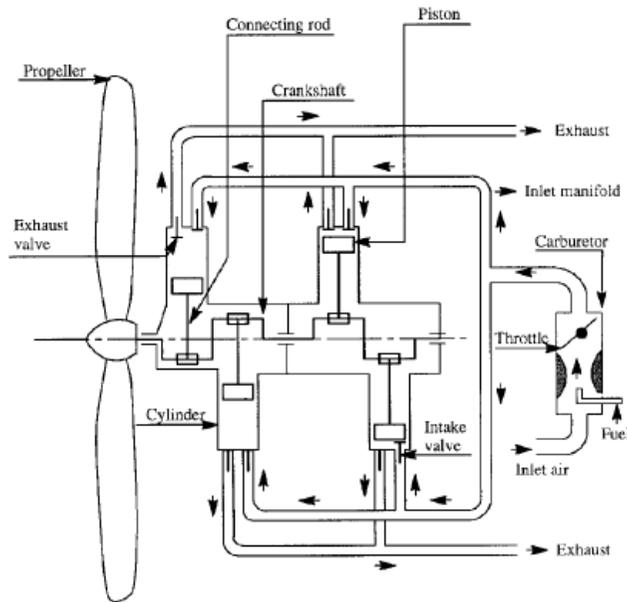
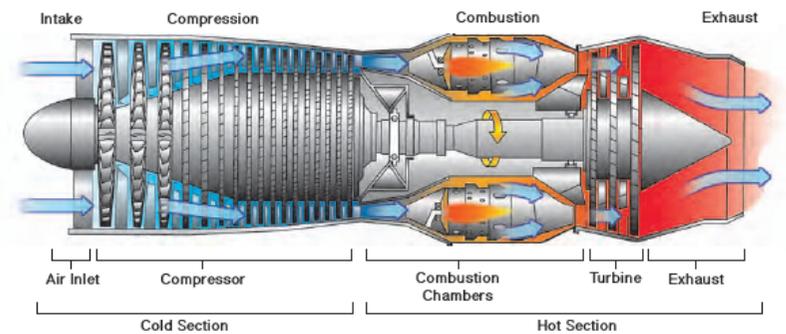
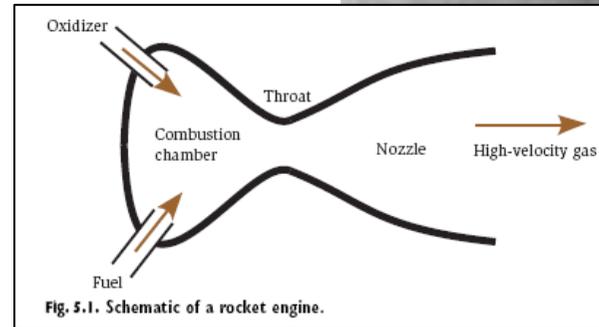


*Corso di MECCANICA DEL VOLO*  
*Modulo Prestazioni*

*Lezioni n. 11 – Caratteristiche propulsive*

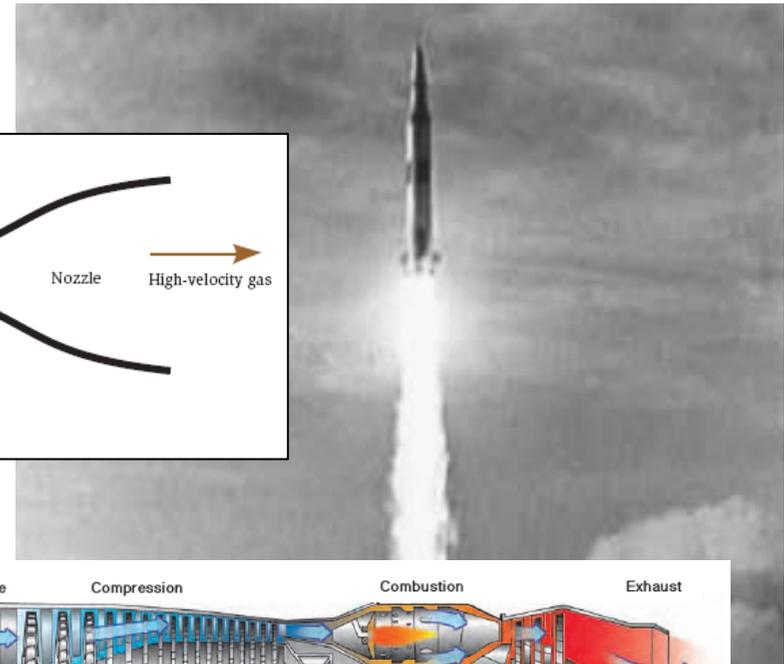
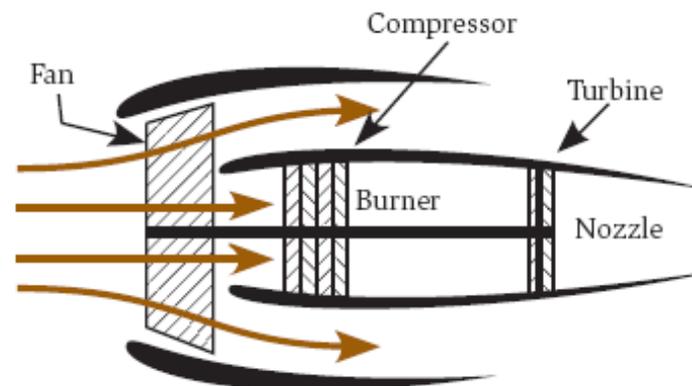
# Cap.6 – Caratteristiche propulsive

- Razzi (Rockets)
- Ramjet
- Turbojet
- Turbofan
- Turboprop
- Motoelica



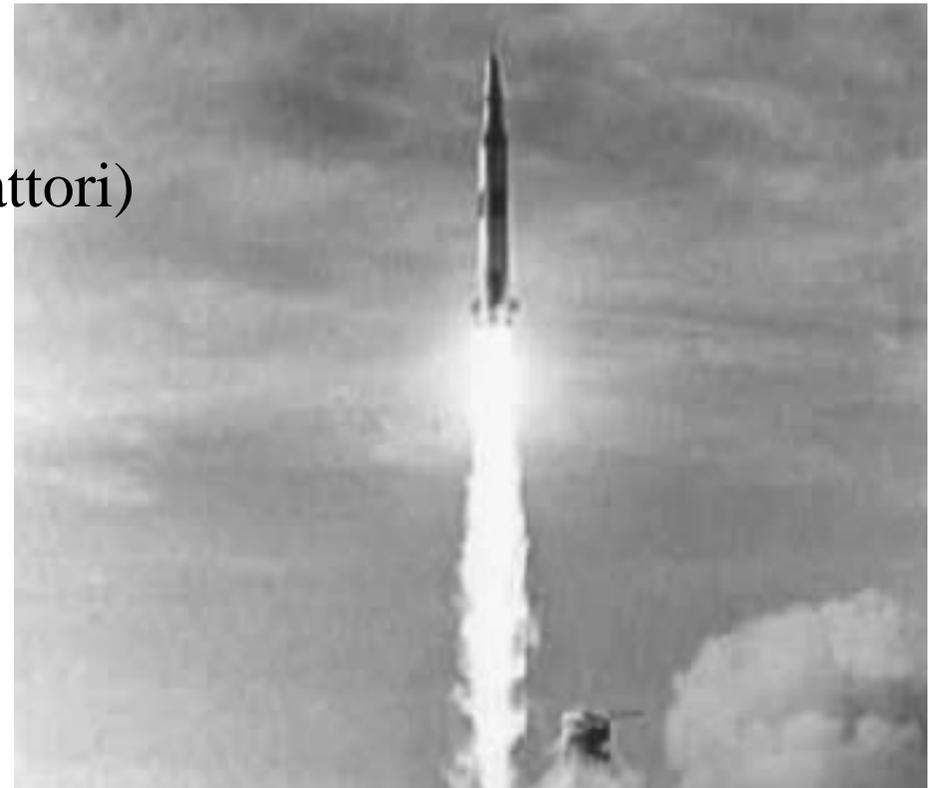
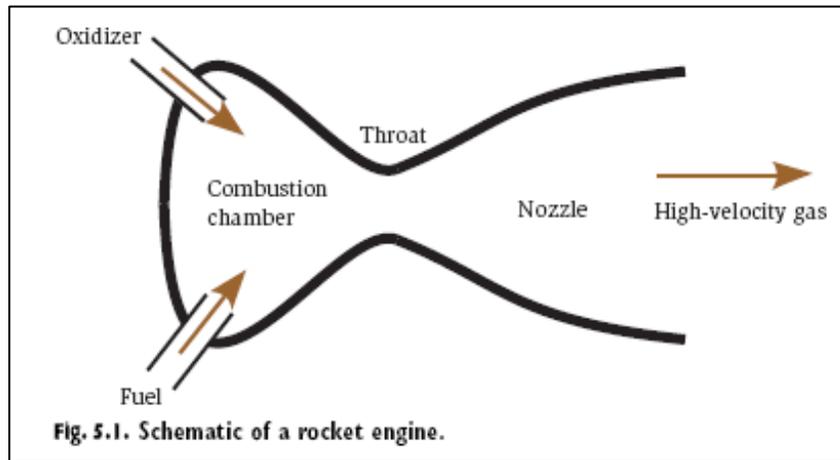
Note: modern engines tend to use fuel injection rather than carburetors

Figure 6.6 Typical Cross-section of a Four-cylinder Piston Engine

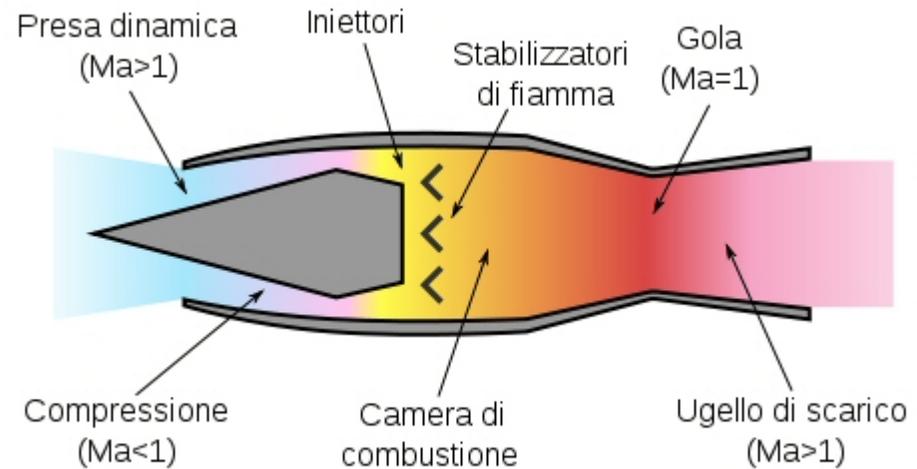


# Cap.6 – Caratteristiche propulsive

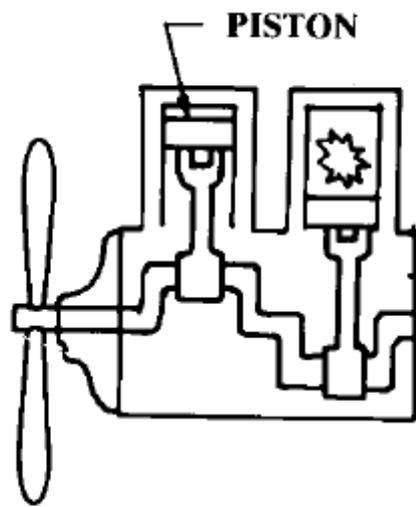
- Razzi (Rockets) (o anche Endoreattori)



