TURBOJET ENGINE THEORY INTRODUCTION

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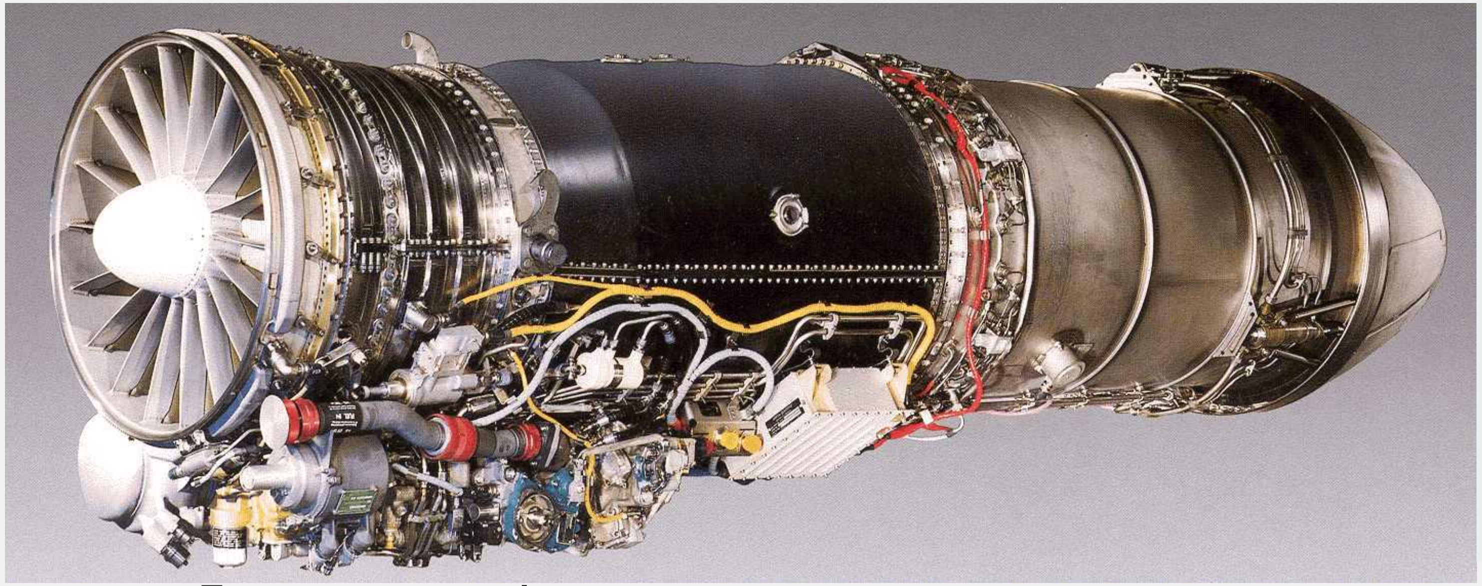
LITERATURE:

- **Jack D. Mattingly, Elements of Propulsion: Gas Turbines and Rockets, AIAA Education Series 2006**
- **Jack D. Mattingly, Elements of Gas Turbine Propulsion, Tata McGraw Hill Education Private Limited, 2013**
- **Gordon C. Oates, Aerothermodynamics of Gas Turbine and Rocket Propulsion, AIAA Education Series, 1997**
- **Ahmed F. El-Sayed, Aircraft Propulsion and Gas Turbine Engines, Taylor & Francis Group, LLC, 2017**

TURBOJET ENGINE

ENGINE HARDWARE



Engine externals

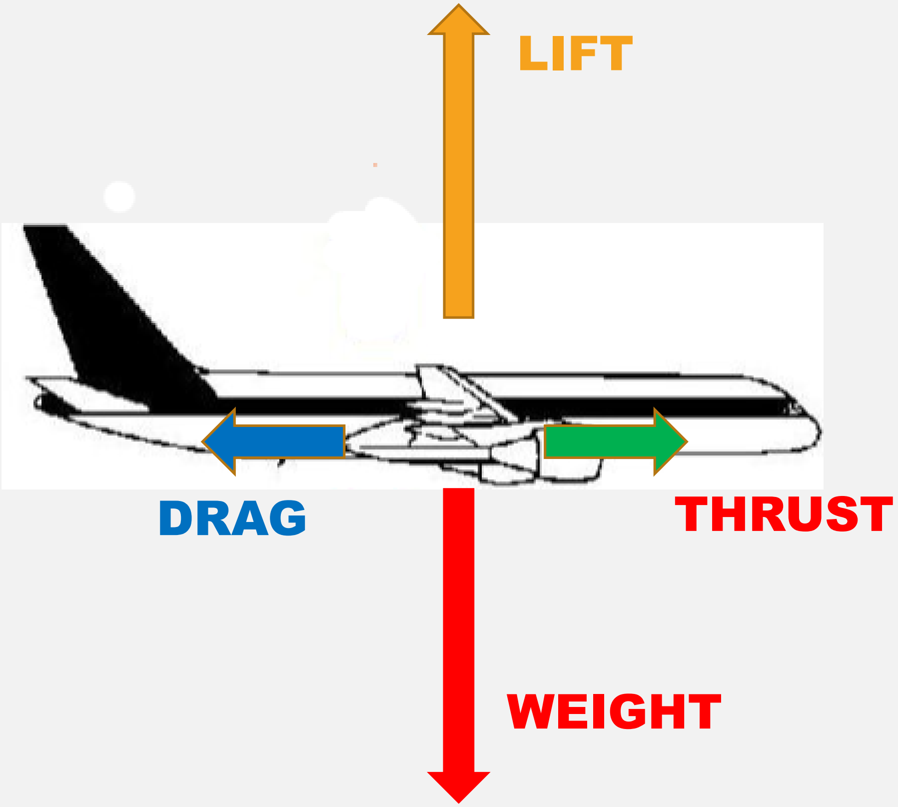
A turbojet engine is a very complex facility.
Its design and production requires knowledge from various filds of science.

