AERO368

AEROSPACE PROPULSION

Reference Books:

1. AIRCRAFT PROPULSION by **Saeed Farokhi**
2. FUNDAMENTALS OF JET PROPULSION WITH APPLICATIONS by **Ronald D. Flack**

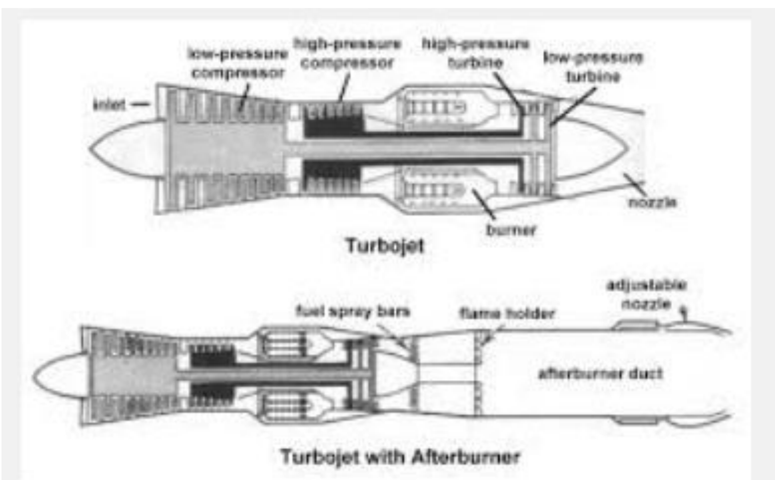
Propulsion basically means to propel, ie to move in a specified (preferred) direction. In other words to impart a motion to a body; this is guided by Newtons 2nd law of motion. Examples of such bodies are automobiles, trains, ships, aircrafts, missiles, spacecrafts, etc.

Engine types:

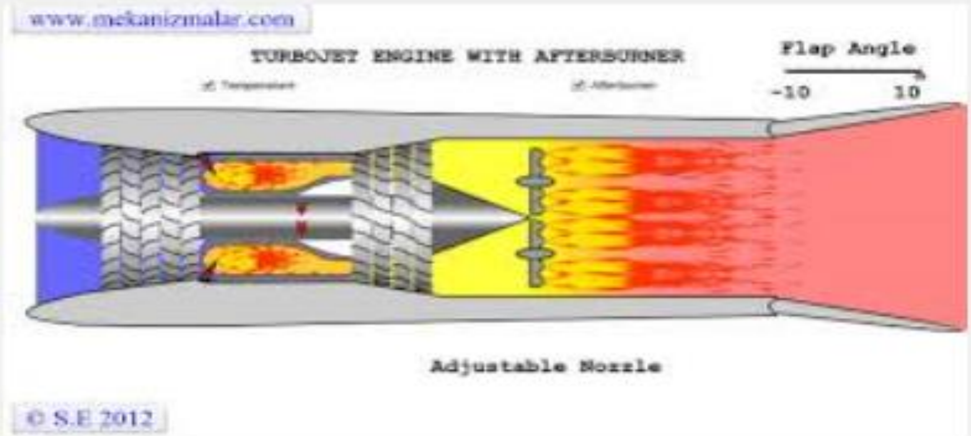
Scramjet

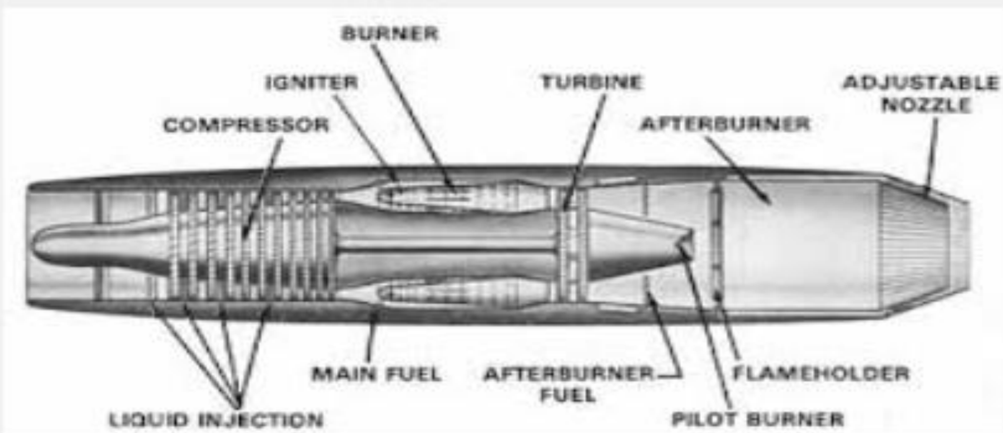
Ramjet

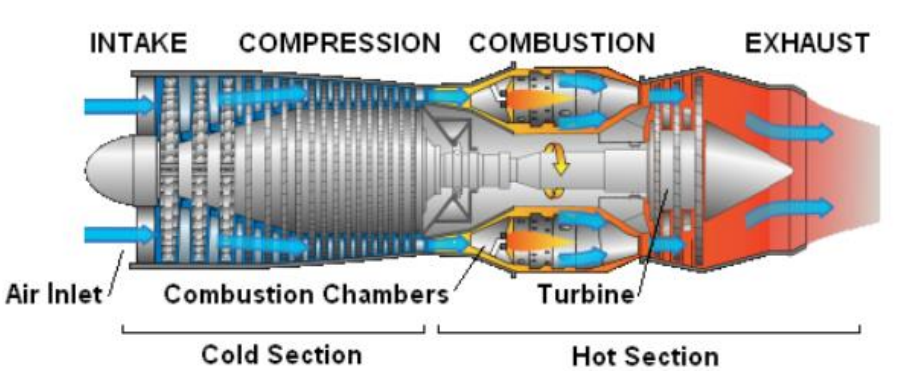
Turbojet



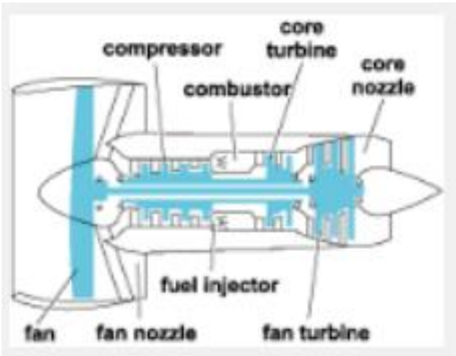
Turbojet with afterburner







Turbofan (front-fan configuration)



Turbofan (aft-fan configuration)