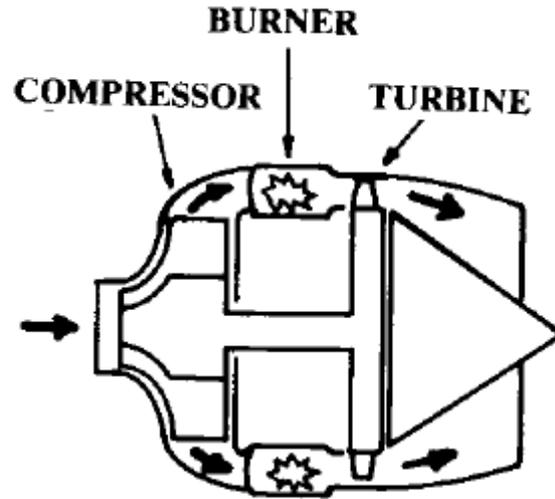
- Ramjet



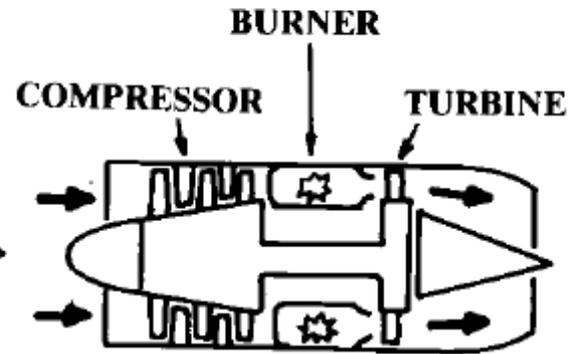
# Cap.6 – Caratteristiche propulsive



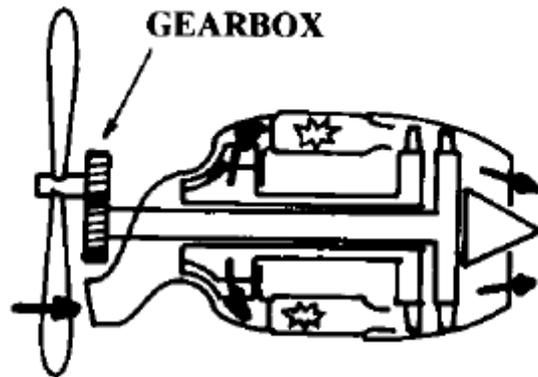
**PISTON-PROP**



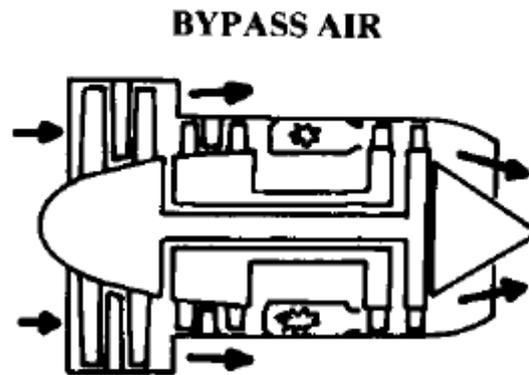
**CENTRIFUGAL TURBOJET**



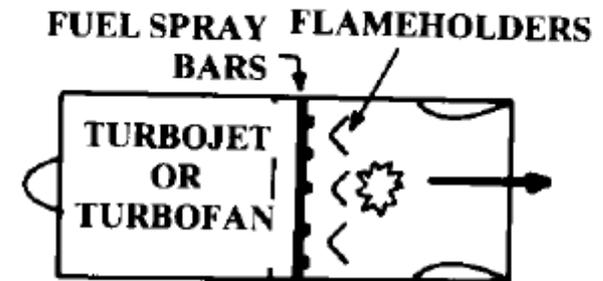
**AXIAL-FLOW TURBOJET**



**TURBO-PROP**

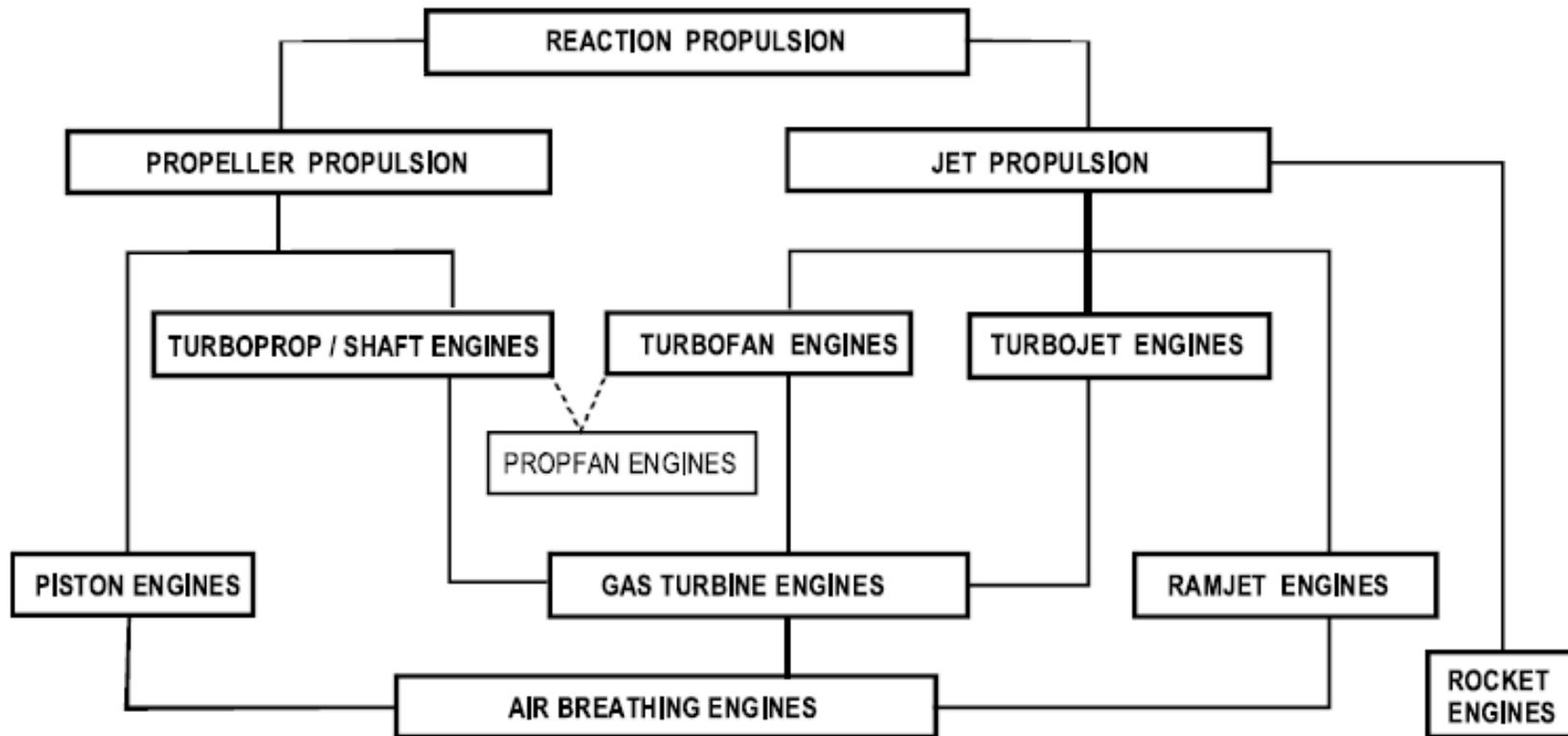


**TURBOFAN**



**AFTERBURNER**

# Cap.6 – Caratteristiche propulsive



# Cap.6 – Caratteristiche propulsive

## Motoelica

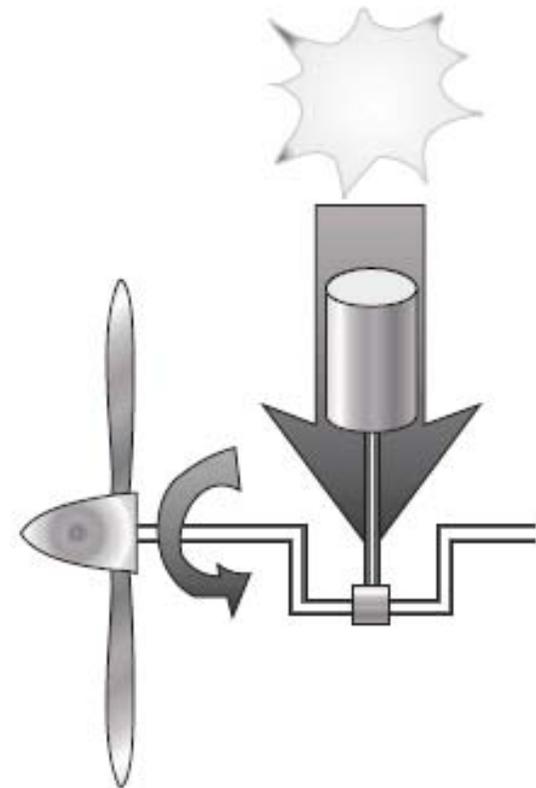
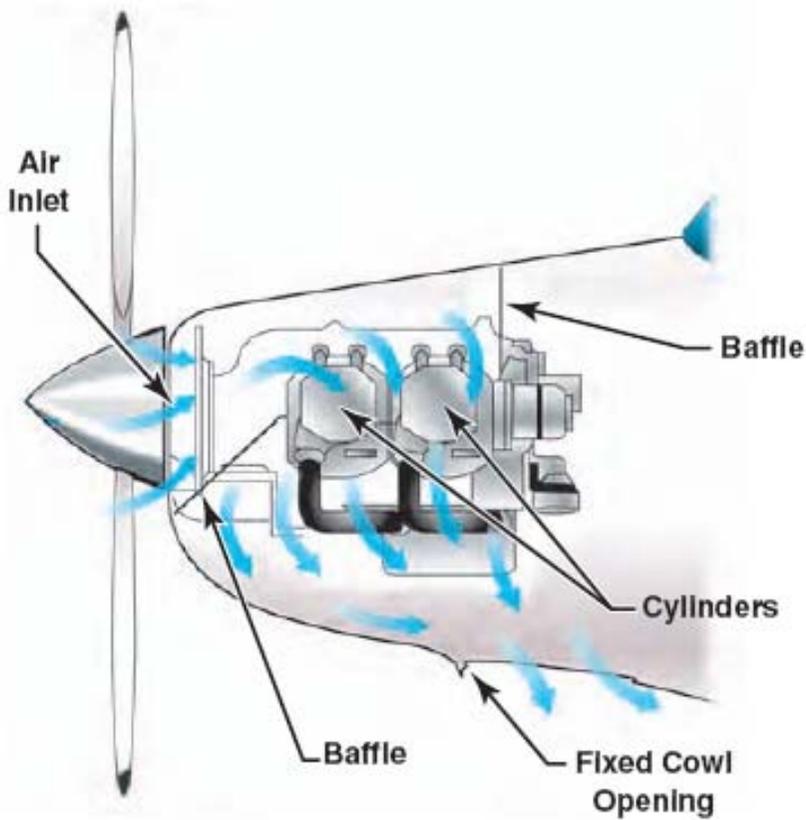


Fig. 5.7. How a piston engine converts chemical energy to propeller rotation.

