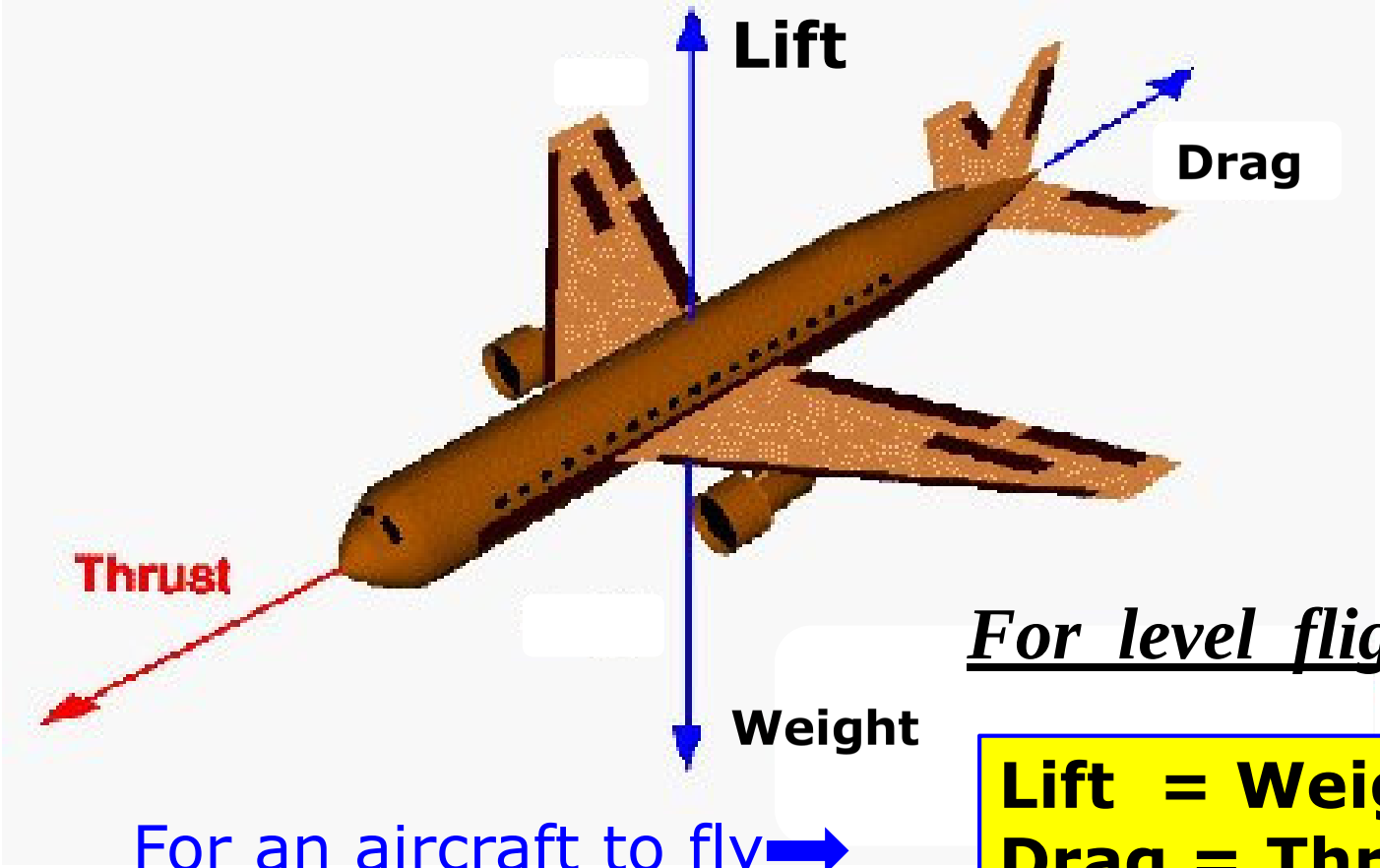
How the thrust is created for flying

- The aircraft is to be moved forward, forcing it to run through still air at a high speed. Only then necessary lift is created for it to fly. This is a continuous requirement.

- This forward thrust for the aircraft comes from one of the two sources: i) a rotating propeller powered by an engine or, ii) a pure Jet engine.

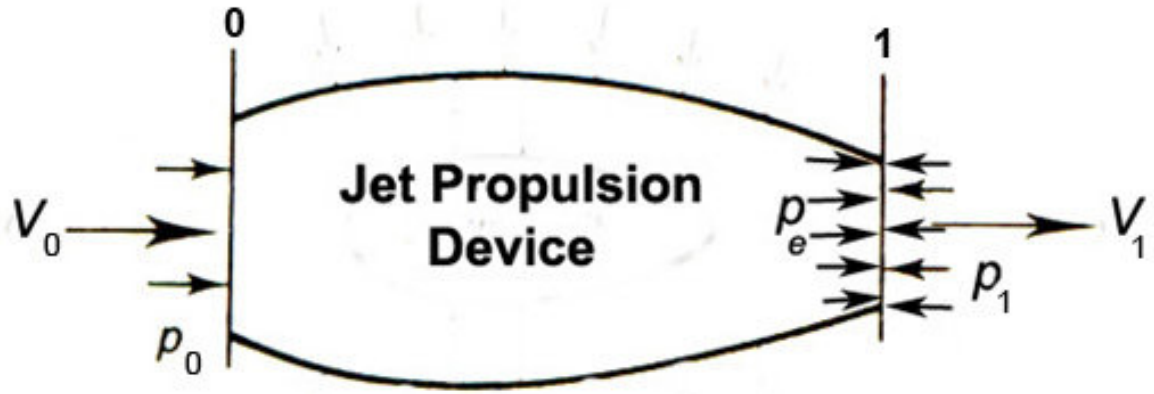
Thrust requirement for aircraft



For level flight

Lift = Weight
Drag = Thrust

For an aircraft to fly ➡



Differential form of thrust generation, $F = \frac{d(mv)}{dt}$

Thrust based on acceleration of mass $F = m\,a$

Thrust based on velocity change in a time period $F = \frac{m(V_1 - V_0)}{(t_1 - t_0)}$

Acceleration, Velocity, Momentum and Force are vector quantities. They all have specific magnitude & direction

Thrust needs to be created for all flight regimes of the aircraft:

- **Take-off** – normally maximum thrust
- **Climb** – reducing from maximum thrust
- **Cruise** – normally minimum thrust
- **Manoevres** – variable thrust
- **Acceleration & Deceleration** - variable
- **Descend** – Low thrust
- **Landing** – Just Less than maximum thrust

• Thrust is a mechanical **force** which is generated through the **reaction** of accelerating a mass of gas, as explained by Newton's III Law of motion.

