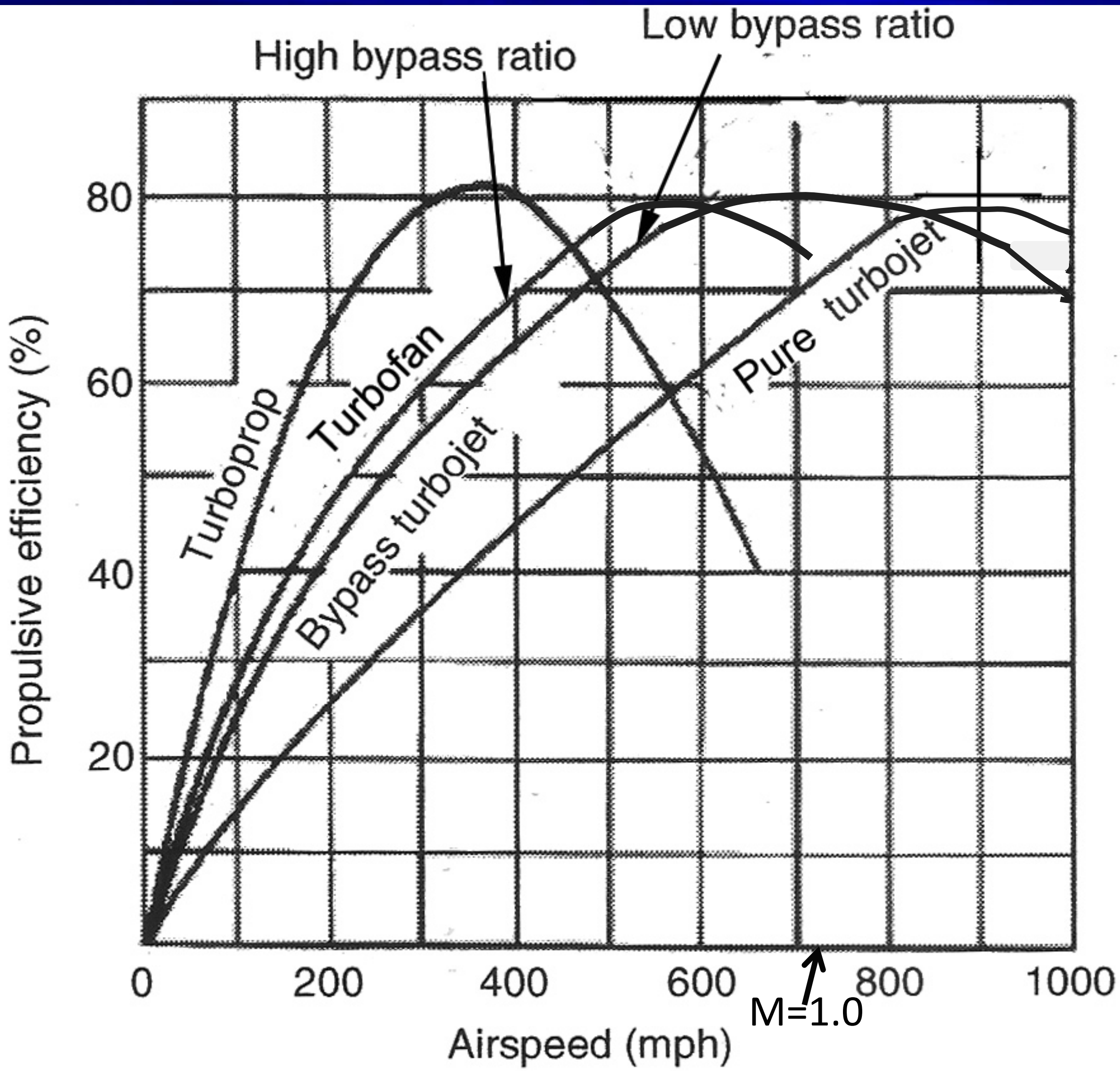
$$SFC_{Reheat} = \frac{\dot{m}_{f-cc} + \dot{m}_{f-rht}}{F_{n-reheat}}$$

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

- For jet engines with reheat or afterburning, the fuel consumption would be quite high, and SFC would show up as high value.

- In such operation sheer thrust requirement outweighs the high SFC.

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



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

Thrust of a bypass engine

$$F_n = [(\dot{m}_a + \dot{m}_f) V_{e\text{-}hot} - \dot{m}_a . V_a]_{hot\text{-}jet}$$

$$+ \ \dot{m}_{a\text{-}bypass} [V_{e\text{-}bypass} - V_a]$$

SFC of a bypass engine

$$SFC = \frac{\dot{m}_{f-cc}}{F_{n-hot} + F_{n-cold}}$$

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

Overall Efficiency of Bypass Jet engine

$$\eta = \frac{\dot{m}.V_a.(V_e - V_a)}{\dot{m}_f.\dot{Q}_{fuel}} = \eta_p.\eta_e$$

Exhaust Jet waste

$$\frac{\dot{m}_{hot}.(V_{e\text{-}hot} - V_a)^2 + \dot{m}_{cold}.(V_{e\text{-}bypass} - V_a)^2}{2}$$