# Cap.6 – Caratteristiche propulsive

## Motoelica

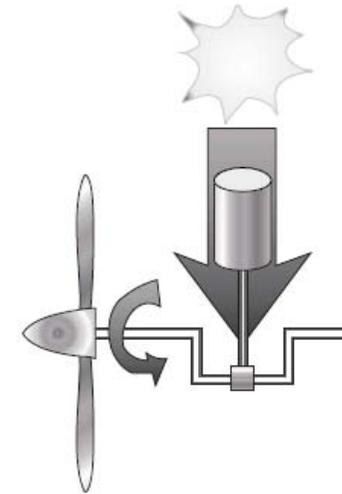


Fig. 5.7. How a piston engine converts chemical energy to propeller rotation.

### **Turbocharger**

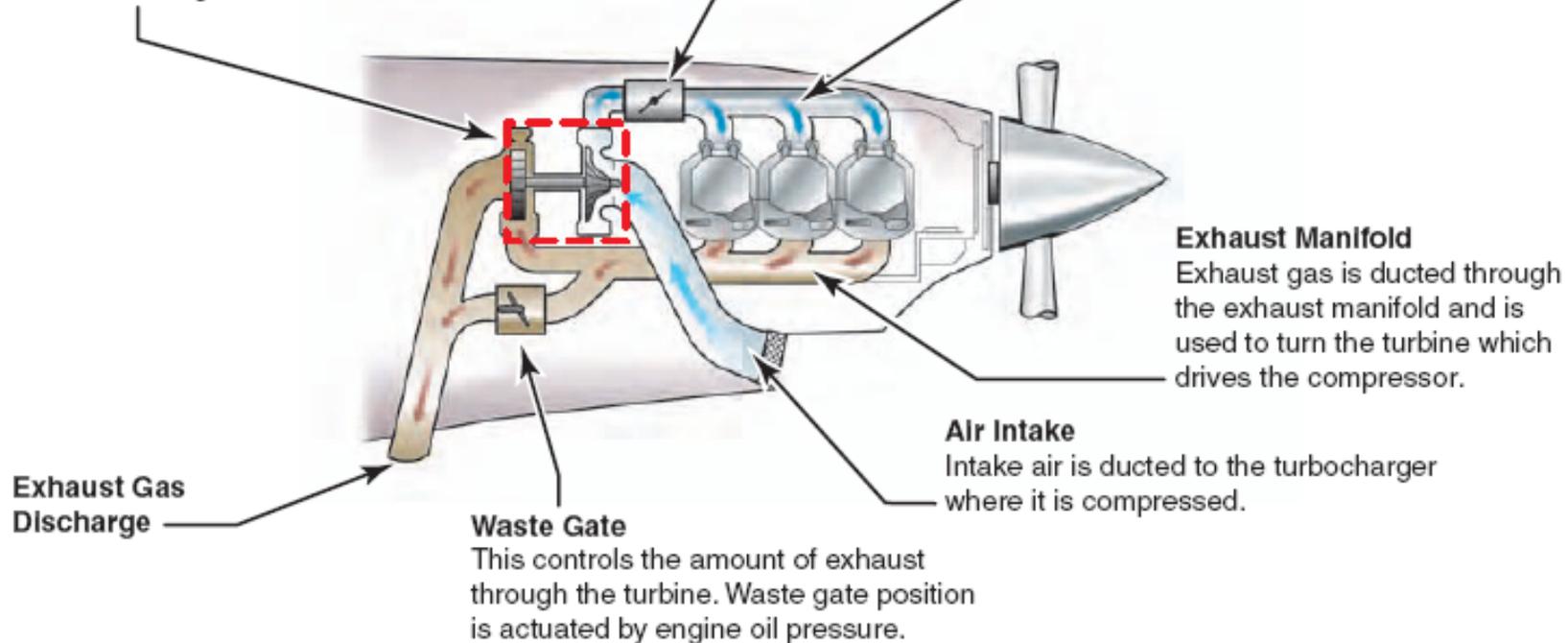
The turbocharger incorporates a turbine, which is driven by exhaust gases, and a compressor that pressurizes the incoming air.

### **Throttle Body**

This regulates airflow to the engine.

### **Intake Manifold**

Pressurized air from the turbocharger is supplied to the cylinders.



### **Exhaust Manifold**

Exhaust gas is ducted through the exhaust manifold and is used to turn the turbine which drives the compressor.

### **Air Intake**

Intake air is ducted to the turbocharger where it is compressed.

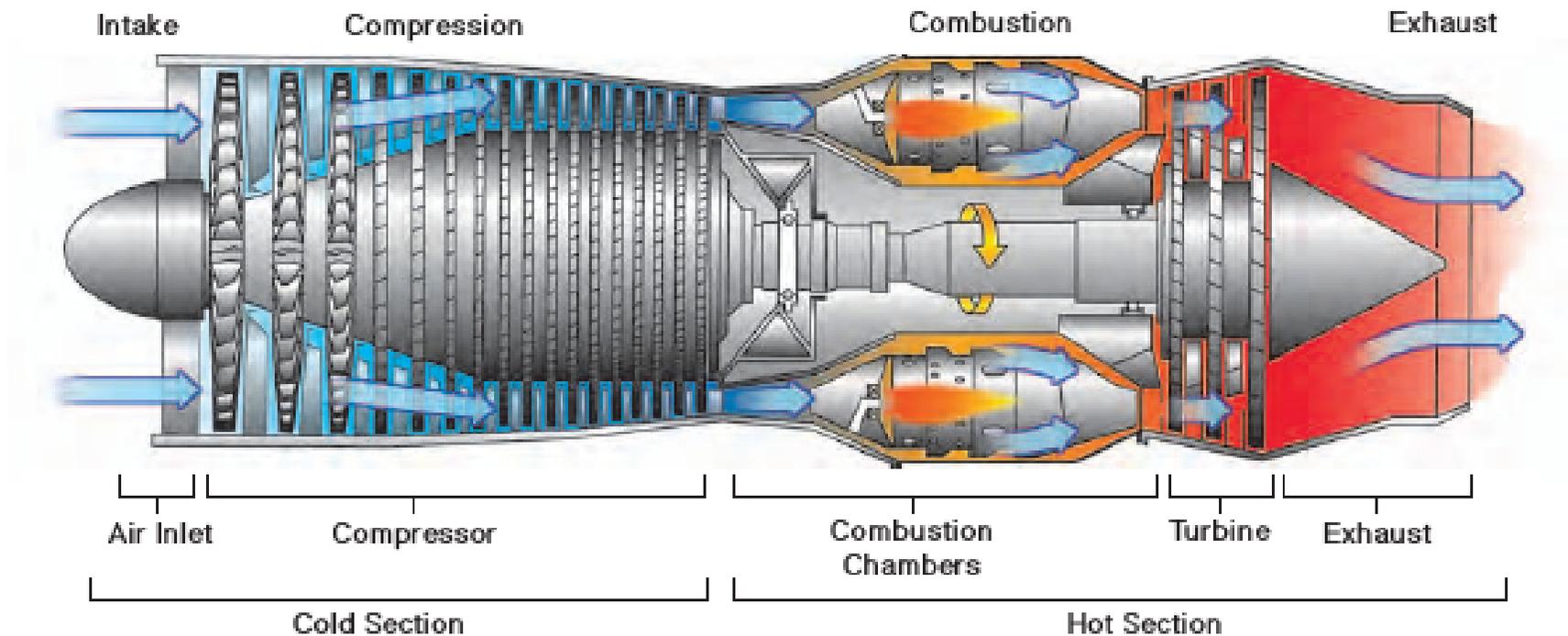
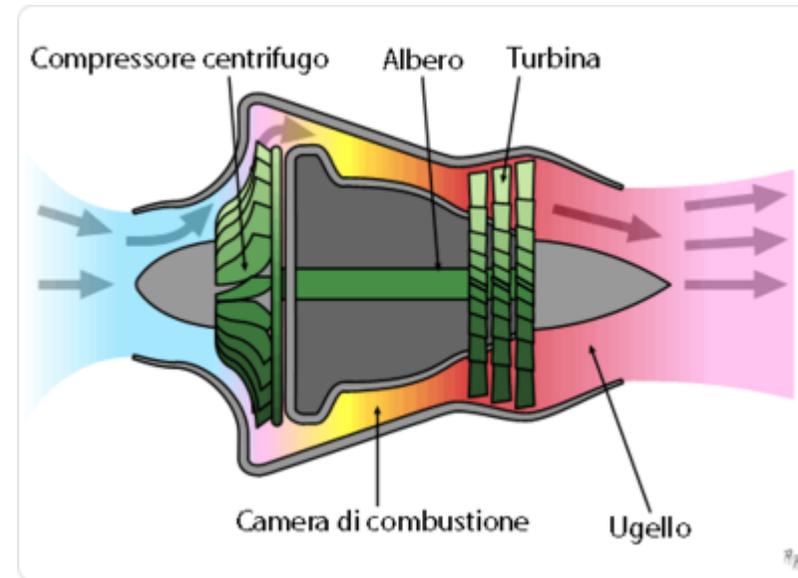
### **Exhaust Gas Discharge**

### **Waste Gate**

This controls the amount of exhaust through the turbine. Waste gate position is actuated by engine oil pressure.