Turbofan with afterburner

Turbofan with fan mixed

Turboprop

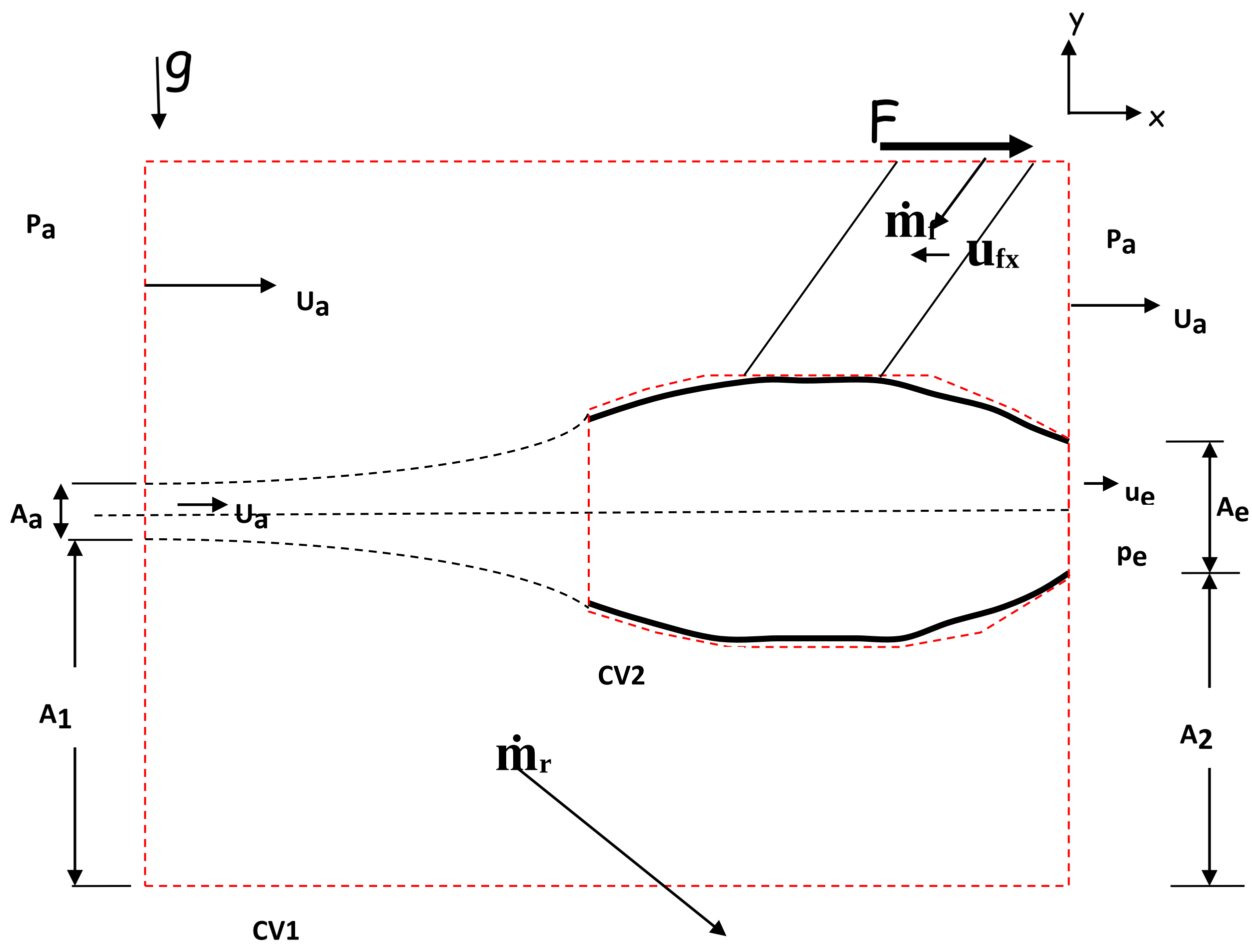
Turboshaft

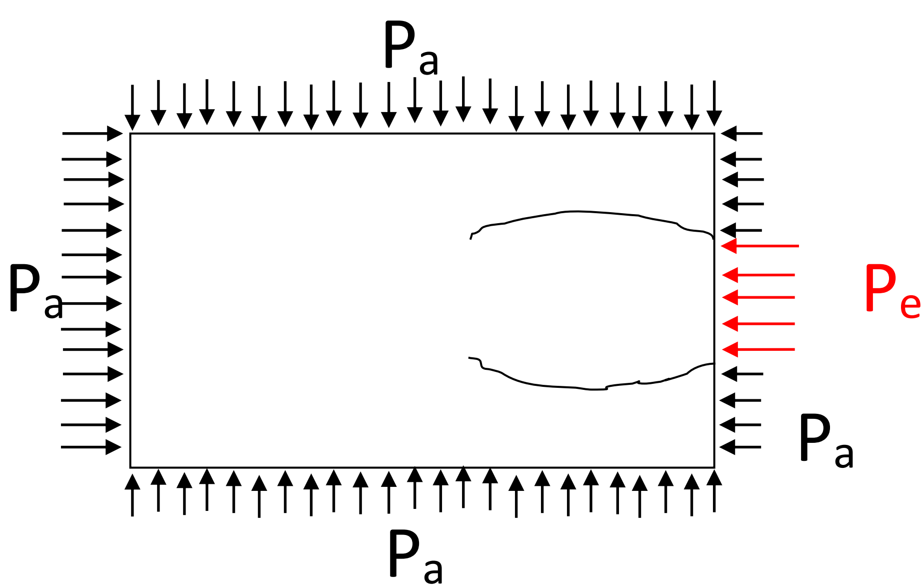
Table 1: Comparison of some engine types

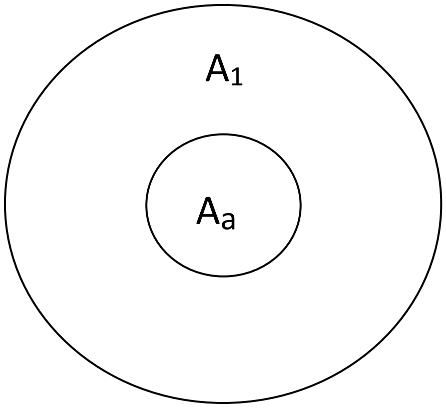
	Ramjet	Turbojet	Turbofan	Turboprop
Speed	Very high	High	Moderate	low
Thrust/weight	Moderate	High	Moderate/low	low
Fuel use/thrust	High	High	Moderate	moderate
Thrust/air flow	High	High	Moderate	moderate
Ground Clearance	Not applicable	Good	Moderate	poor

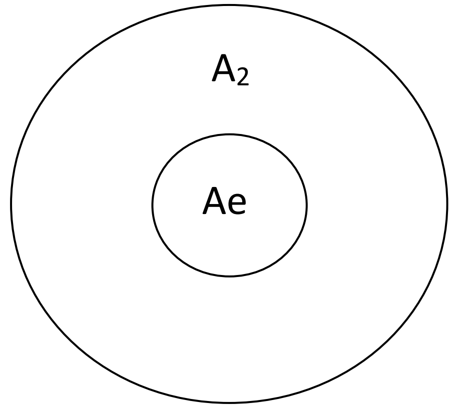
Engine Thrust:

Turbojet









From Newton's 2nd law

$$\sum_{i=1}^{i=n} F_i = \sum_{i=1}^{i=n} (ma)_i = \sum_{i=1}^{i=n} (\dot{m}_i u_i)_{exit} - \sum_{i=1}^{i=n} (\dot{m}_i u_i)_{inlet}$$

Considering the x-component of the above equation

$$\sum_{i=1}^{i=n} F_{xi} = \sum_{i=1}^{i=n} (ma)_{xi} = \sum_{i=1}^{i=n} (\dot{m}_i u_{xi})_{exit} - \sum_{i=1}^{i=n} (\dot{m}_i u_{xi})_{inlet}$$

Force	Sign	Comment
F	Positive	Towards +ve x-axis
$P_a A_a$	Positive	Pressure acting on the area Aa and is towards +ve x-axis
$P_a A_1$	Positive	Pressure acting on the area A_1 and is towards +ve x-axis
$P_e A_e$	Negative	Exit Pressure acting on the area A_e and is towards -ve x-axis

P_aA_2		Pressure acting on the area A_2 and is towards -ve x-axis
F_{bx}		The x-component of the body force

Mass momentum	Condition	Comment
$\dot{m}_r u_a$	Exit	+ve
$\dot{m}_e u_e$	Exit	+ve
$\rho_a A_2 u_a u_a$	Exit	+ve
$\dot{m}_f u_{fx}$	Entry	-ve
$\rho_a A_1 u_a u_a$	Entry	-ve
$\rho_a A_a u_a u_a$	Entry	-ve

$$F + p_a A_a + p_a A_1 - p_e A_e - p_a A_2 + F_{bx} = -u_a \rho_a A_a u_a + u_e \rho_e A_e u_e - u_a \rho_a A_1 u_a + u_a \rho_a A_2 u_a + \dot{m}_r u_a - \dot{m}_f u_{fx}$$

$$\rho = \frac{m}{v}$$

$$m = \rho v$$

$$\dot{m}_a = \rho_a A_a u_a$$

$$\dot{m}_e = \rho_e A_e u_e$$

$$A_1 + A_a = A_2 + A_e$$

$$A_1 + A_a - A_2 = A_e$$

$$F + p_a(A_a + A_1 - A_2) - p_e A_e = \dot{m}_e u_e - \dot{m}_a u_a + \dot{m}_r u_a - u_a^2 \rho_a (A_1 - A_2) - \dot{m}_f u_{fx}$$

From control volume CV1, consider the conservation of mass

$$\dot{m}_e + \rho_a u_a A_2 + \dot{m}_r = \dot{m}_a + \rho_a u_a A_1 + \dot{m}_f$$

$$\dot{m}_e + \dot{m}_r - \dot{m}_f - \dot{m}_a = \rho_a u_a (A_1 - A_2)$$

$$F + p_a(A_a + A_1 - A_2) - p_e A_e = \dot{m}_e u_e - \dot{m}_a u_a + \dot{m}_r u_a - u_a(\dot{m}_e + \dot{m}_r - \dot{m}_f - \dot{m}_a) - \dot{m}_f u_{fx}$$

$$F + p_a A_e - p_e A_e = \dot{m}_e u_e - \dot{m}_a u_a + \dot{m}_r u_a - u_a(\dot{m}_e + \dot{m}_r - \dot{m}_f - \dot{m}_a) - \dot{m}_f u_{fx}$$

$$F = \dot{m}_f u_a + \dot{m}_e(u_e - u_a) + A_e(p_e - p_a) - \dot{m}_f u_{fx}$$

The x-component of the fuel flow is negligible

$$F = \dot{m}_f u_a + \dot{m}_e(u_e - u_a) + A_e(p_e - p_a)$$

The thrust equation, below and above, involves the fuel flow rate, exit gas flow rate, exit velocity, jet velocity, exit area, exit pressure, and ambient pressure. The quantities are arranged different for making different quick comments/decision/calculations.