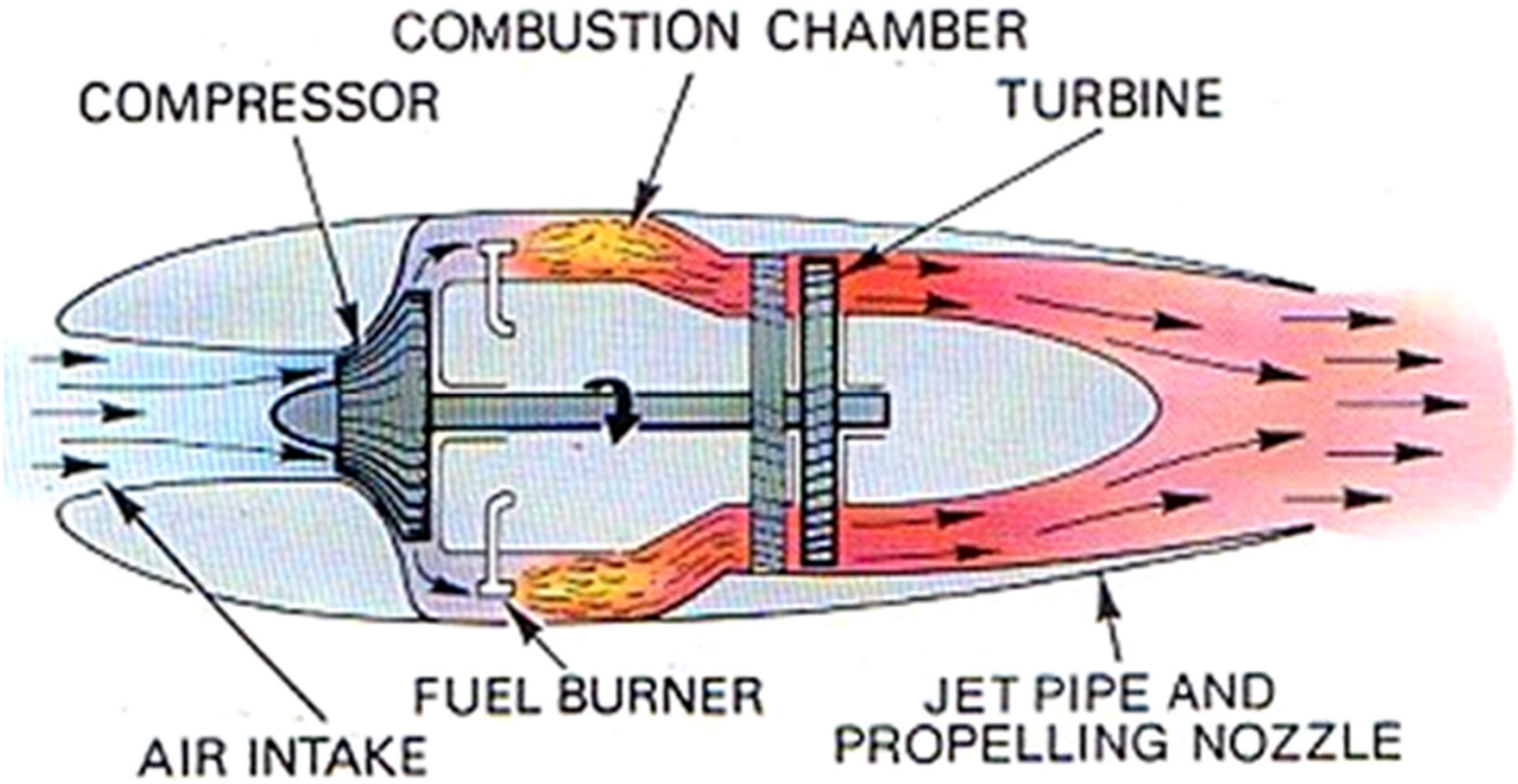
• A gas or air, used as a **working fluid** is accelerated to the rear and the engine attached to the aircraft are accelerated in the forward direction.

• To accelerate the gas, we need some kind of propulsion system. A propulsion system is an energy consuming machine which accelerates a gas/ air.

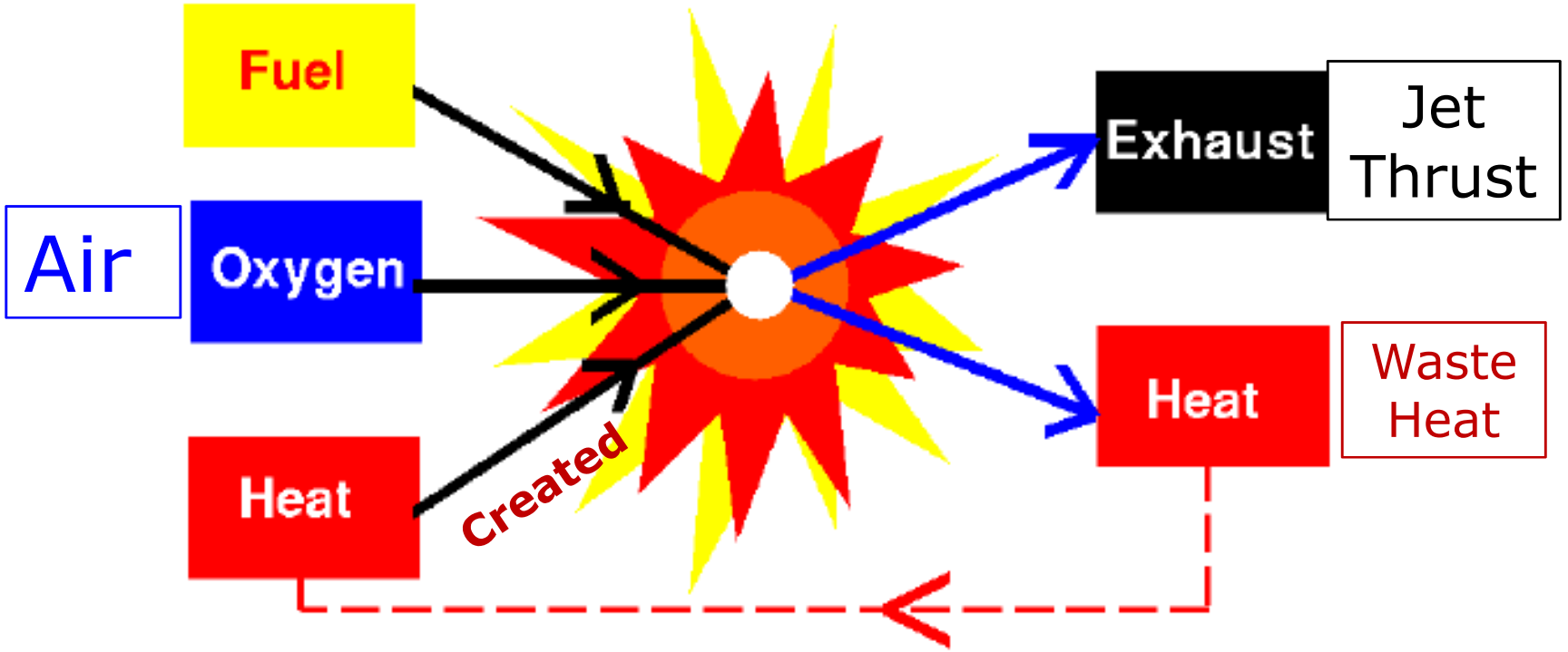
- But if we are dealing with a fluid (liquid or gas) and particularly if we are dealing with a moving fluid, keeping track of the mass gets tricky. For a moving fluid, the most important parameter is the mass flow rate.

- Since the mass flow rate already contains the time dependence (mass/time), we can express the rate of change of momentum across the propulsion device as mass flow rate times the change in the flow velocity.