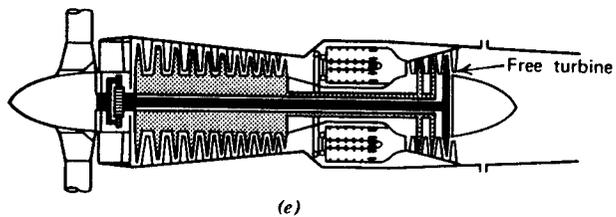
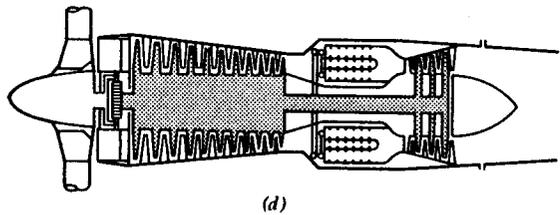
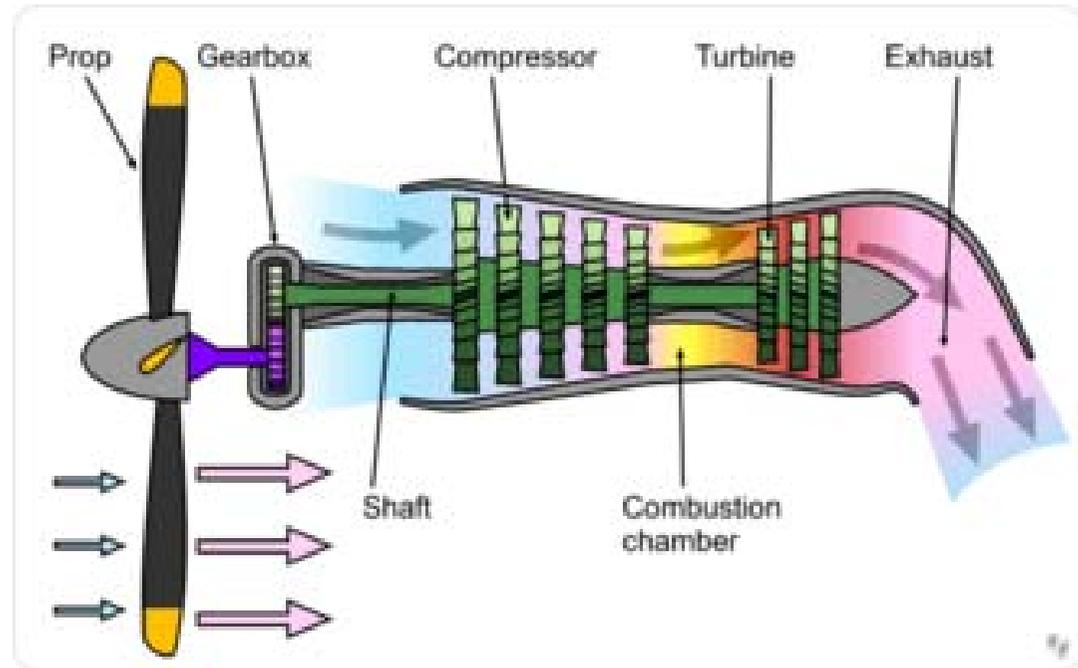
# Cap.6 – Caratteristiche propulsive

## Turbogetto



# Cap.6 – Caratteristiche propulsive

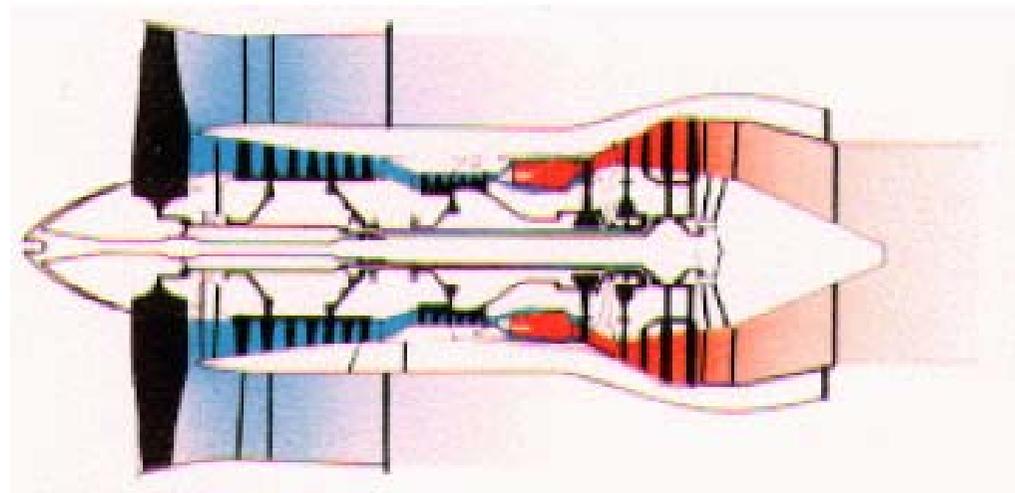
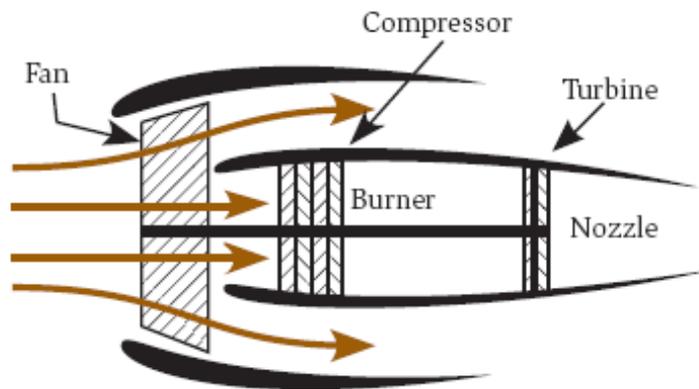
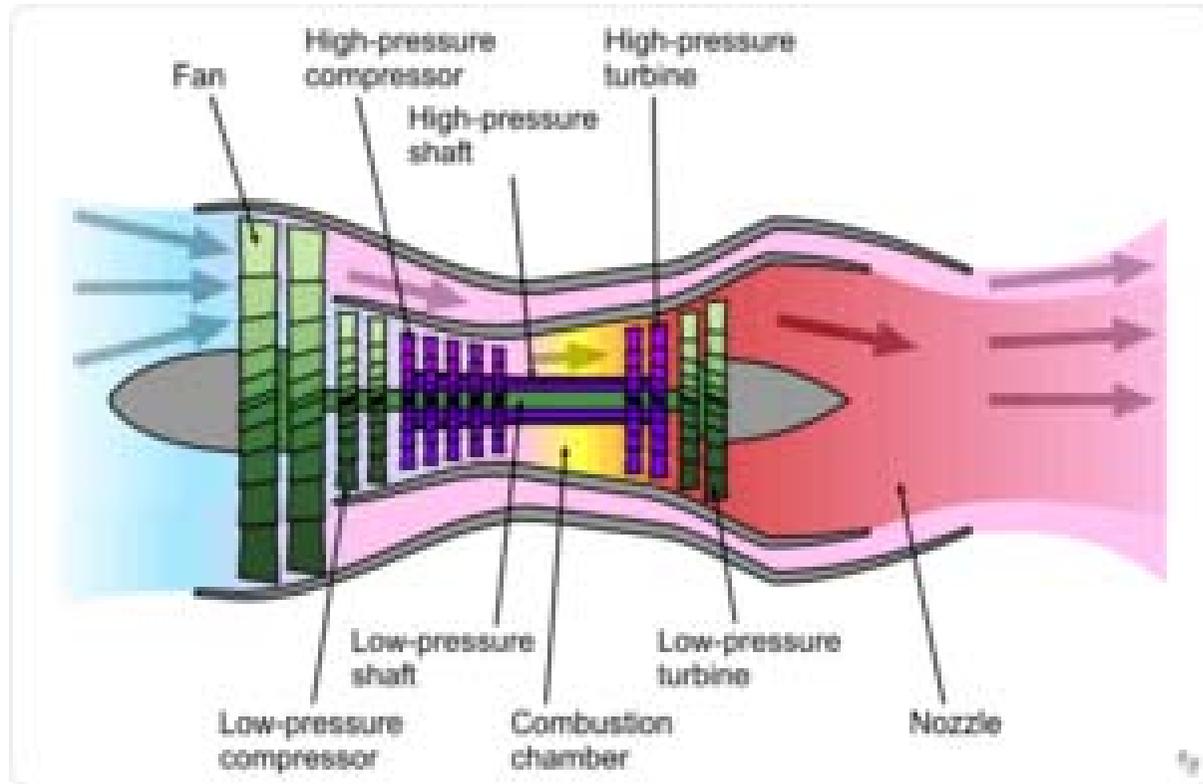
## Turboprop (tipo ATR42)



# Cap.6 – Caratteristiche propulsive

## Turbofan

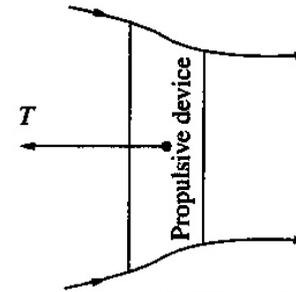
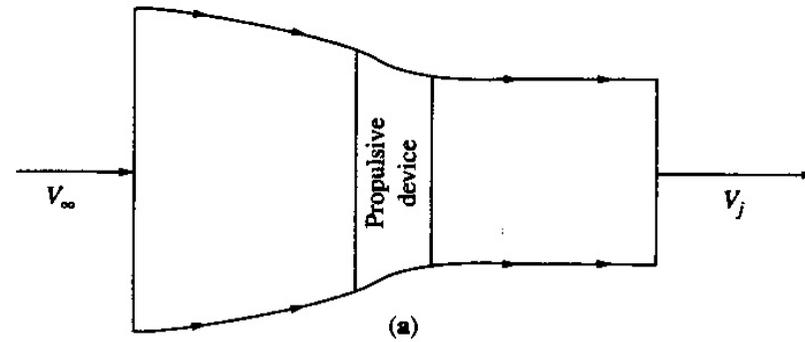
BPR (By-Pass Ratio)



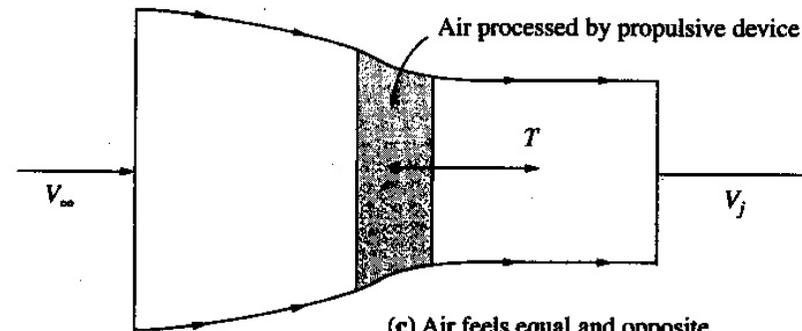
# Cap.6 – Caratteristiche propulsive

## Principio di funzionamento

$$T = \dot{m}(V_j - V_\infty)$$



(b) Propulsive device produces thrust  $T$  acting to the left.