$$F = (\dot{m}_a + \dot{m}_f) u_e - \dot{m}_a u_a + (p_e - p_a) A_e$$

$$\dot{m}_e = \dot{m}_a + \dot{m}_f$$

$$\dot{m}_f \ll \dot{m}_a$$

$$\dot{m}_e = \dot{m}_a = \dot{m}$$

$$F = \dot{m}(u_e - u_a) + A_e(p_e - p_a)$$

Turbofan

$$F = \dot{m}_f u_a + \dot{m}_e(u_e - u_a) + \dot{m}_s(u_s - u_a) + A_s(p_s - p_a) + A_e(p_e - p_a)$$

$$\alpha = \frac{\dot{m}_s}{\dot{m}_a}$$

Where 'α' is the **bypass ratio** which is the ratio of the air mass flow rate through the fan to the air mass flow rate through the diffuser or the compressor

Turboprop

$$F = \dot{m}_f u_a + \dot{m}_e(u_e - u_a) + A_e(p_e - p_a) + F_p$$

Performance measure

Propulsion Measures

Aside the engine thrust, **thrust –specific fuel consumption, TSFC** is another important quantity that is worth calculating. The quantity deals with the amount of fuel needed for a given thrust.

$$TSFC = \frac{\dot{m}_{ft}}{F}$$

Where $\dot{m}_{ft}$ is the total fuel flow rate from primary burner and the afterburner

When the TSFC is multiplied by the ambient sound speed, $\mathbf{a_s}$, the resulting quantity becomes nondimensionalized.

$\overline{TSFC} = TSFC\ x\ a_s$

Another dimensionless quantity of importance is the dimensionless thrust

$$\overline{F} = \frac{F}{\dot{m}_t a_s}$$

Where $\dot{m}_t$ is the total air mass flow rate into the engine

Propulsive efficiency, η_k, is another characteristic quantity and can be expressed as

$$\eta_k = \frac{F u_a}{[(\sum \dot{m}_{exit} u_{exit}^2) - \dot{m}_a u_a^2]}$$

This propulsive efficiency expression is for turbojet or a mixed turbofan only which will have one exit stream.

Specific Impulse, Isp, or I, is the ratio of the thrust, F, to the product of acceleration due to gravity,g, and the total fuel mass flow rate, $\dot{m}_{ft}$.

$$I = \frac{F}{g\dot{m}_{ft}}$$

$$I = \frac{1}{gTSFC}$$

The thermal efficiency

Example 1

A turbojet operates at sea level and moves at 243.8 m/s. It ingests 113.4 kg/s of air and has negligible fuel flow. The diameter of the exit is 0.762 m. The exit pressure is 151.7 kPa, and the exit velocity is 396.2 m/s. Find the developed thrust.

Example 2

A turbofan operates at sea level and moves at 269.7 m/s. It ingests 121.1 kg/s of air into the core and five times this amount into the fan (bypass ratio), which all exhausts through the fan exhaust. The fuel flow is negligible. The exit areas of the fan and core are 1.580 m2 and 1.704 m2 respectively. The exit pressures from the fan and the core are 154.4 kPa and 144.8 kPa respectively. The exhaust velocities from the fan and core are 328.6 m/s and 362.7 m/s respectively. Find the developed thrust.

IDEAL CYCLE ANALYSIS

Ideal is qualifying the cycle analysis and it implies that no losses occur in any of the components. It also presupposes that a component is designed to operate at a given conditions.

An adiabatic process means NO heat transfer and Isentropy process implies constant Enthropy. An Isentropic process is achieved through as adiabatic and reversible process. Cycle analysis is simply the study of the individual component making the assembly in order to predict the overall performance of an engine. Through the studies of the components, equations are developed which will serve

1. A model of the engine
2. Understanding of parameters which influence the overall performance of the engine
3. Means of optimizing the overall performance of the engine

An engine can be an assembly of the following:- propeller, diffuser, fan, compressor, burner, turbine, mixer, bypass duct, afterburner, fan nozzle, primary nozzle.

adfas

COMPONENTS	DESIGNED OPERATIONAL CONDITIONS
External to Inlet	Isentropy and adiabatic flow
Inlet or diffuser	Isentropy and adiabatic flow
Compressor	Isentropy and adiabatic flow
Fan	Isentropy and adiabatic flow
Propeller	All propeller power generates thrust
Combustor	Constant static and total Pressure; Very Low Velocities
Turbine	Isentropy and adiabatic flow
Bypass Duct	Isentropy and adiabatic flow
Bypass Mixer	Isentropy and adiabatic flow
Afterburner	Constant static and total Pressure; Very Low Velocities
Exhaust Nozzle or exhaust stack	Isentropy and adiabatic flow and Exit Pressure Matches Atmospheric Pressure
Overall	Thermally and calorically perfect gas steady state constant Cp, Cv, (andγ) throughout engine.; Negligible fuel flow; No power loss by shaft