A Jet Engine Schematic

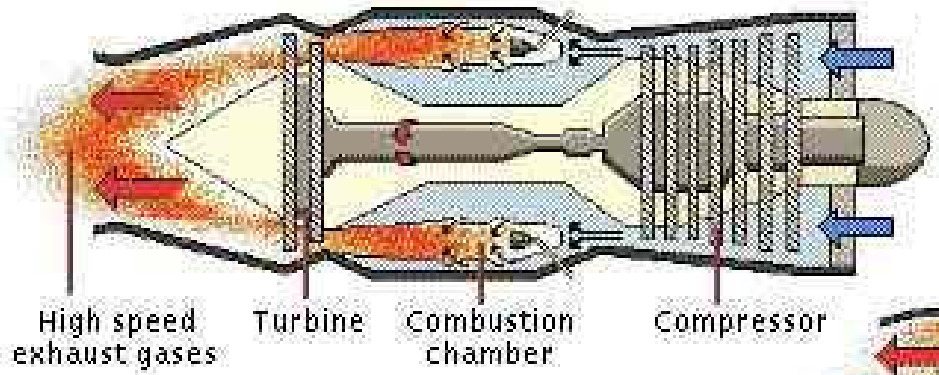


Jet Engine fundamentally is a Heat Engine



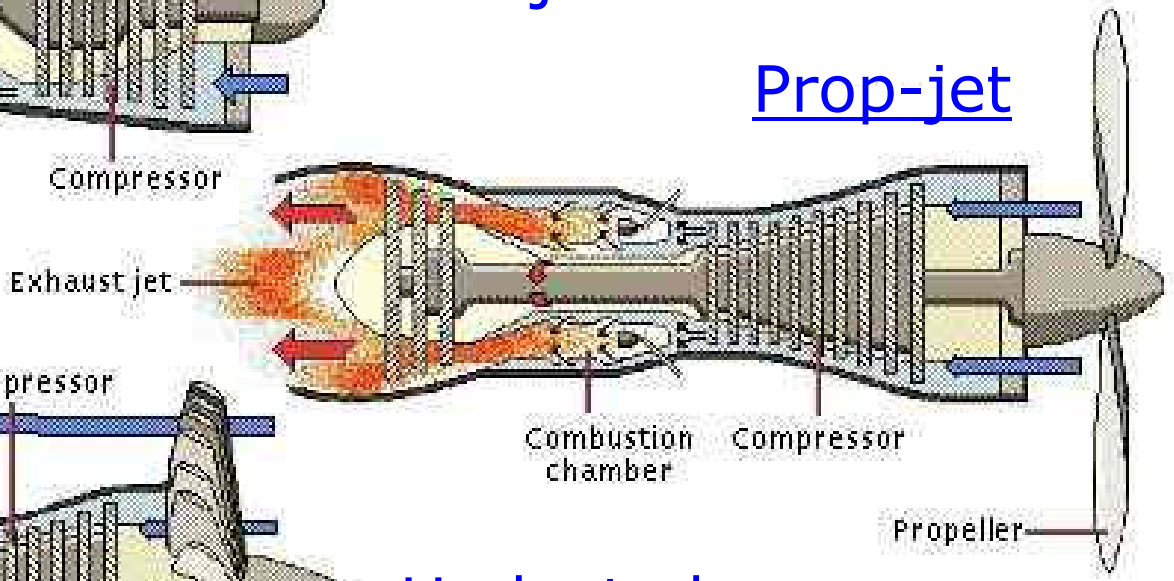
***Combustion** is the energy input in to the engine and is key to the operation of a jet engine*