The turbojet engine is designed for specific purpose. It is a part of an aircraft and the reaqirments caming from this are crucial for determination engine feature (dimentions and performance)

ENGINE ROLE IN THE PLANE

- How do Airplanes fly? - YouTube
- https://www.youtube.com/watch?v=YyeX6ArxCYI&t

HORIZONTAL FLIGHT - SPEED AND ALTITUDE INCREASE



Energy consideration performance equation:

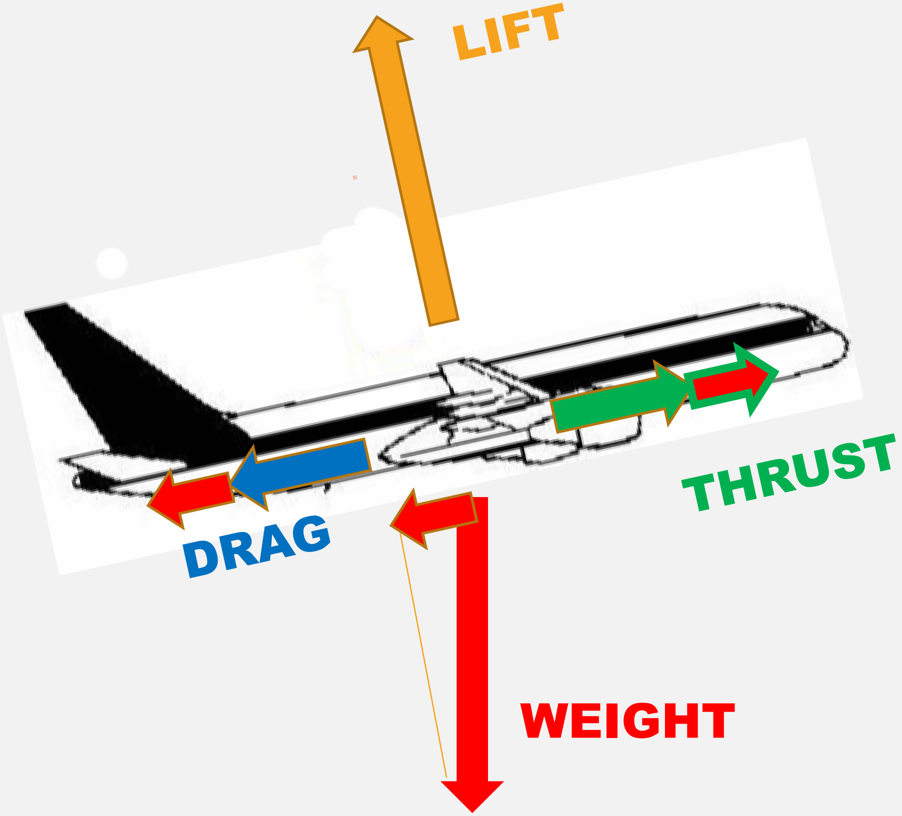
$$(T - DR) * V = W\frac{dh}{dt} + W\frac{d}{dt}\left(\frac{V^2}{2}\right)$$

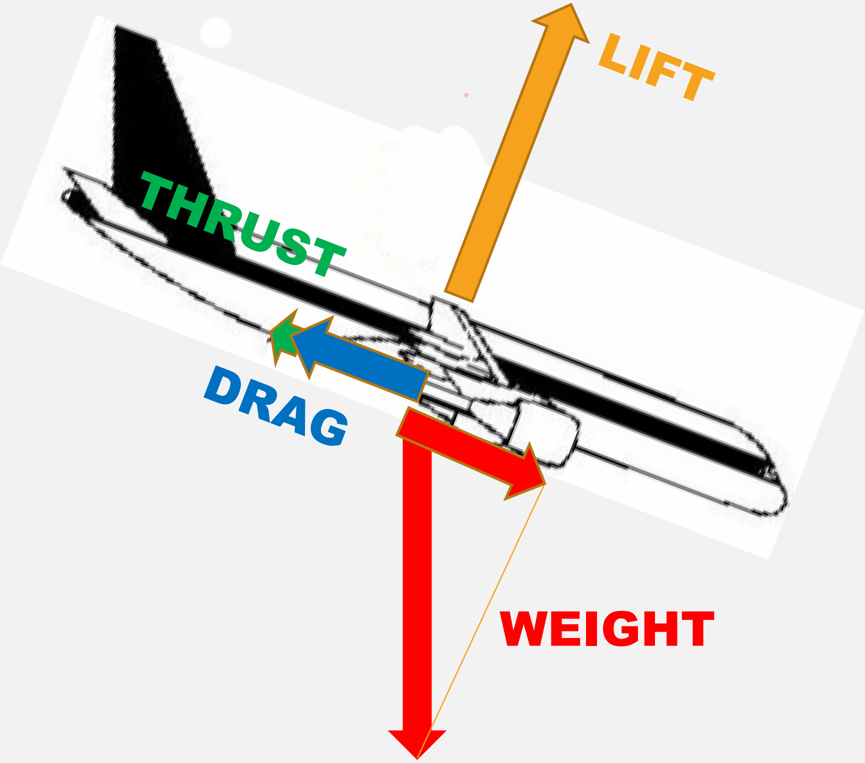
$$\frac{(T - DR)}{W} = \frac{1}{V}\frac{d}{dt}\left(h + \frac{V^2}{2}\right)$$

For horizontal flight with constant speed:
Thrust = Drag and Lift = Weight

Weight specific excess power $\frac{(TR-DR)}{W}$ is proportional to rate of climb $\frac{dh}{dt}$, and acceleration $\frac{dV}{dt}$

ASCENT AND DESCENT





Engines thrust should be increased of additional weight component in ascent phase

Engine negative thrust could occur during descent due to an additional forward weight component.