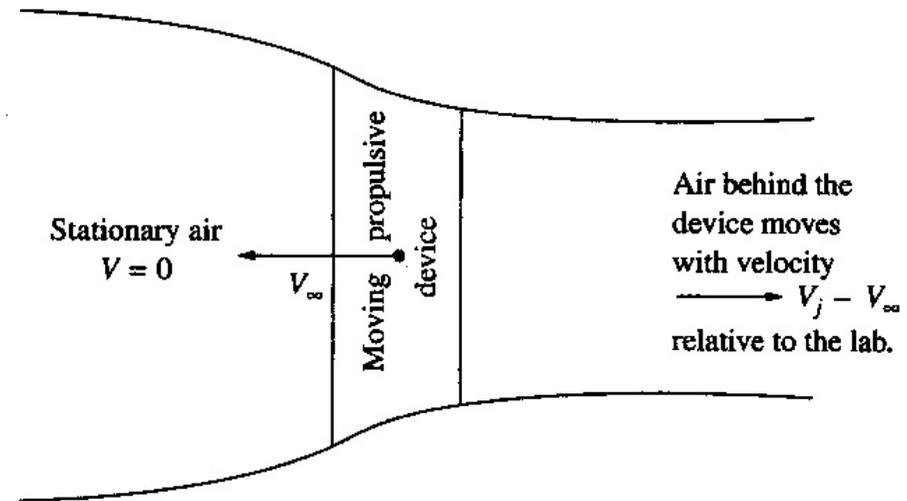
(c) Air feels equal and opposite force  $T$  acting to the right.

## Cap.6 – Caratteristiche propulsive

### Principio di funzionamento

Aria si muove a vel.

$$V_j - V_\infty$$



Energia cinetica per unità di massa

$$\frac{1}{2}(V_j - V_\infty)^2$$

Quest'energia cinetica è interamente dissipata

*Potenza = forza  $\times$  velocità*

## Cap.6 – Caratteristiche propulsive

La *potenza utile*, chiamata *potenza disponibile*

$$\Pi_d = TV_\infty$$

Ma c'è anche una quantità di potenza dissipata (aria in uscita)

$$\frac{1}{2}\dot{m}(V_j - V_\infty)^2$$

=> *Potenza totale prodotta dal congegno propulsivo*

$$= TV_\infty + \frac{1}{2}\dot{m}(V_j - V_\infty)^2$$

$$\eta_j = \frac{\text{potenza disponibile}}{\text{potenza totale prodotta}}$$

## Cap.6 – Caratteristiche propulsive

$$\eta_j = \frac{TV_\infty}{TV_\infty + \frac{1}{2}\dot{m}(V_j - V_\infty)^2}$$

$$\eta_j = \frac{\dot{m}(V_j - V_\infty)V_\infty}{\dot{m}(V_j - V_\infty)V_\infty + \frac{1}{2}\dot{m}(V_j - V_\infty)^2}$$

Dividendo num e denom. per  $\dot{m}(V_j - V_\infty)V_\infty$

$$\eta_j = \frac{1}{1 + \frac{1}{2}(V_j - V_\infty)/V_\infty} = \frac{1}{\frac{1}{2}(1 + \frac{V_j}{V_\infty})}$$

$$\eta_j = \frac{2}{1 + \frac{V_j}{V_\infty}}$$

EFFICIENZA PROPULSIVA (Froude Efficiency)

## Cap.6 – Caratteristiche propulsive

Possiamo definire anche la spinta specifica:

$$\frac{T}{\dot{m}} = (V_j - V_\infty) \quad \text{Spinta prodotta per unità di portata di massa} \\ [\text{N}/(\text{kg}/\text{sec})] \quad \text{o anche dimensione di una vel. [m/s]}$$

$$\eta_j = \frac{2}{2 + (V_j - V_\infty)/V_\infty} = \frac{2}{2 + \frac{T}{\dot{m}} V_\infty} = \frac{2}{2 + C_j}$$

Abbiamo introdotto il “jet velocity coeff.”

$$C_j = \frac{T}{\dot{m}} V_\infty = \frac{V_j}{V_\infty} - 1$$

$$\eta_j = \frac{2}{1 + \frac{V_j}{V_\infty}}$$

$$\eta_j = \frac{2}{2 + C_j}$$

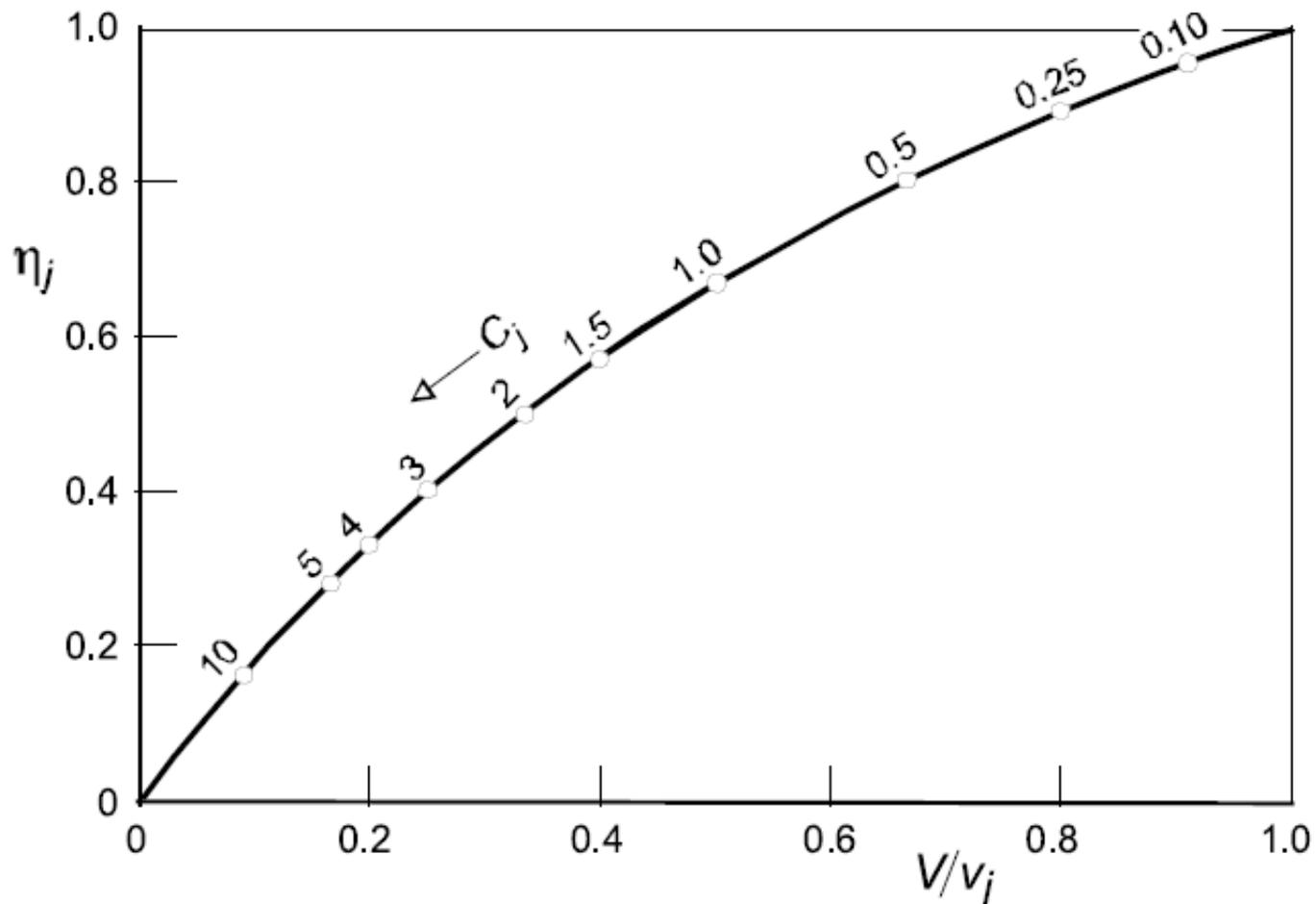
## Cap.6 – Caratteristiche propulsive

$$C_j = \frac{T}{\dot{m}} V_\infty = \frac{V_j}{V_\infty} - 1 \quad \text{jet velocity coeff.}$$

$$\eta_j = \frac{2}{1 + \frac{V_j}{V_\infty}}$$

*Propulsive efficiency*

$$\eta_j = \frac{2}{2 + C_j}$$



## Cap.6 – Caratteristiche propulsive

**Table 5.1** Example of *propulsive efficiency* data.

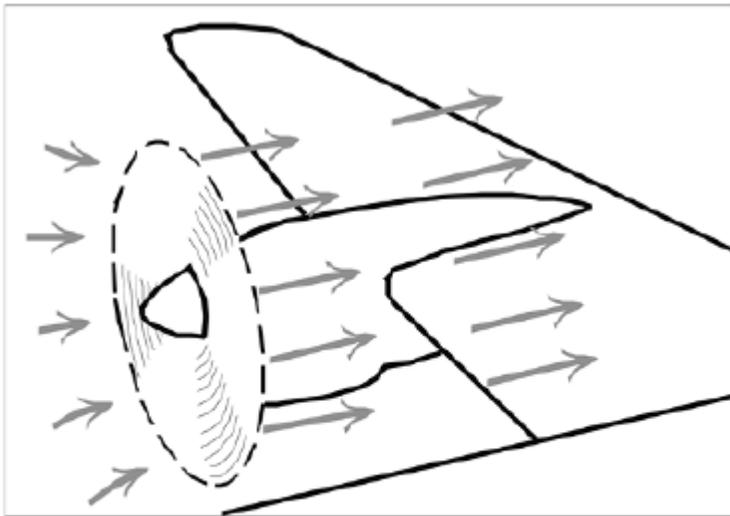
<i>Type of propulsion</i>	<i>Altitude</i> km	<i>Flight speed</i> $V$ , m/s (Mach no.)	<i>Jet velocity</i> $v_j$ , m/s	<i>Speed ratio</i> $v_j/V$	<i>Specific thrust</i> $T/\dot{m}_a$ , m/s	<i>Jet coefficient</i> $C_j$	<i>Propulsive efficiency</i> $\eta_j$
propeller	6	150	160 (0.47)	1.07	10	0.067	0.97
subsonic jet engine	9	250 (0.82)	750	3.00	500	2.00	0.50
low BPR turbofan	9	250 (0.82)	582*	2.33	332	1.33	0.60
high BPR turbofan	9	250 (0.82)	418*	1.67	168	0.67	0.75
supersonic jet engine	16	600 (2.03)	1,000	1.67	400	0.67	0.75

\* weighted average of primary and secondary airflow

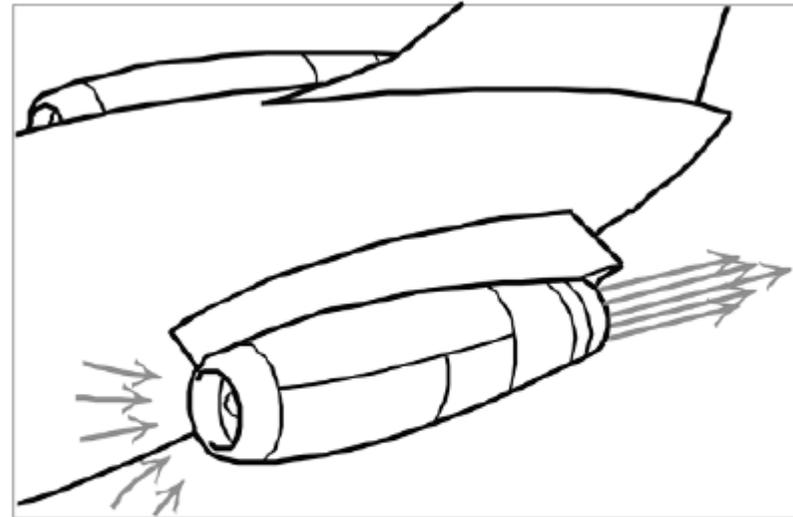
## Cap.6 – Caratteristiche propulsive

L'efficienza propulsiva dell'elica è maggiore di quella del getto.