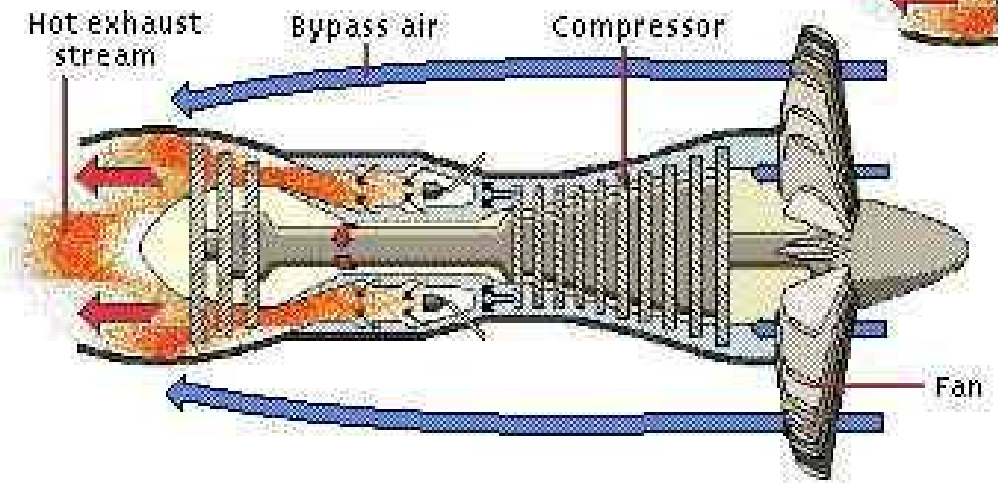
Fundamental varieties of jet engine



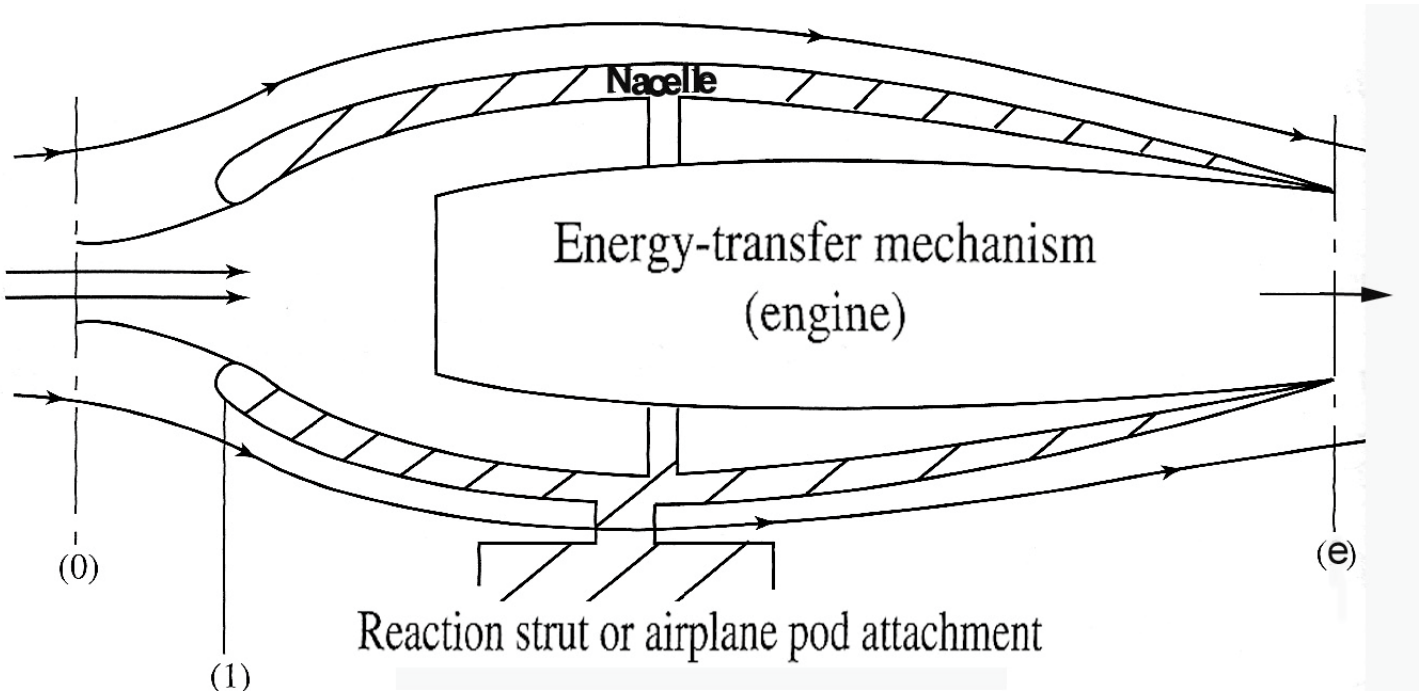
Pure Turbojet

Prop-jet





Unducted or Ducted fan



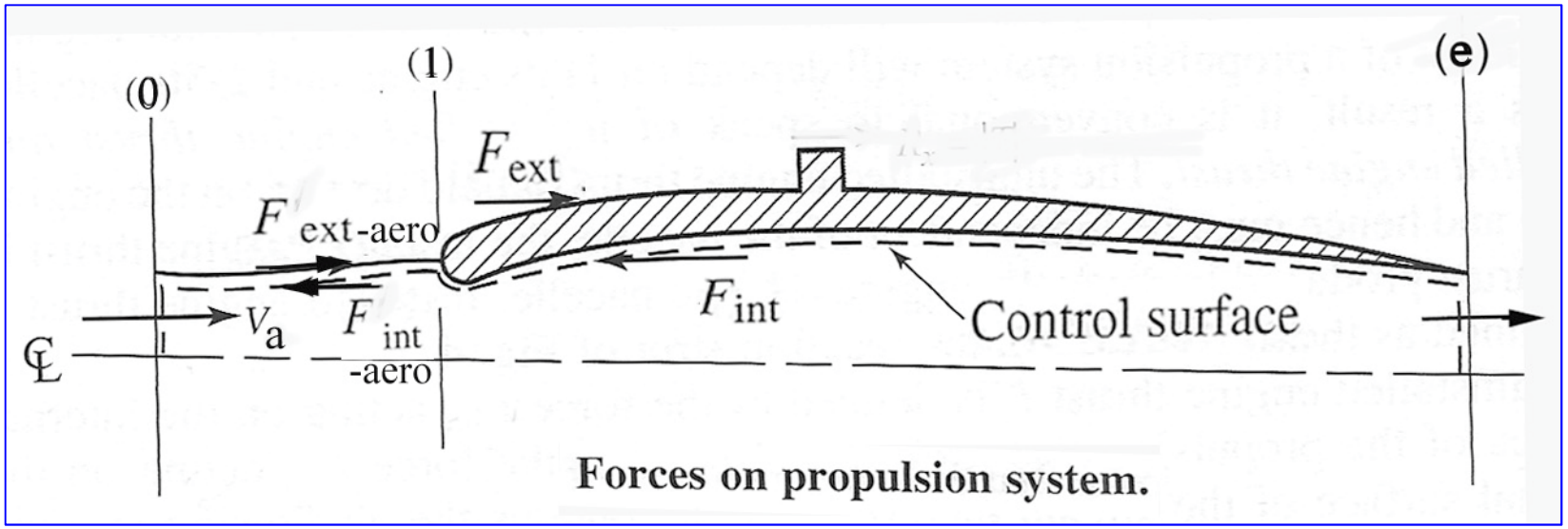
The **thrust equation** is given by:

$$F_n = [(\dot{m} \cdot V)_e - (\dot{m} \cdot V)_a] + [(p_e - p_a) \cdot A_e]$$

Momentum Thrust **Pressure Thrust**

Normally, the magnitude of the pressure thrust is small relative to the $\dot{m}$xV term.

This is the uninstalled thrust of the engine



Forces on propulsion system.

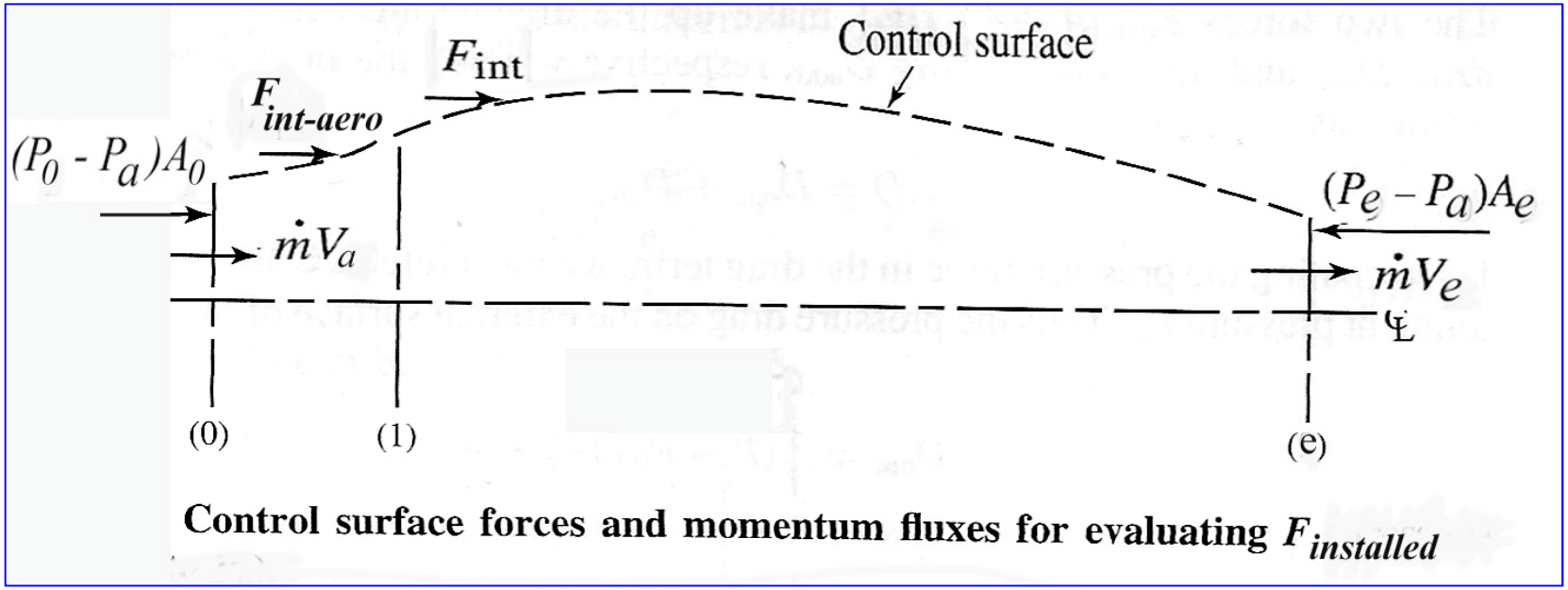
Installed Engine thrust = $\mathbf{F_{installed} = F_n - D}$

where, D is the drag of the engine= $\mathbf{D_{nacelle} - D_{aero\text{-}inlet}}$