ENGINE ROLE IN THE PLANE

Plane	MTOW	Takeoff thrust	Thrust/MTOW
A330	251 t	2x324 kN (64,8 t)	0,258
737 MAX9	88,3 t	2x130 kN (26 t)	0,294
A320	79 t	2x120 kN (24t)	0,304

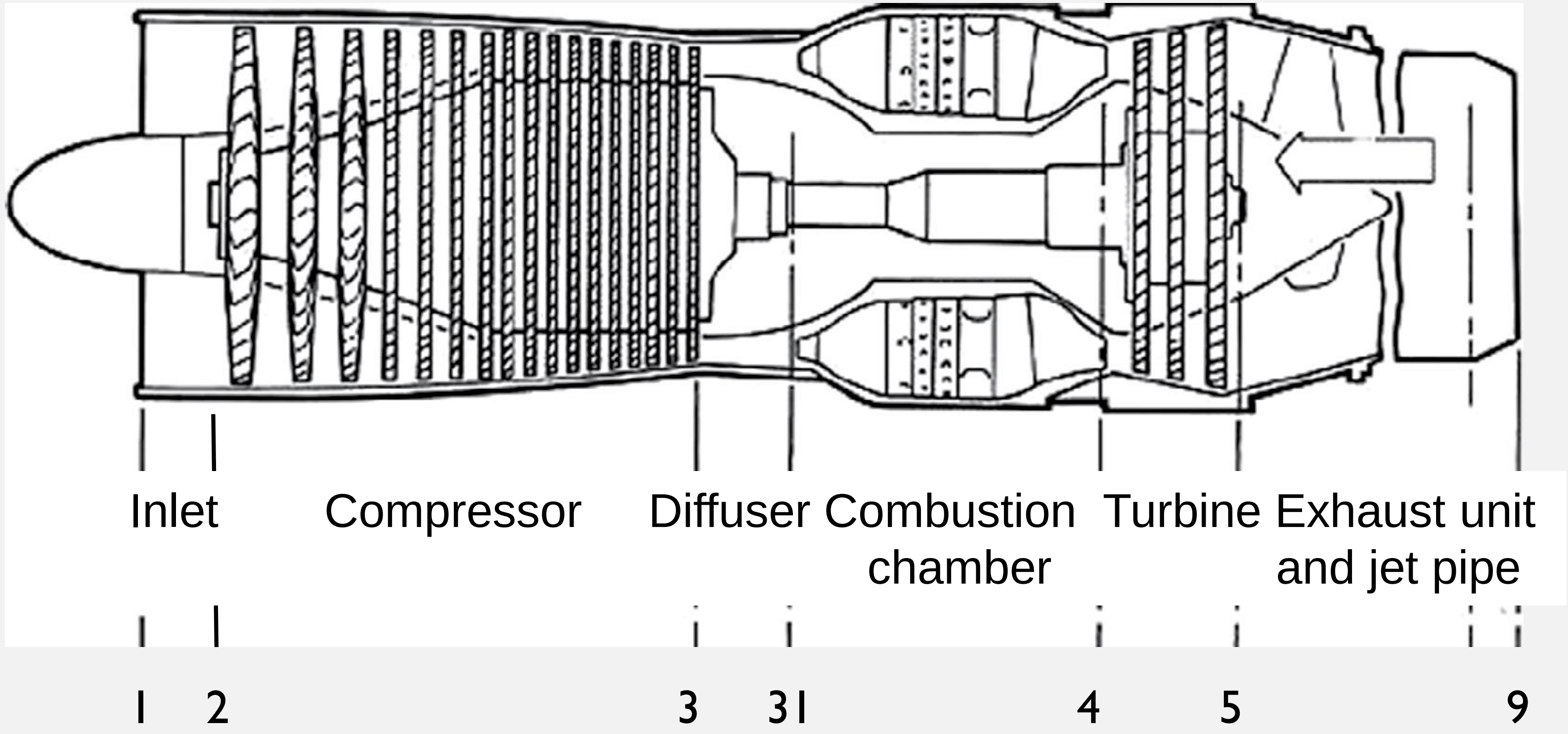
Engine should produce thrust wich:

- should compensate drag force in horizontal flight
- should compensate drag force and add additional component to lift force to balance plane weight in ascent flight phase
- is nearly 0 or negative in descent flight phase

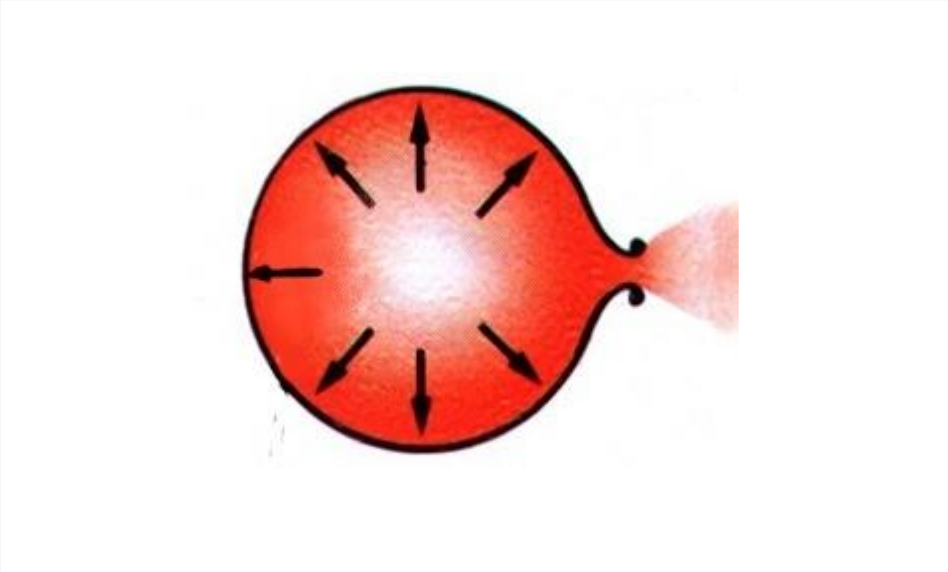
HOW THE TURBOJET ENGINE WORK

- https://www.youtube.com/watch?v=L24Wf0VITE0

SIMPLE TURBOJET ENGINE



THRUST – WHAT IS IT?