- Elica: piccolo incremento di velocità ad una grossa massa aria
- Jet: grande incremento di velocità ad una piccola quantità di aria



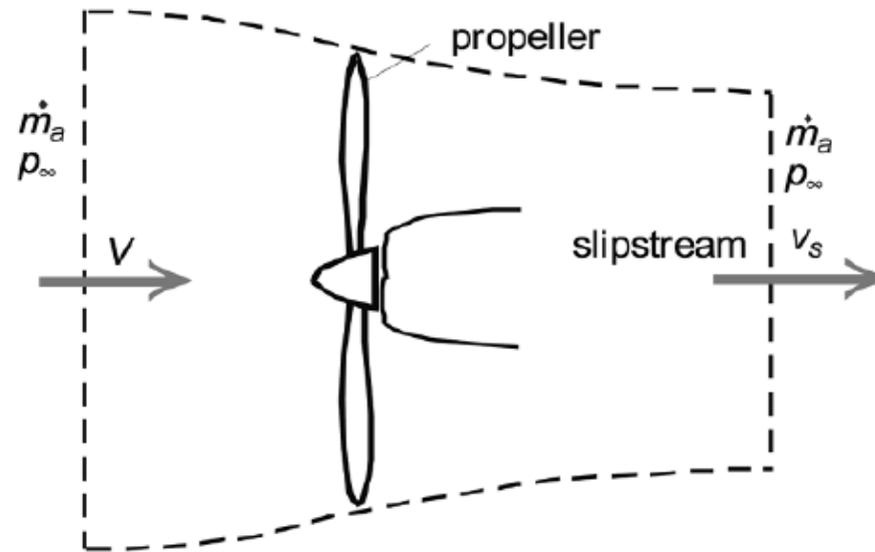
(a) A propeller imparts a small velocity increment to a large mass of air



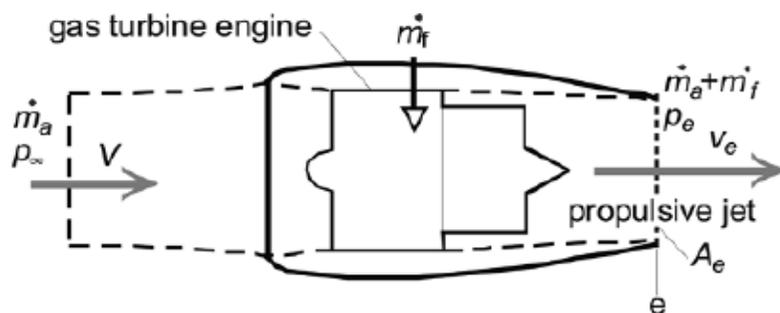
(b) A turbojet engine imparts a large velocity increment to a (relatively) small amount of air

# Cap.6 – Caratteristiche propulsive

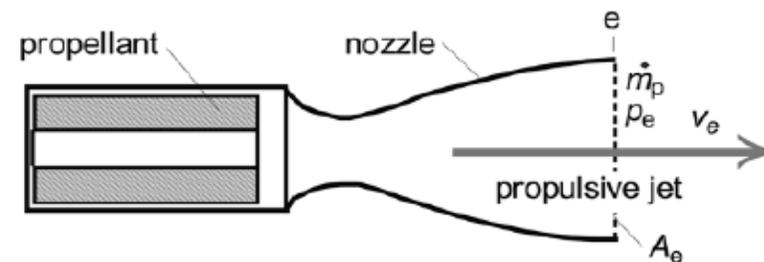
## Principio di funzionamento



(a) Airflow through a propeller

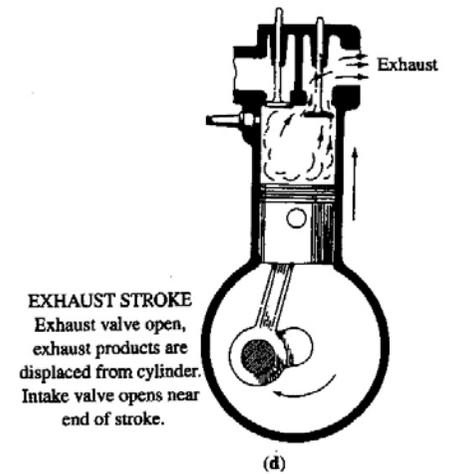
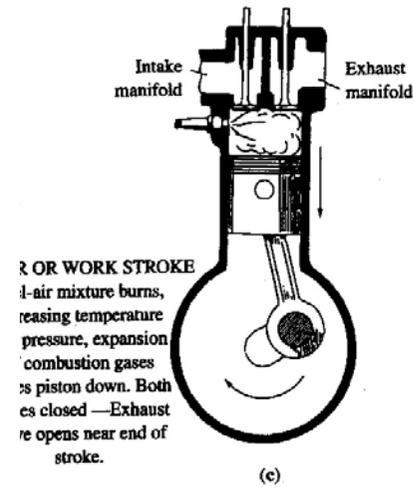
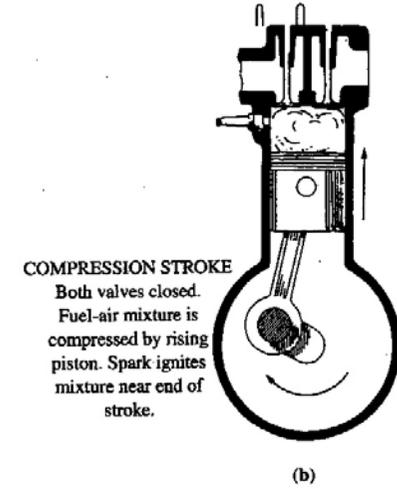
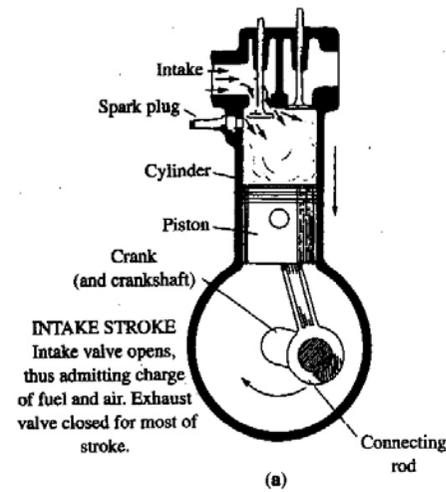
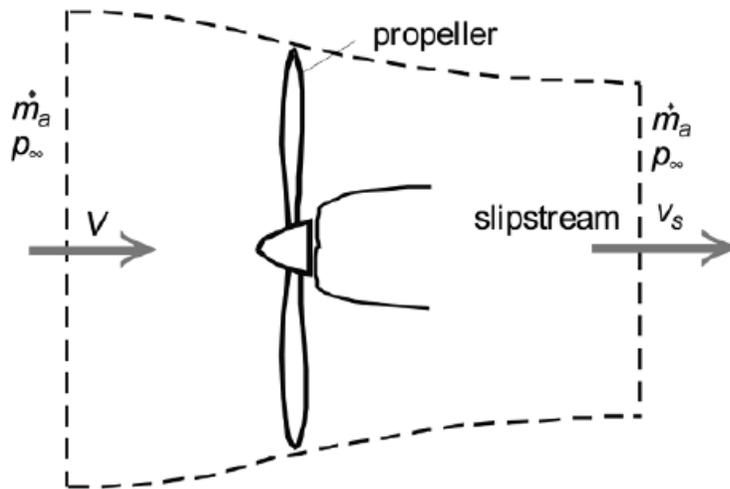
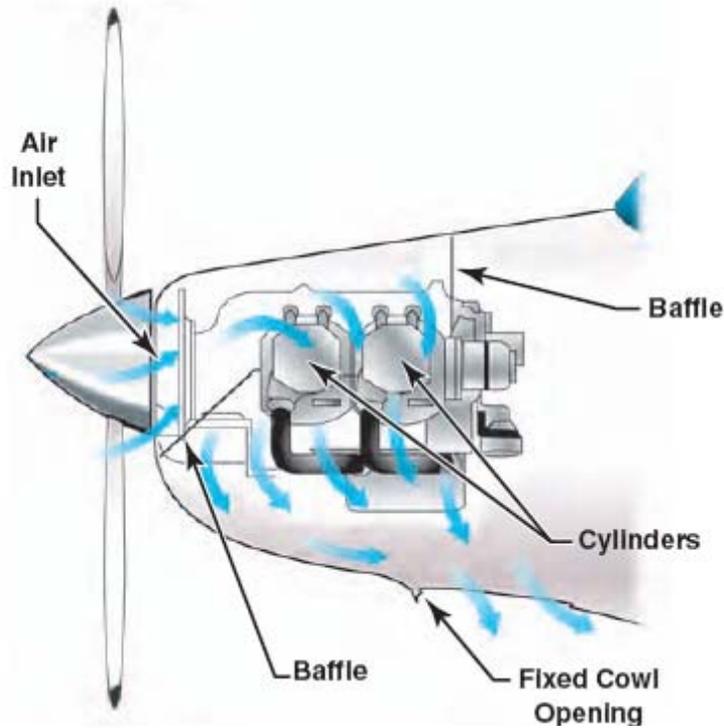


(b) Airflow through a jet engine



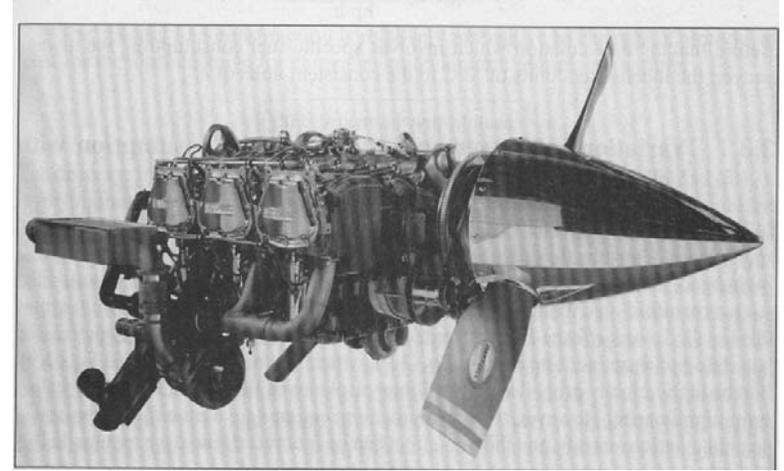
(c) Principle of a solid rocket engine

# Cap.6 – Caratteristiche propulsive MOTOELICA



## Cap.6 – Caratteristiche propulsive MOTOELICA

$$\Pi_a \propto d \cdot p_e \cdot RPM$$



- la cilindrata con  $d$  (dall'inglese *displacement*)
- *pressione media efficace*  $p_e$

### Consumo specifico

$$c = \frac{\text{peso di combustibile consumato per dato incremento di tempo}}{(\text{potenza sviluppata})(\text{incremento di tempo})}$$

$$[c] = \frac{lb}{(ft \cdot lb / s)(s)}$$

$$[c] = \frac{N}{W \cdot s}$$

## Cap.6 – Caratteristiche propulsive MOTOELICA

$$SFC = \frac{lb}{hp \cdot h}$$

Unità ingegneristiche

valore tipico 0.40-0.50 [lb/(hp h)].