Then,

$$\mathbf{F_{installed} = F_{internal} - F_{external}}$$

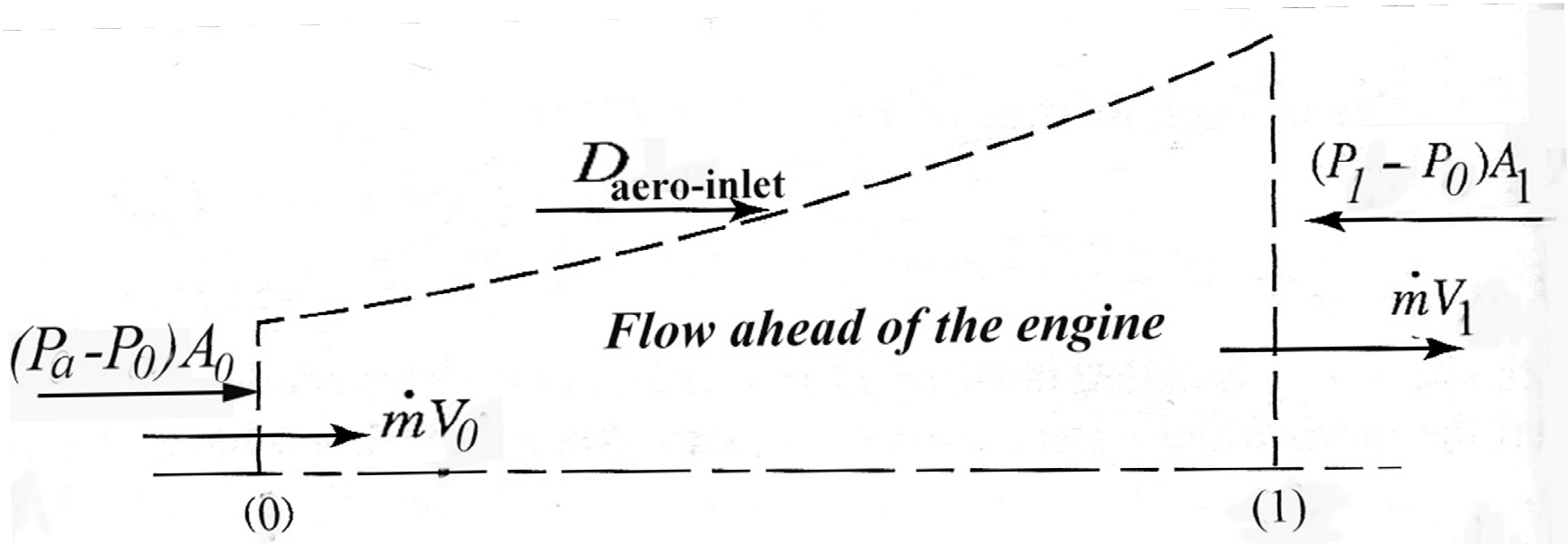
$$\mathbf{= F_{internal} + F_{aero\text{-}int} - (F_{external} + F_{aero\text{-}ext})}$$



Control surface forces and momentum fluxes for evaluating $F_{installed}$

Forces in the stream tube, $\int_1^e (P - P_a).dA - \int_0^1 (P - P_a).dA$

Change in momentum flux, $\int_e \rho.V_e^2.dA - \int_1 \rho.V_1^2.dA$



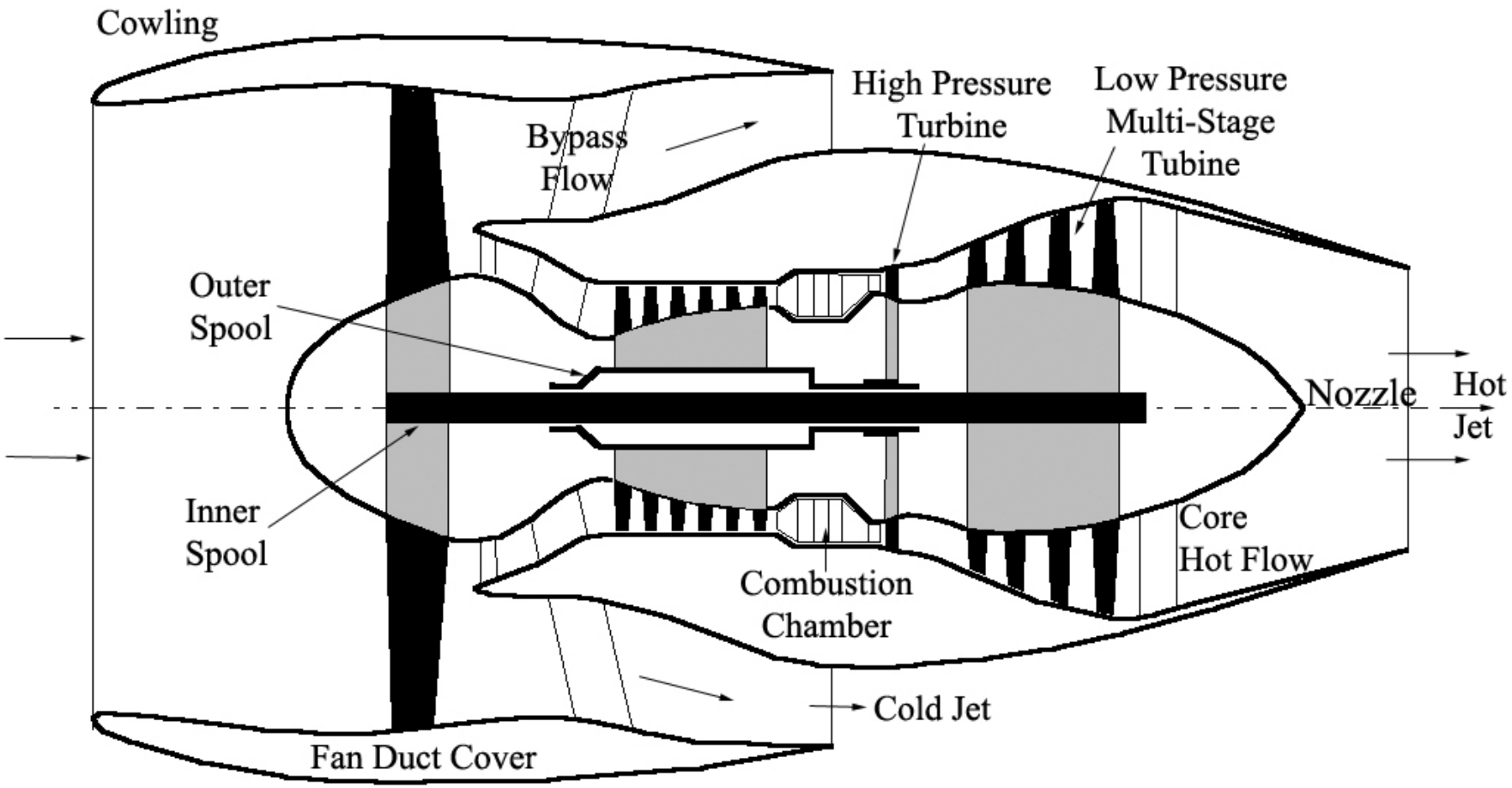
Momentum equation applied to stream tube of engine air inlet