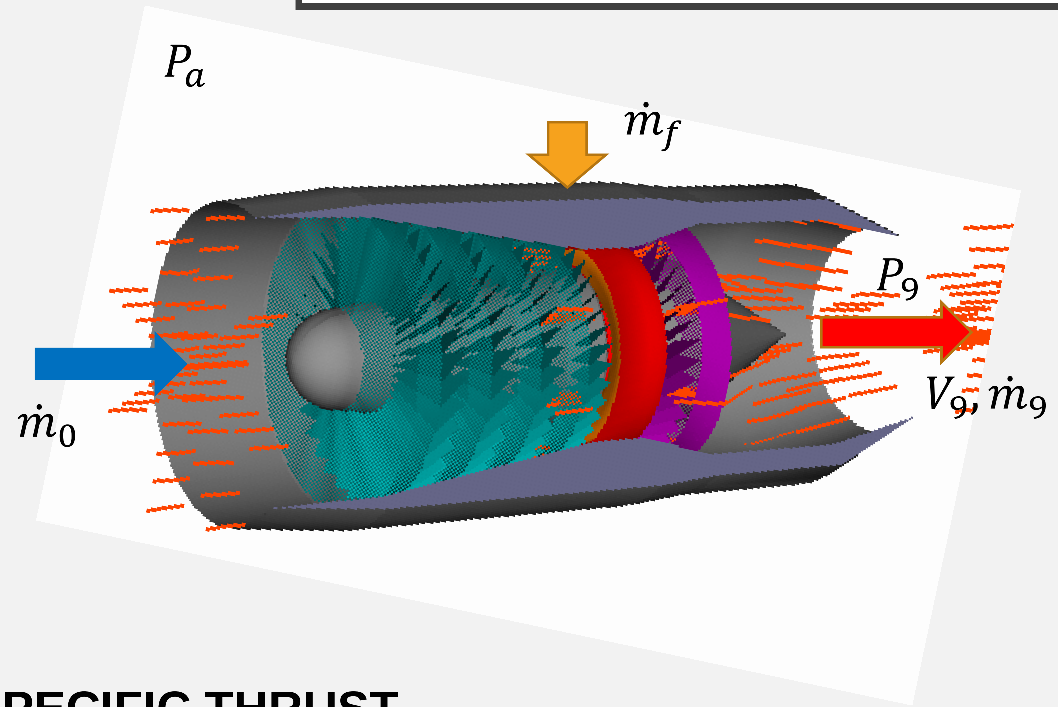


Newton's second law of motion: the sum of the forces is proportional to the rate of change of the momentum (M = *mV*).

$$\sum F = \frac{d(mV)}{dt} = \dot{m}V$$

Force of jet stream reaction is proportional to fluid mass flow and its velocity

ENGINE THRUST AND SPECIFIC PARAMETERS



SPECIFIC THRUST

$$ST = T/\dot{m}_0$$

SPECIFIC FUEL CONSUMPTION

$$\text{SFC} = \dot{m}_f/T$$

Flight speed is 0

THTUST / GROS THRUST

$$T = \dot{m}_9 V_9 + A_9(P_9 - P_a)$$

effective exhaust velocity

$$V_{eff} = V_9 + A_9(P_9 - P_a)/\dot{m}_9$$

$$T = \dot{m}_9 V_{eff}$$

Exit pressure = ambient pressure

$$T = \dot{m}_9 V_9$$

Flight speed > 0

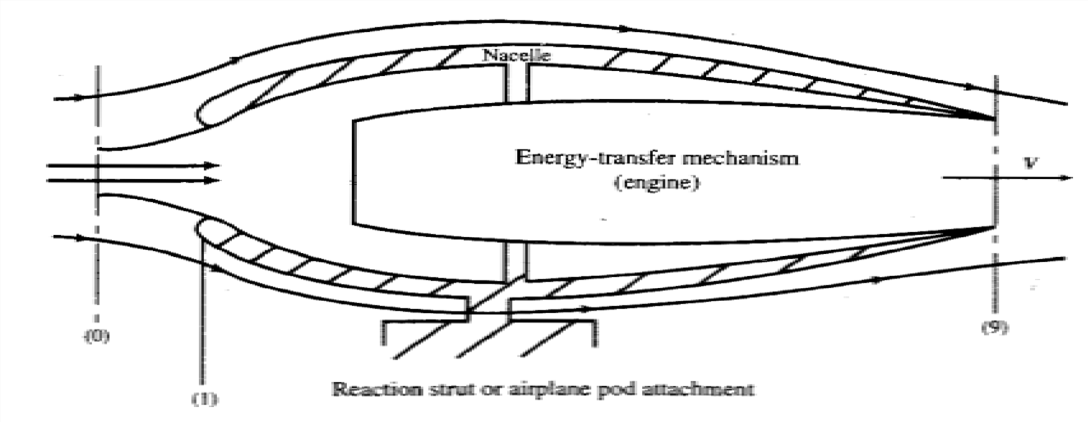
THTUST / NET THRUST

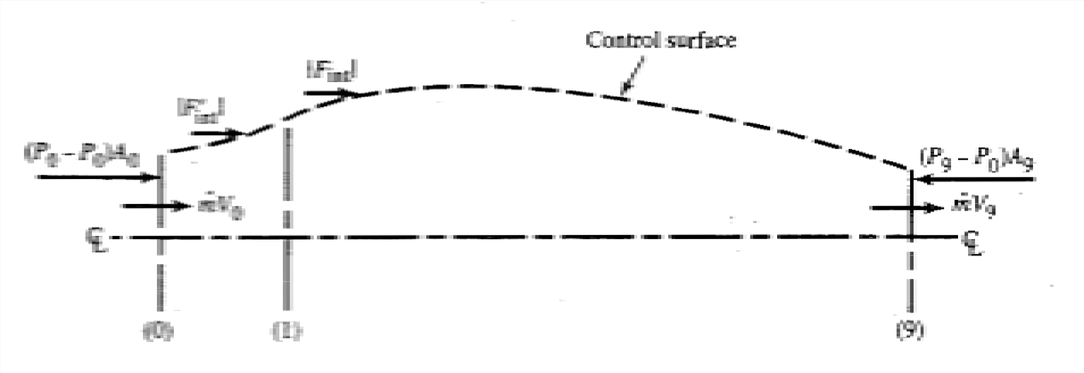
$$T = \dot{m}_9 V_9 + A_9(P_9 - P_a) - \dot{m}_0 V_0 = \dot{m}_9 V_{eff} - \dot{m}_0 V_0$$