Il che vuol dire che un motore da 100 hp in funzionamento al massimo della potenza per un'ora di volo consuma circa 50 lb di combustibile (cioè circa 25 Kg di combustibile). Teniamo anche presente che il peso specifico del combustibile è circa 0.70 Kg/l , quindi un serbatoio da 100 l di combustibile è capace di trasportare 70 Kg di combustibile.

## Cap.6 – Caratteristiche propulsive MOTOELICA

Variazione di potenza e SFC con vel e quota

- $\Pi_a$  è ragionevolmente costante con la velocità
- SFC è ragionevolmente costante con la velocità

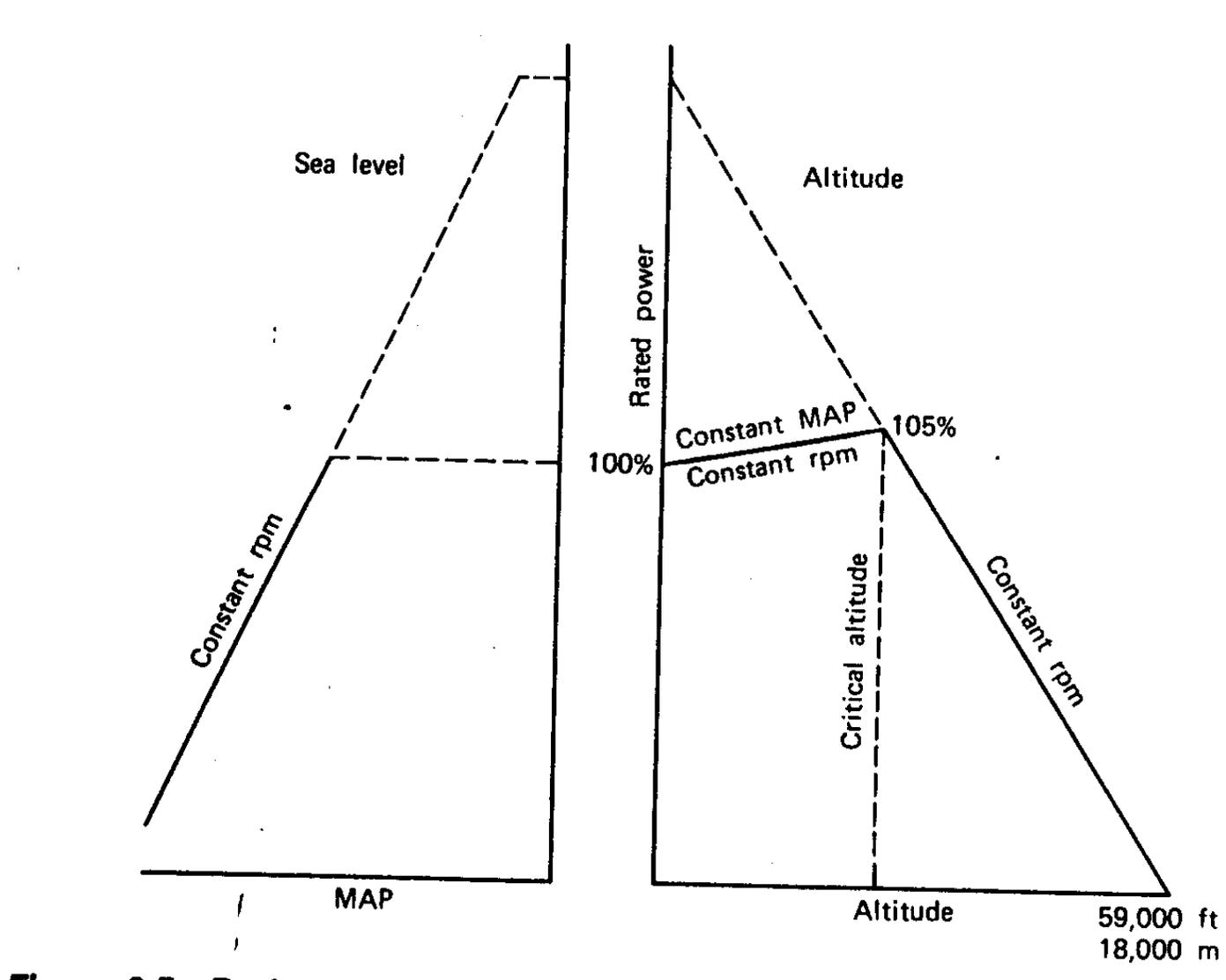
Negli Stati Uniti i due principali produttori di motori alternativi aerei sono Teledyne Continental e Textron Lycoming. I cavalli vapore a livello del mare per questi motori generalmente variano da 75 a 300 hp. Per questi motori un tipico valore di SFC è 0.4lb di carburante consumate per cavallo vapore per ora.

### Effetto quota

$$\frac{\Pi_a}{\Pi_{a0}} = \frac{\rho}{\rho_0} \quad \text{oppure} \quad \frac{\Pi_a}{\Pi_{a0}} = 1.132 \frac{\rho}{\rho_0} - 0.132$$

# Cap.6 – Caratteristiche propulsive MOTOELICA

## Motori Supercharged (turbocompressi)



## Cap.6 – Caratteristiche propulsive MOTOELICA

$$\Pi_a = \Pi_{a_0} \sigma \varphi$$

Quindi effetto della quota e del grado di ammissione

# Cap.6 – Caratteristiche propulsive ELICHE

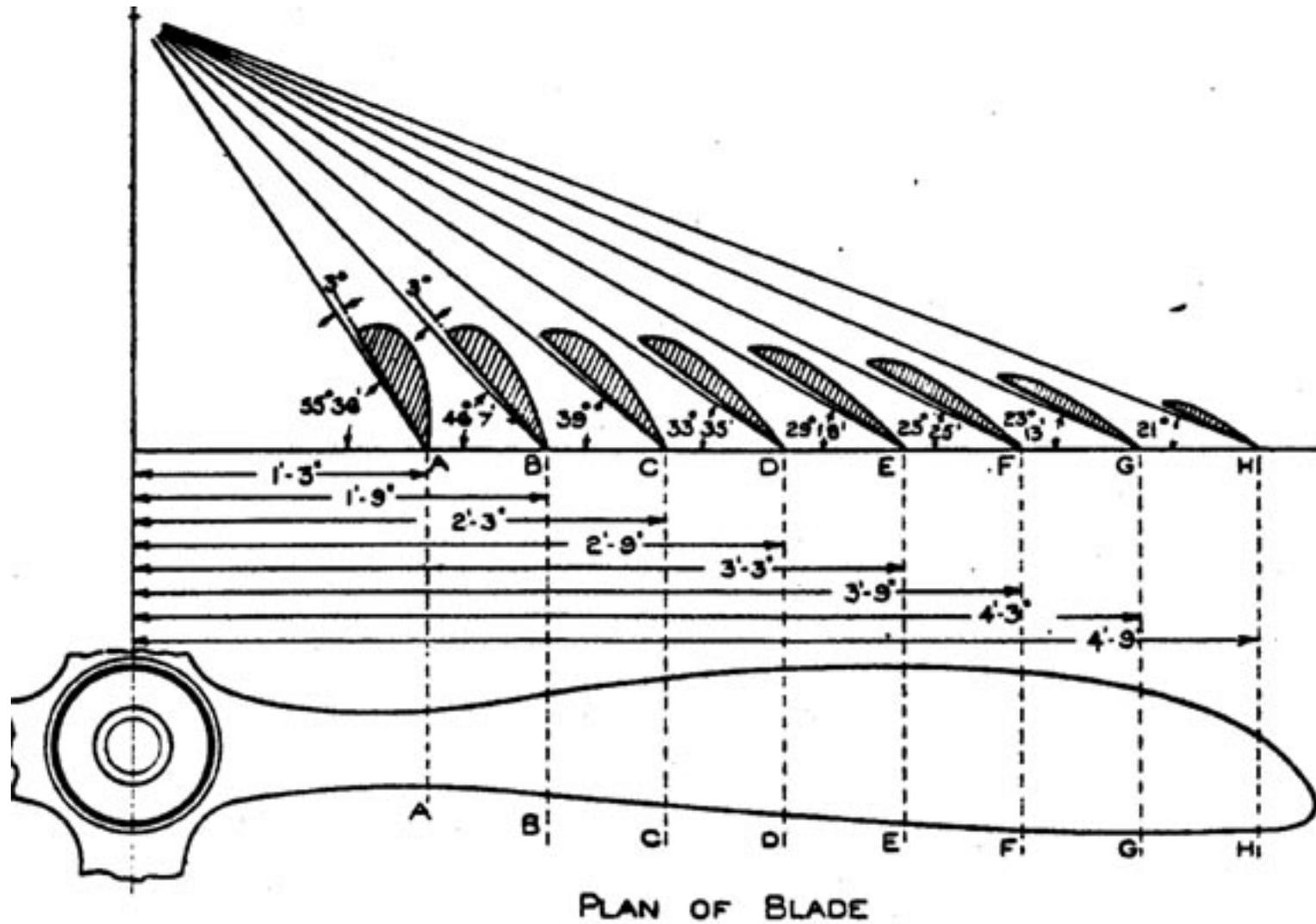
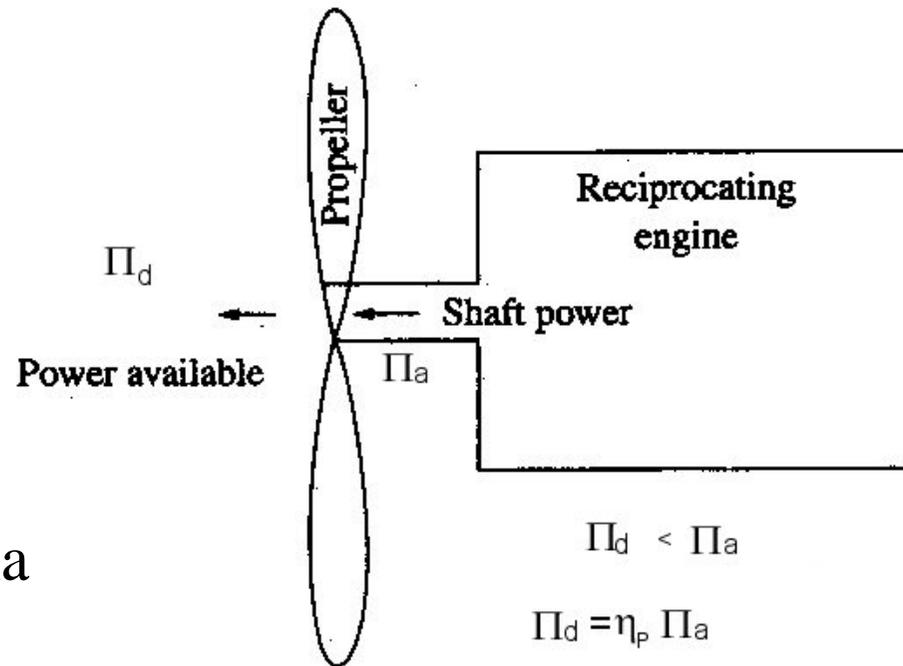


FIG. 219.—Lay-out of an Aircscrew.