$$D_{inlet-aero} = P_1.A_1.(1+\gamma.M_1^2) - P_0.A_0.\gamma.M_0^2 - P_a.A_1$$

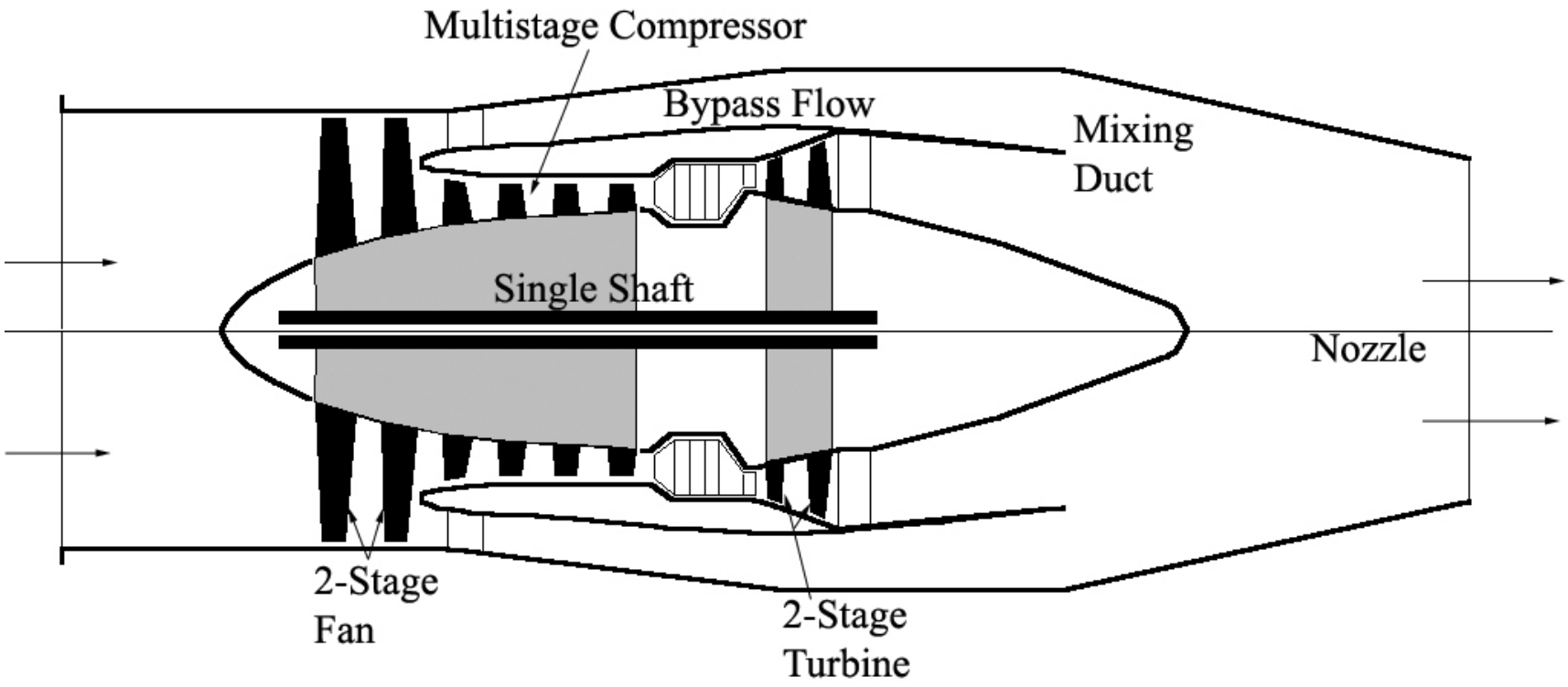
at $M_0 \approx 0$, i.e. at T.O. condition