Net thrust = Gross thrust –Momentum drag

Details in: **Ahmed F. El-Sayed, Aircraft Propulsion and Gas Turbine Engines, (chapter 2.2)**

UNINSTALED – INSTALED THRUST





Uninstalled engine thrust is defined as the force acting on the internal surface of the propulsion system which contains the air flowing into the engine. It will be shown that UNINSTALED THRUST is independent of the nacelle.

$$T = \dot{m}_9 V_9 + A_9(P_9 - P_a) - \dot{m}_0 V_0$$

Installed engine thrust is real thrust produced by engine in real enviroment including nacelle drag and inlet free stream additive drag

$$T_{INS} = T - (D_{nac} + D_{add})$$

D_{add} = pressure force on external stream tube surface from I to I which is called additive drag or preentry drag

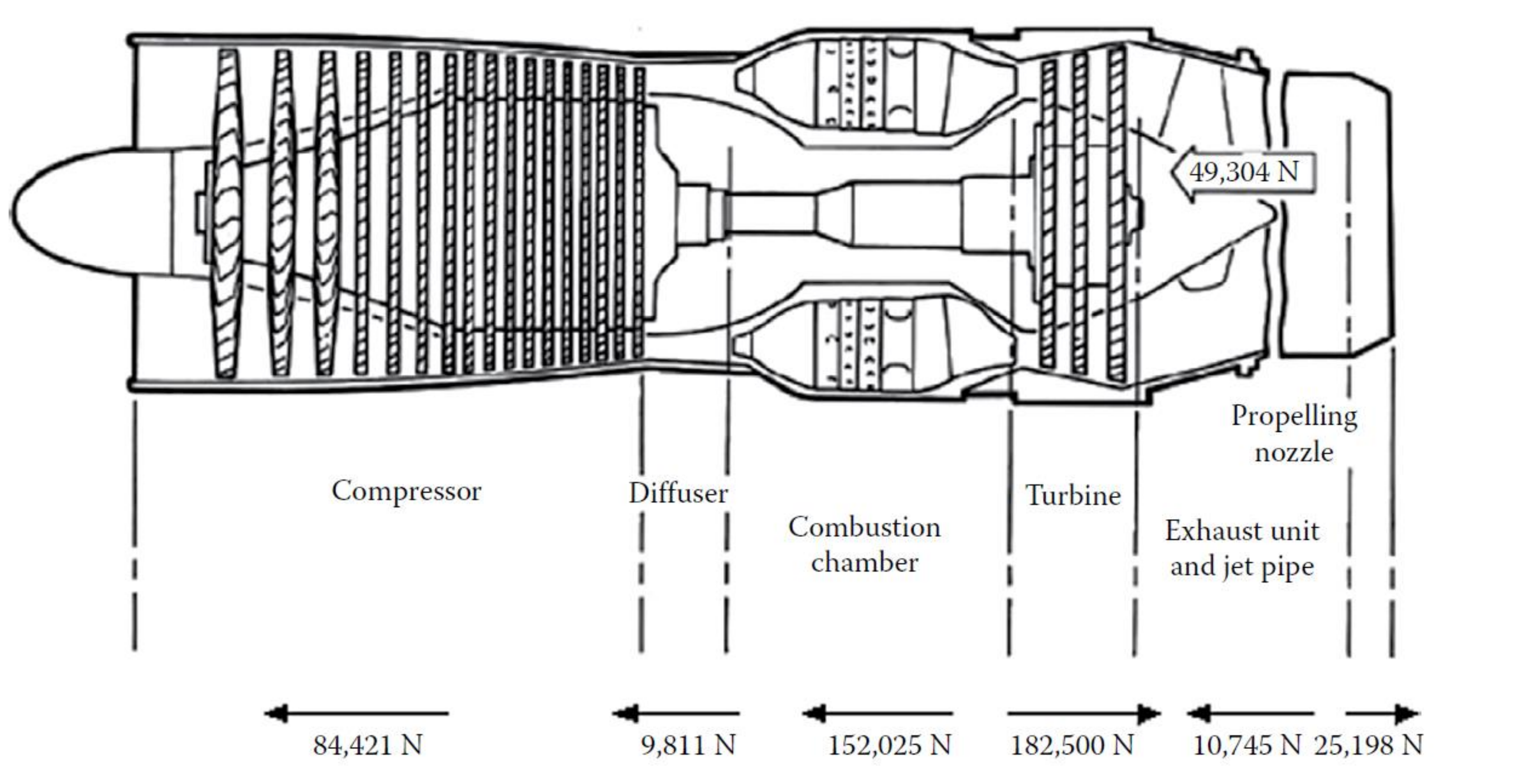
D_{nac}= pressure force on nacelle's external surface

$$D_{add} = \int_0^1 (P - P_0)dA_y \qquad D_{nac} = \int_1^9 (P - P_0)dA_y$$

Jack D. Mattingly, Elements of Gas Turbine Propulsion, (chapter 4.2)

ENGINE THRUST BY ENGINE COMPONENTS

Component Thrust= $P_e A_e - P_i A_i + \dot{m}_e c_e - \dot{m}_i c_i$



	Forward	Rearward
Force	84,421	–182,500
	9,811	–25,198
	152,025	
	10,745	
Total	257,002	–207,698

$$\text{Total thrust} = 49,304\ \text{N}$$

Compressor, diffuser and combustor produce positive thrust

Details in: **Ahmed F. El-Sayed, Aircraft Propulsion and Gas Turbine Engines, (chapter 2.2)**

ENGINE EFFICIENCIES

Thermal efficency

$$\eta_{TH} = \frac{\text{Power imparted to engine airflow}}{\text{Rate of energy supplied in the fuel}}$$

$$\eta_{TH} = \frac{0{,}5 * (\dot{m}_9 {V_{9e}}^2 - \dot{m}_0 {V_0}^2)}{\dot{m}_f FHV}$$