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

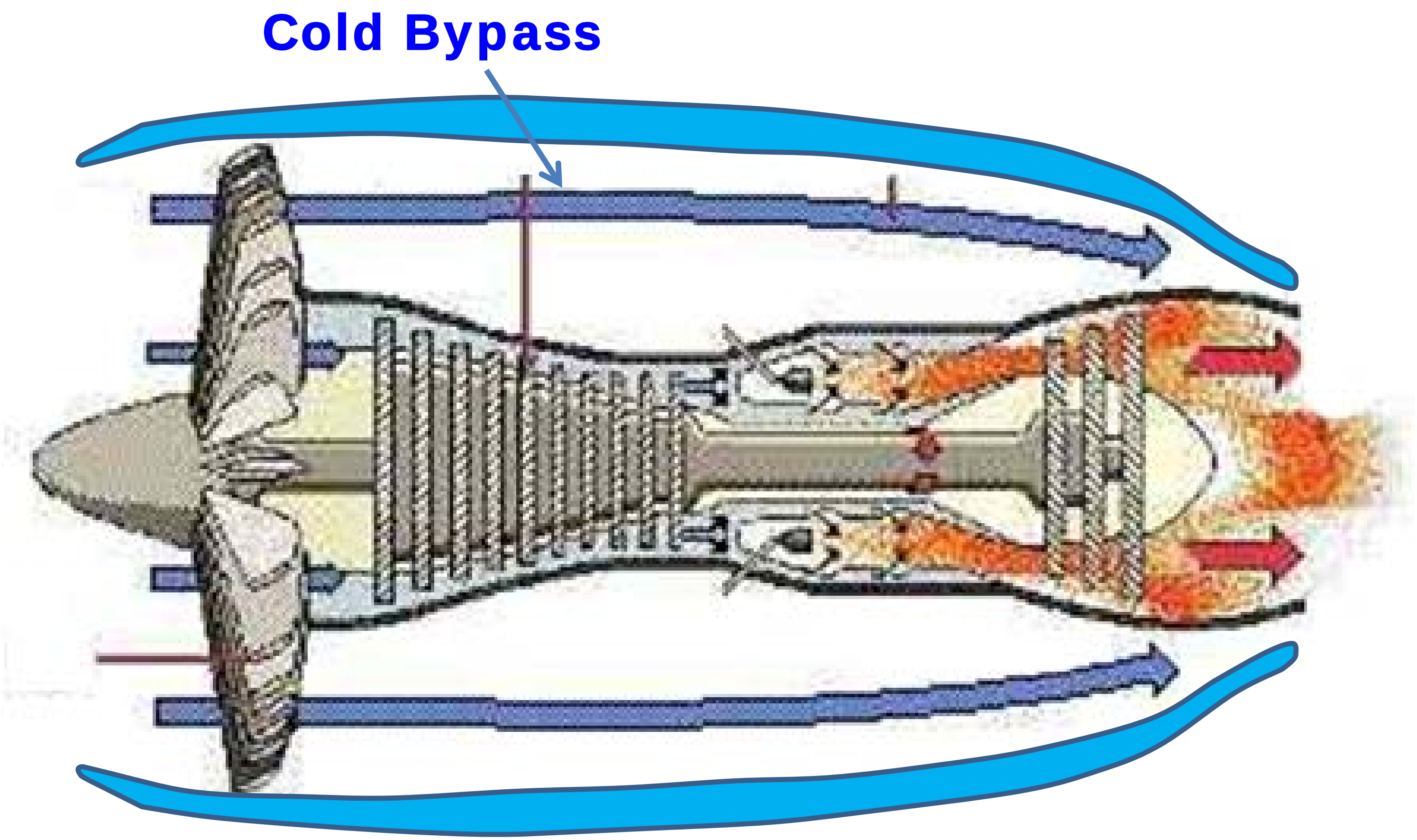
Propulsive Efficiency of the bypass jet engine

$$\eta_p = \frac{[\dot{m}_a . V_a . (V_e - V_a)]_{hot} + [\dot{m}_a . V_a . (V_e - V_a)]_{bypass}}{\dot{m}_{a\text{-core}} . [V_a . (V_e - V_a)]_{hot} + \dot{m}_{a\text{-bypass}} [V_a . (V_e - V_a)]_{bypass} + \dot{m}_{a\text{-core}} \frac{(V_{e\text{-hot}} - V_a)^2}{2} + \dot{m}_{a\text{-bypass}} \frac{(V_{e\text{-cold}} - V_a)^2}{2}}$$

$$= \frac{2}{1 + \frac{V_{e-average}}{V_a}} \qquad \text{where, } V_{e\text{-average}} = \frac{\dot{m}_{a\text{-hot}} . V_{e\text{-hot}} + \dot{m}_{a\text{-bypass}} . V_{e\text{-bypass}}}{\dot{m}_{a\text{-hot}} + \dot{m}_{a\text{-bypass}}}$$

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

Single Spool Turbofan engine



Next class :

Multi-spool Turbojet and Turbofan engines

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