$$D_{inlet-aero} = P_1.A_1.(1+\gamma.M_1^2) - P_a.A_1$$

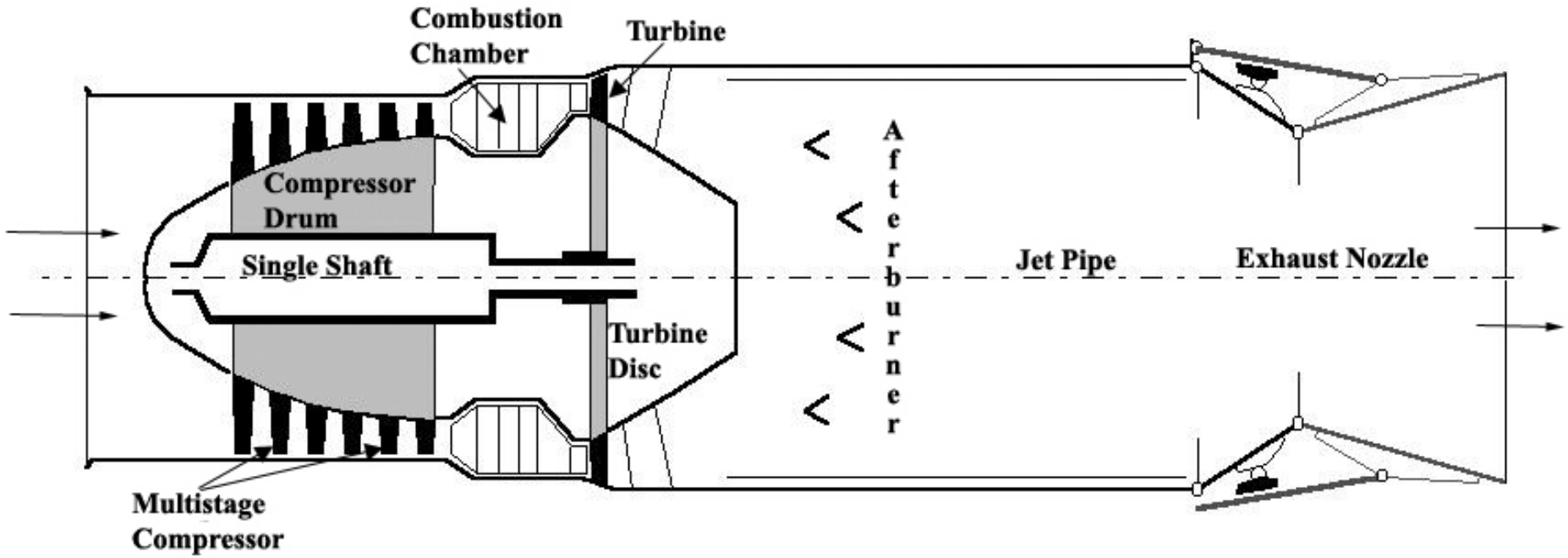
A Bypass Jet engine



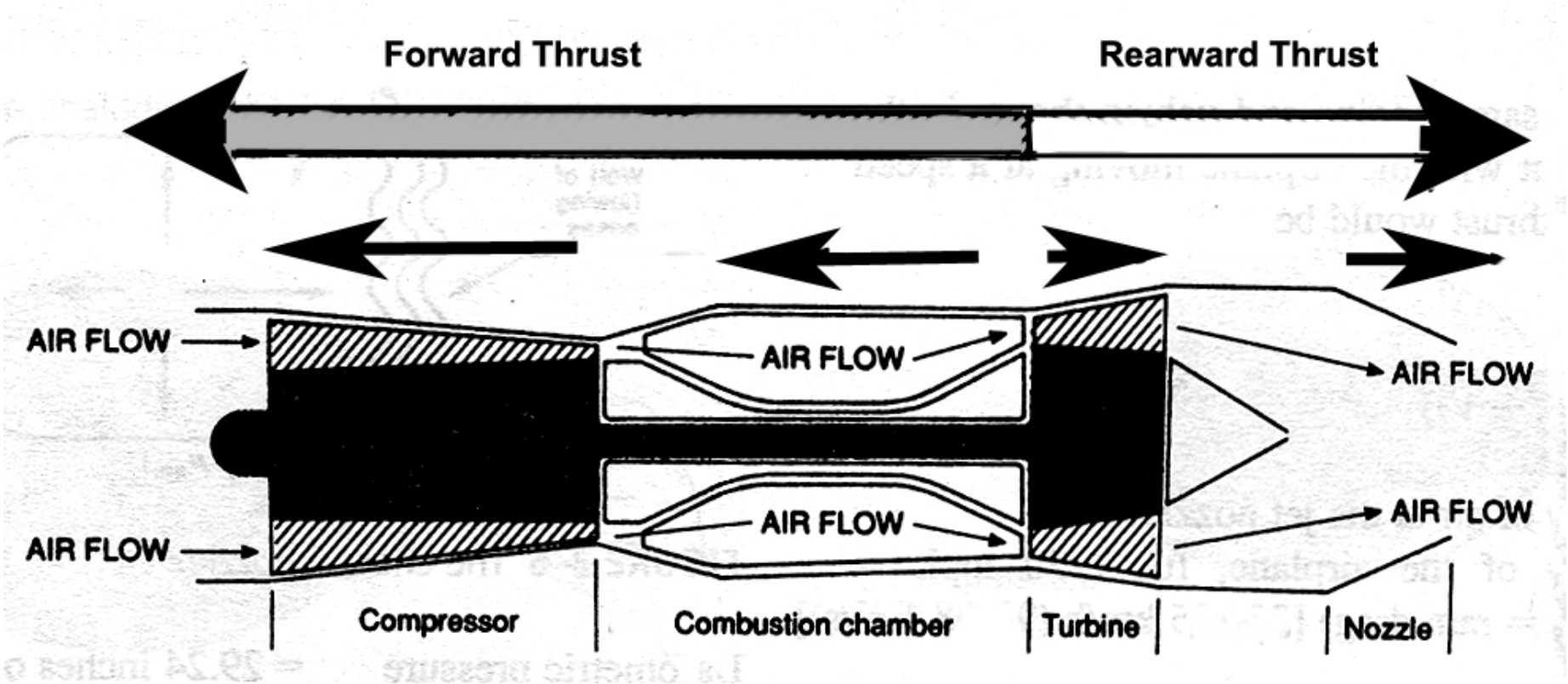
A mixed flow bypass jet engine



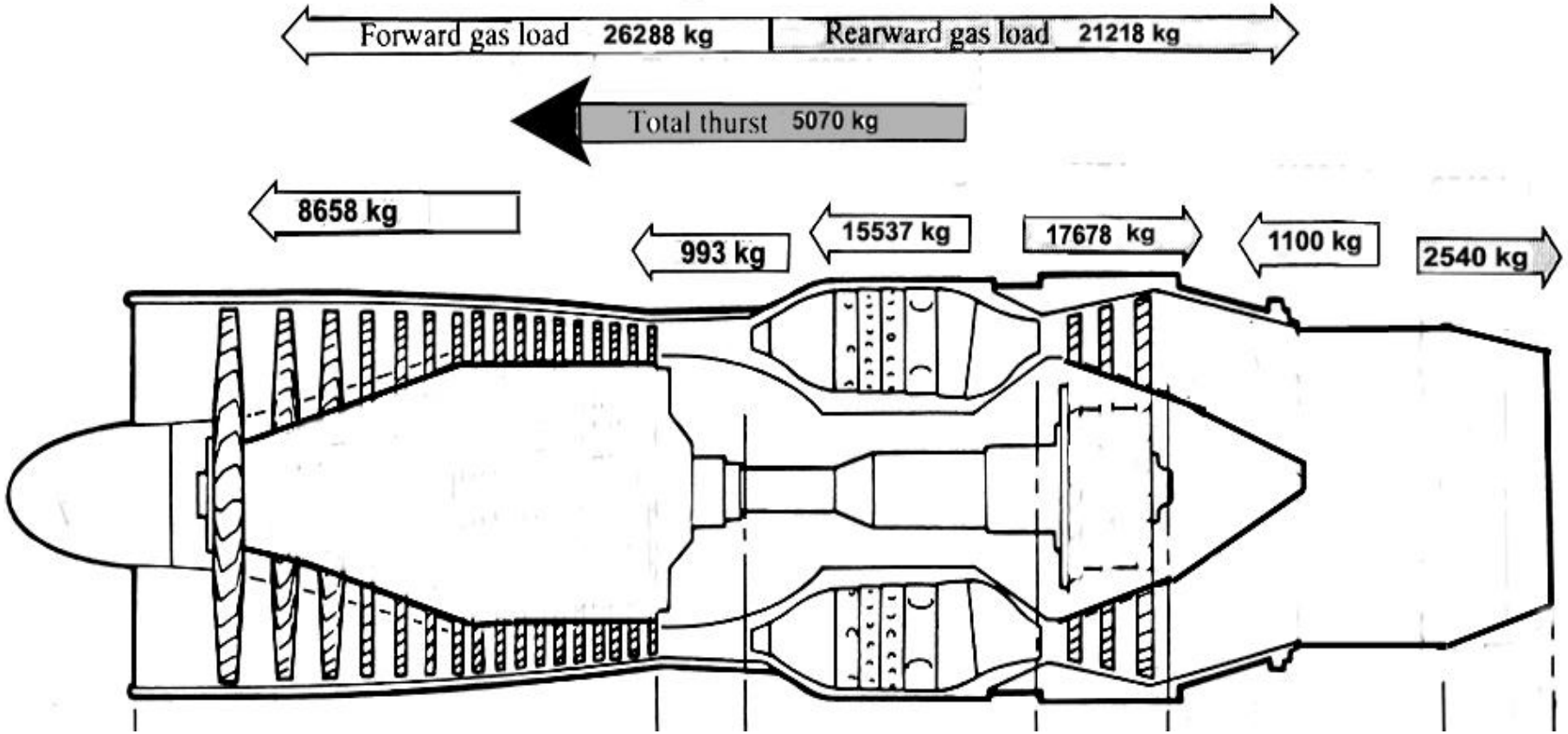
A pure turbojet engine with afterburner (mixed flow)