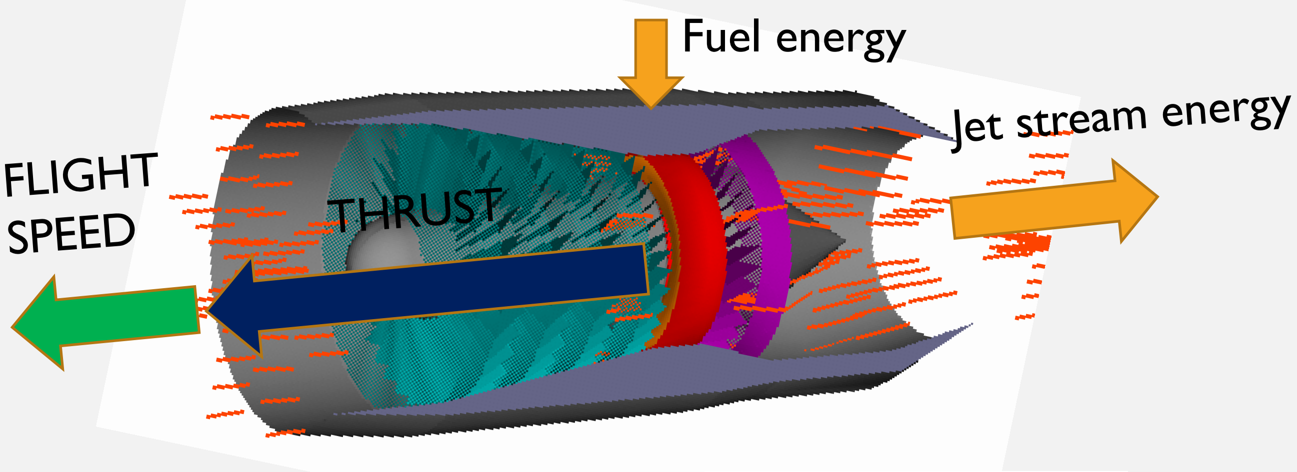
Propulsive efficency

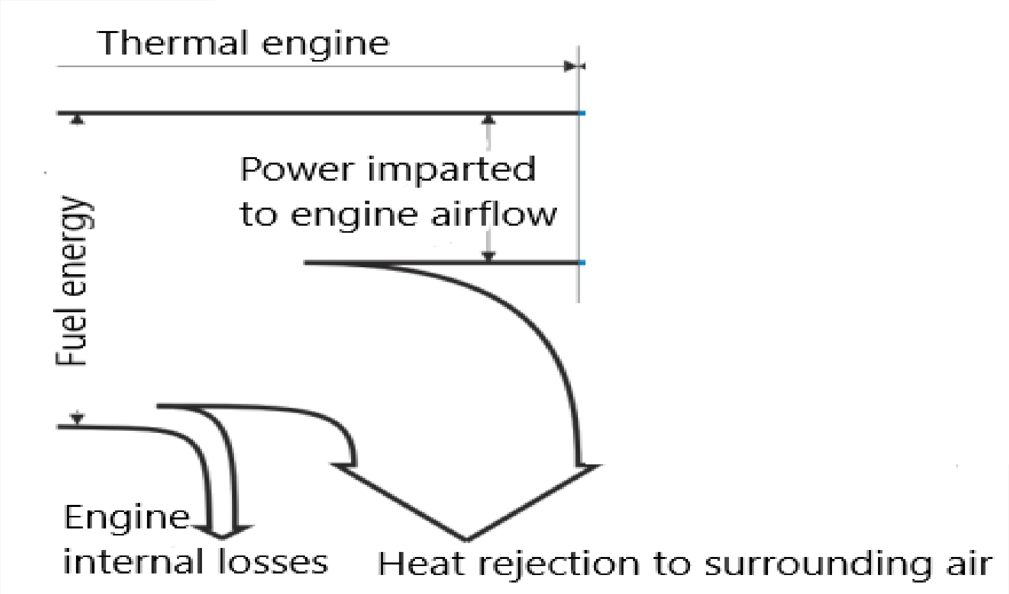
$$\eta_P = \frac{\text{Thrust power}}{\text{Power imparted to engine airflow}}$$

$$\eta_P = \frac{V_0 * T}{0{,}5 * (\dot{m}_9 {V_{9e}}^2 - \dot{m}_0 {V_0}^2)}$$

Overall efficency

$$\eta_O = \eta_{TH} * \eta_P = \frac{V_0 * T}{\dot{m}_f FHV}$$





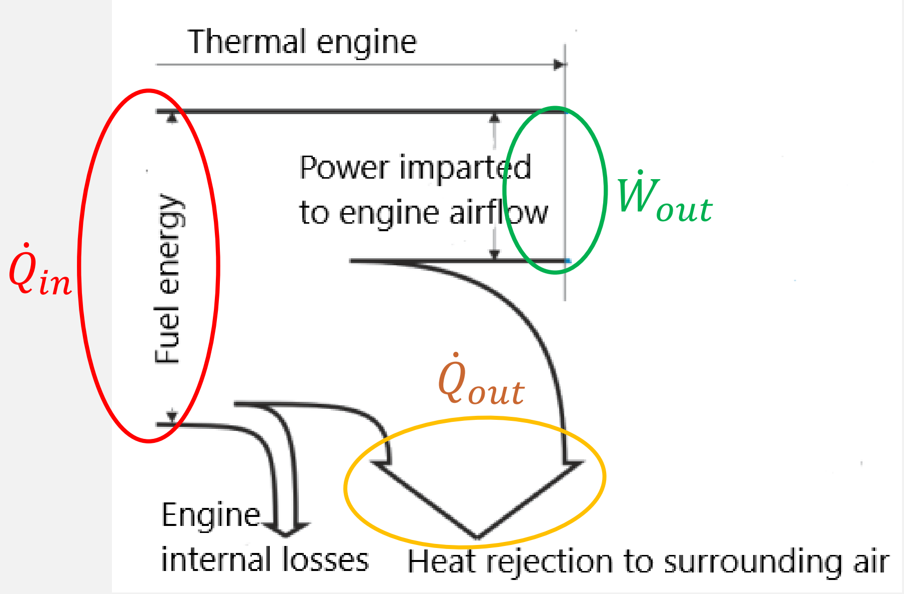
THERMAL EFFICIENCY

$$\eta_{TH} = \frac{\dot{W}_{out}}{\dot{Q}_{in}} \quad \Rightarrow \quad \eta_{TH} = \frac{\dot{Q}_{in} - \dot{Q}_{out}}{\dot{Q}_{in}} = 1 - \frac{\dot{Q}_{out}}{\dot{Q}_{in}}$$

where, $\dot{Q}_{out} = \dot{m}_9 c_p (T_9 - T_0)$

- Wout = net power out of engine (engine work)
- Qin= rate of thermal energy released/suplied in the fuel)

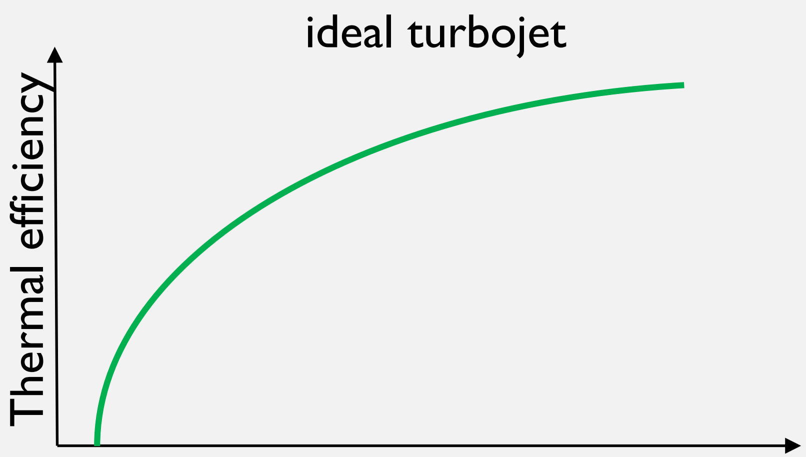
Higher thermal efficiency causes lower specific fuel consumption
Thermal efficiency is higher when exhaust gas temperature is closer to the ambient temperature



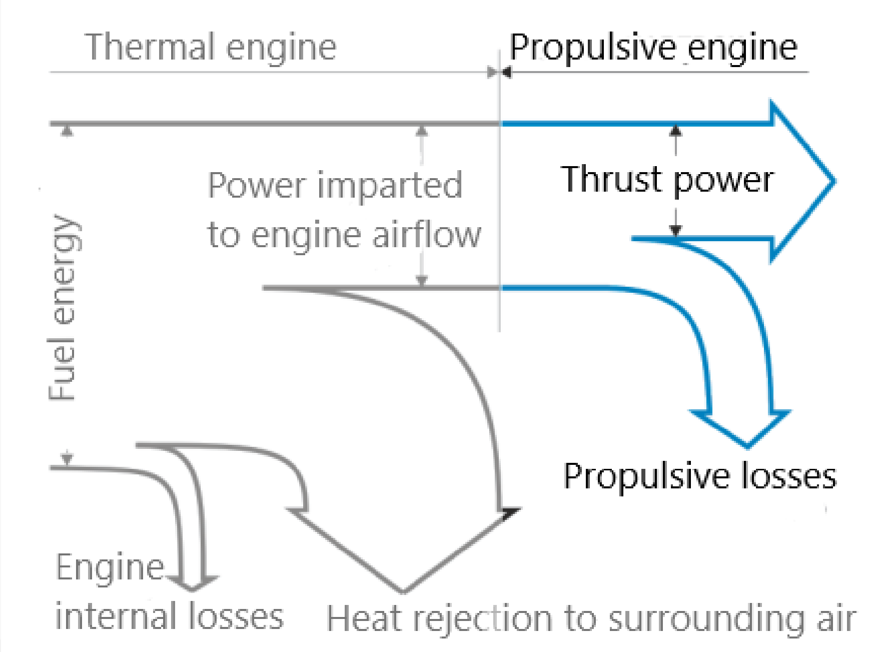
For ideal turbojet engine:

$\eta_{TH} = 1 - \frac{1}{\pi^{(k-1)/k}}$,

where π – engine compression pressure ratio, k- isentropic exponent



PROPULSIVE EFFICIENCY

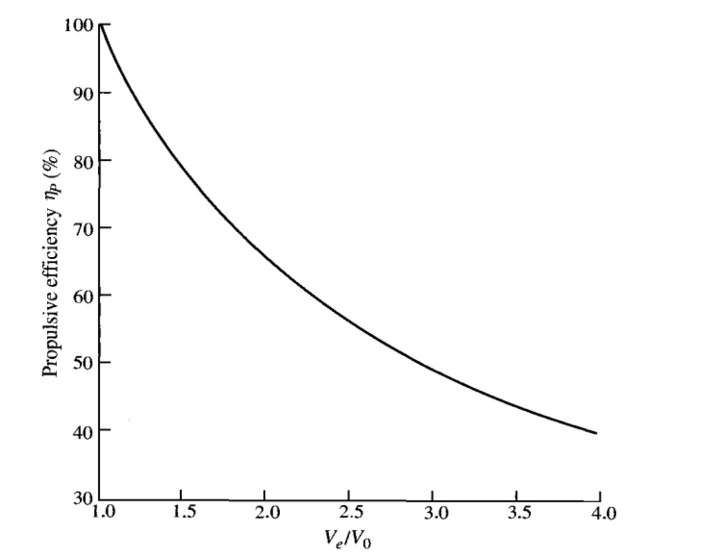


$$\eta_P = \frac{V_0 * T}{0{,}5 * (\dot{m}_9 {V_{9e}}^2 - \dot{m}_0 {V_0}^2)}$$

$$T = \dot{m}_9 V_{9e} - \dot{m}_0 V_0 \quad and \quad \dot{m}_9 = \dot{m}_0$$

$$\eta_P = \frac{V_0(V_{9e} - V_0)}{0{,}5 * ({V_{9e}}^2 - {V_0}^2)} = \frac{2V_0(V_{9e} - V_0)}{(V_{9e} - V_0)(V_{9e} + V_0)} = \frac{2}{1 + V_{9e}/V_0}$$