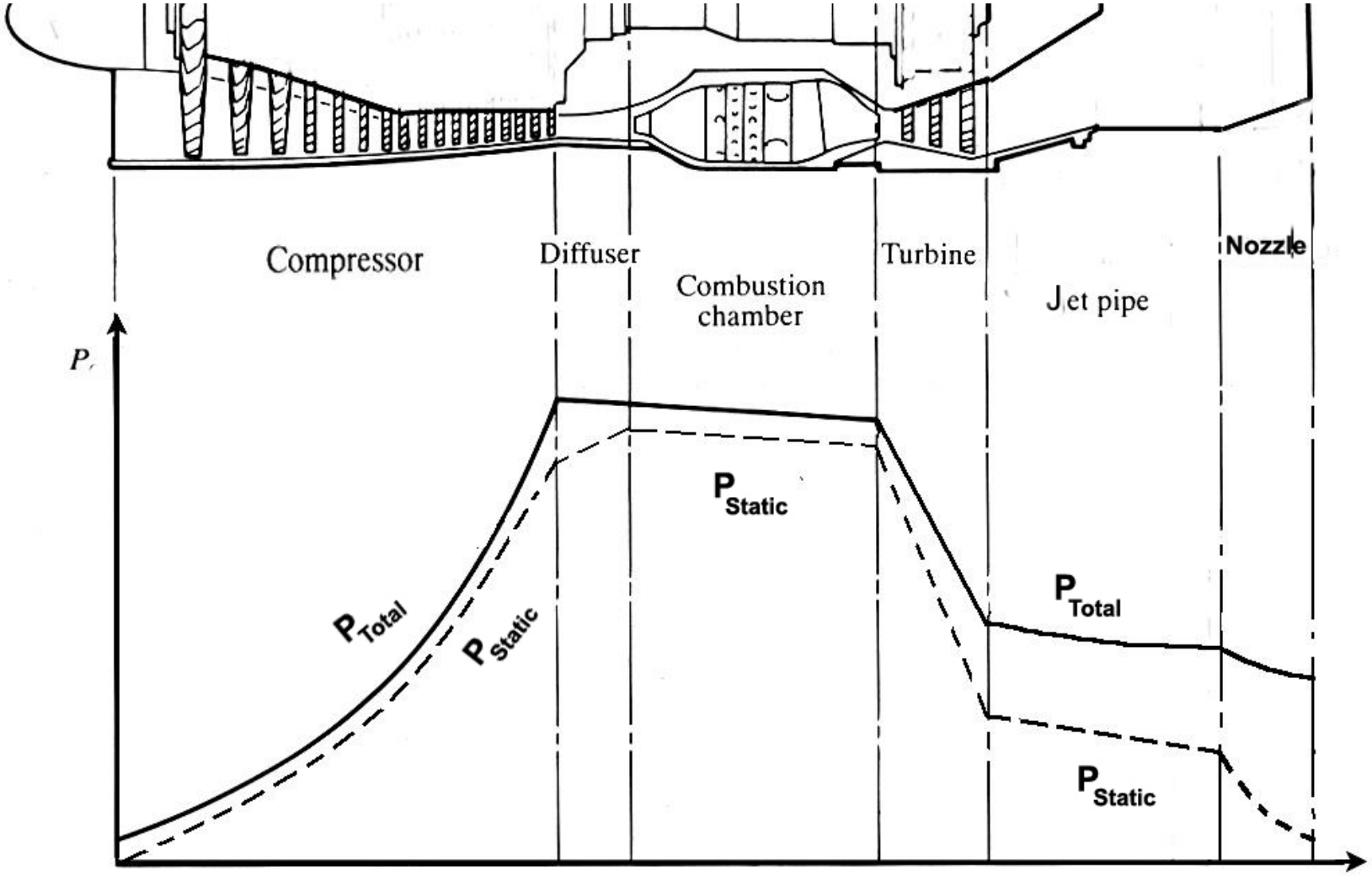
Mechanical Creation of Thrust by all components



Mechanical Forces created by various components of a Jet engine

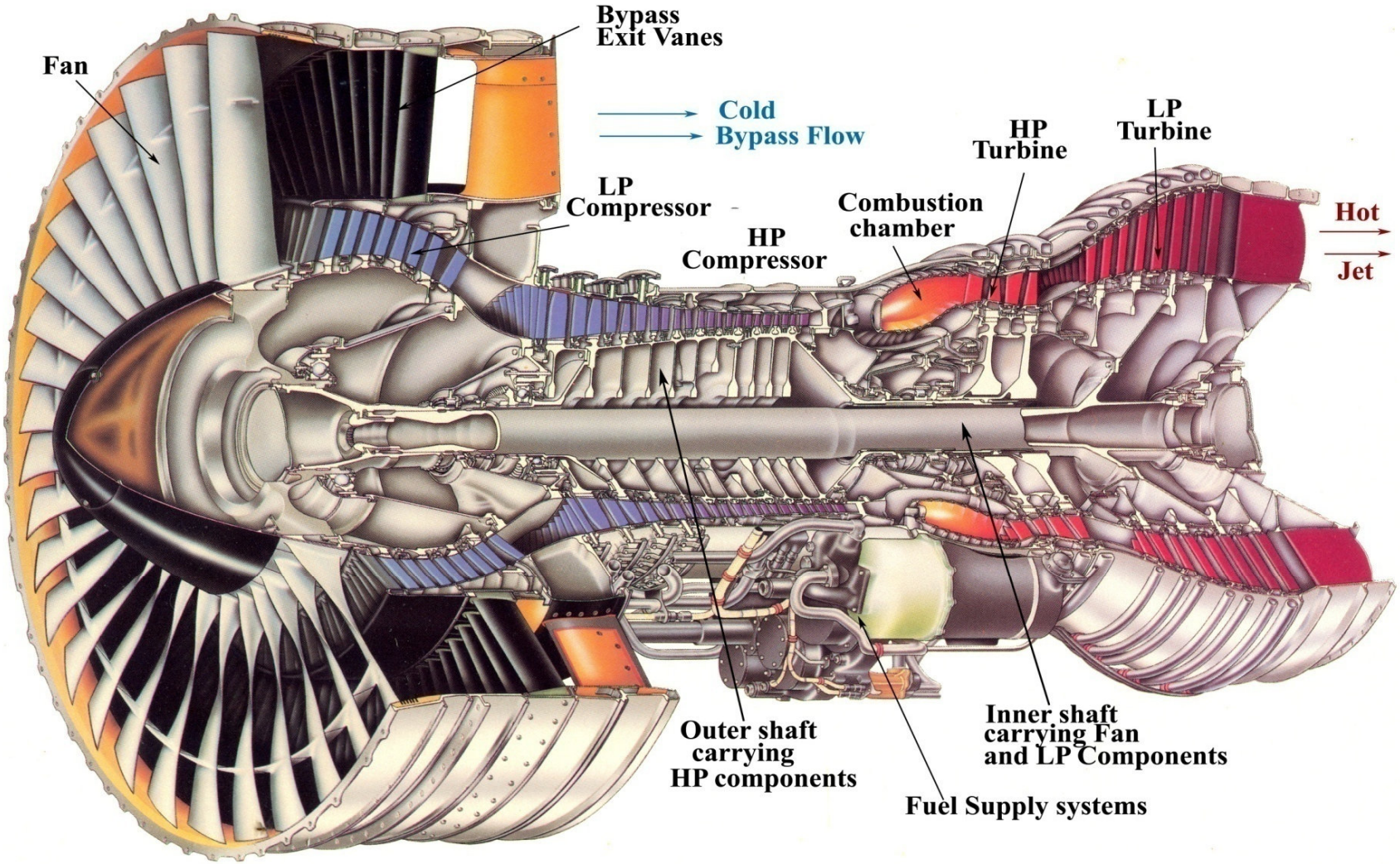


Total and Static Pressures acting on various parts of a jet engine



- All Mechanical loads (e.g. gas loads) are to be borne by various components of the engine. These components also transfer the load to the structure of the engine. The engine, rigidly attached to the aircraft, and provides pull (thrust) for motion.
- The loads are variable and continuous during all the operations of the engine.
- The load bearing components, e.g. bearings, struts etc. need to be designed and installed to withstand these continuous and variable forces. Otherwise the engine is liable to fail under mechanical loads.

A high Bypass Turbofan Engine



A modern very-low bypass engine