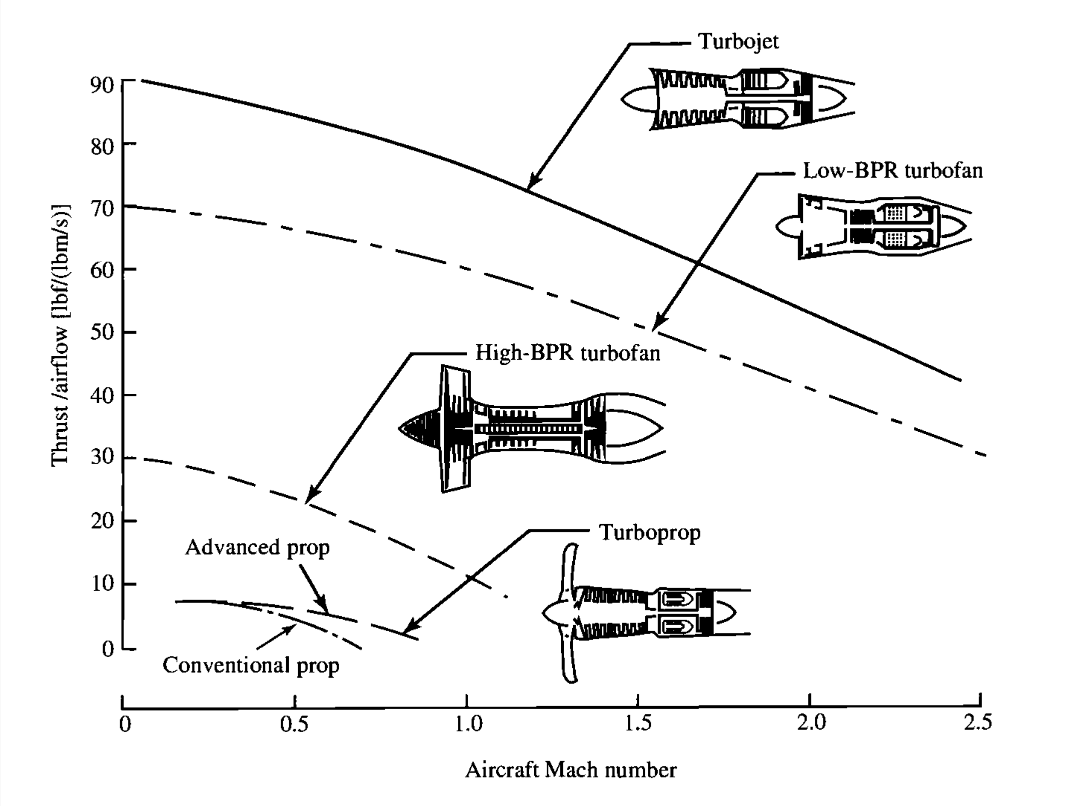
$$\eta_P \Rightarrow 1, gdy \;\; V_{9e} \Rightarrow V_0$$



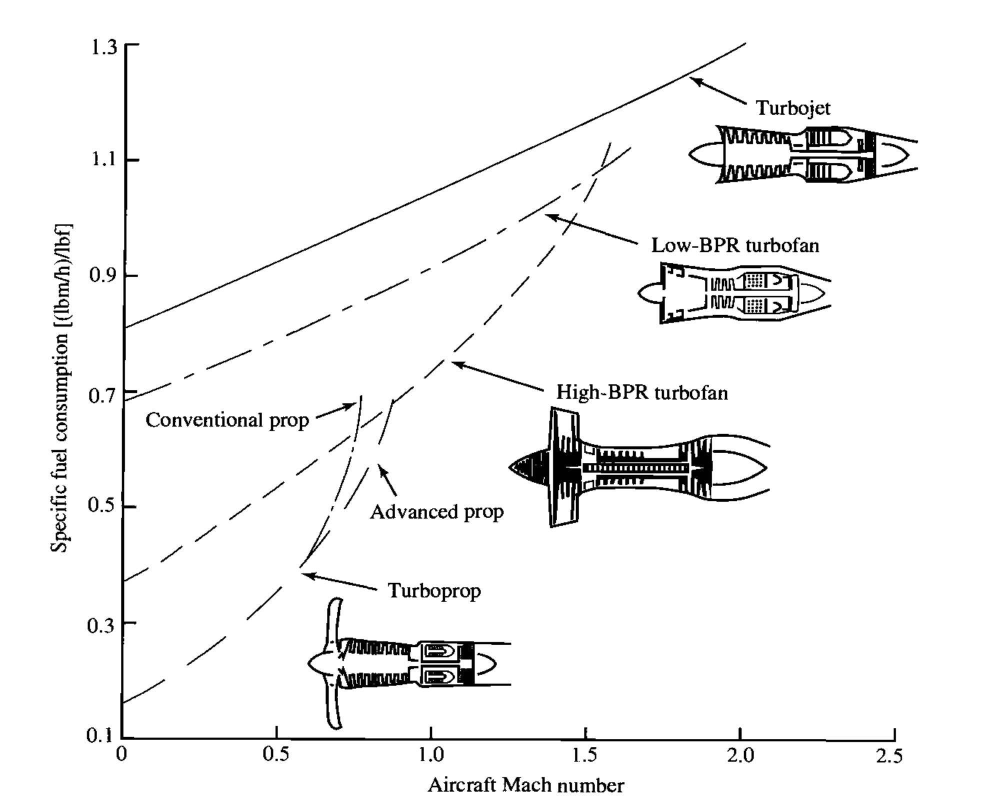
Propulsiv efficiency define the thrust produced for specific flight speed from kinetic energy added to engine airflow

ENGINES PERFORMANCE

Specific thrust vs. flight speed



Specific fuel consumption vs. flight speed



Propulsions of high specific thrust have got high specific fuel consumption
Low specific fuel consumption is characteristic for propulsions dedicated for low speed

Figures from: **Jack D. Mattingly, Elements of Propulsion: Gas Turbines and Rockets, AIAA Education Series 2006**

THANKS FOR YOUR ATENTION

Questions and Comments ?

1. …….
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