## Cap.6 – Caratteristiche propulsive ELICHE

$$\Pi_d = \eta_{pr} \Pi_a$$



Il rendimento dell'elica è una funzione del *rapporto di avanzamento*  $J$  definito come

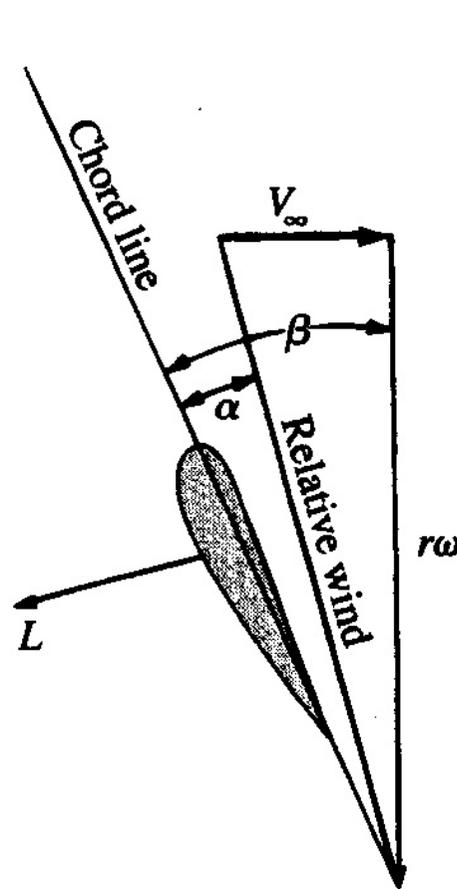
$$J = \frac{V_\infty}{ND}$$

# Cap.6 – Caratteristiche propulsive ELICHE

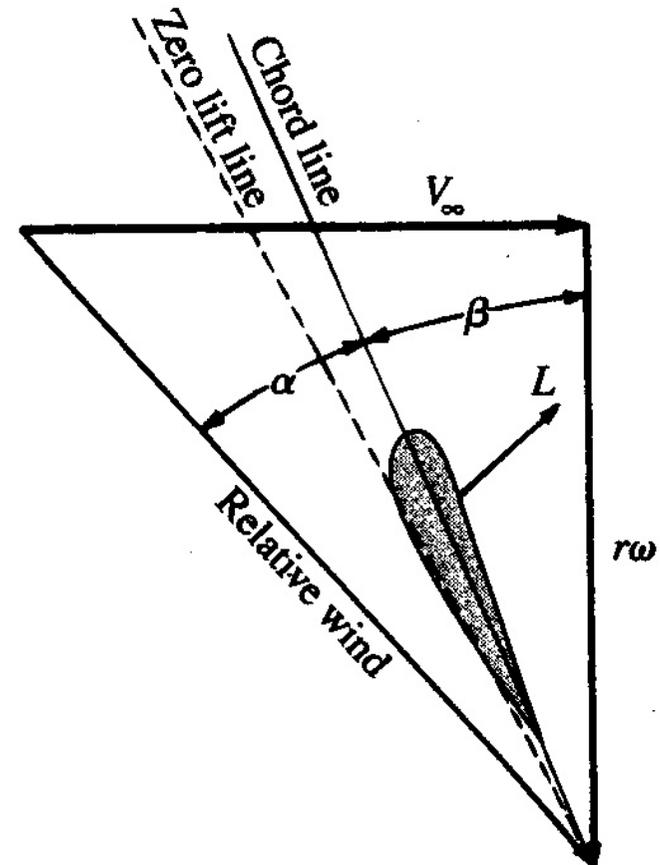
$$(r\omega)_{tip} = \pi ND$$

$$\frac{V_\infty}{r\omega} = \frac{V_\infty}{r(2\pi N)} \quad (\text{angolo vel locale})$$

$$\left(\frac{V_\infty}{r\omega}\right)_{tip} = \frac{V_\infty}{(D/2)(2\pi N)} = \frac{V_\infty}{\pi ND} = \frac{J}{\pi}$$



(a)



(b)

## Cap.6 – Caratteristiche propulsive ELICHE

$$(r\omega)_{tip} = \pi ND$$

$$\frac{V_\infty}{r\omega} = \frac{V_\infty}{r(2\pi N)} \quad (\text{angolo vel locale}) \quad \left(\frac{V_\infty}{r\omega}\right)_{tip} = \frac{V_\infty}{(D/2)(2\pi N)} = \frac{V_\infty}{\pi ND} = \frac{J}{\pi}$$

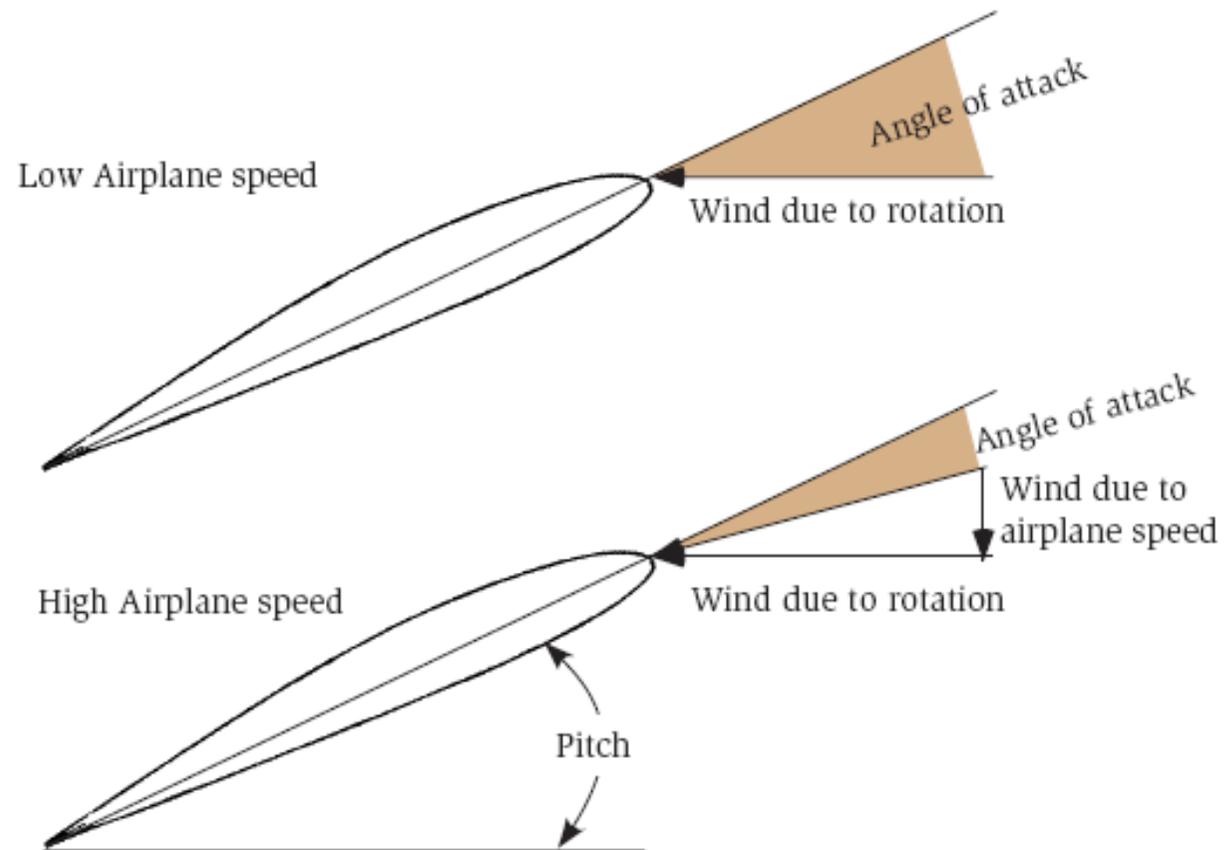
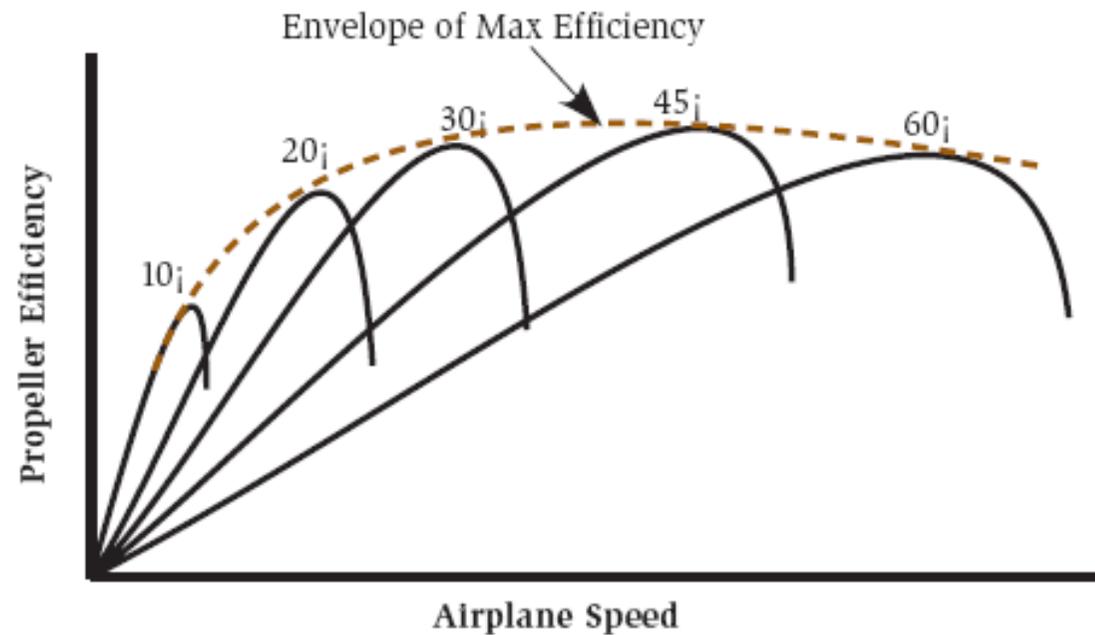
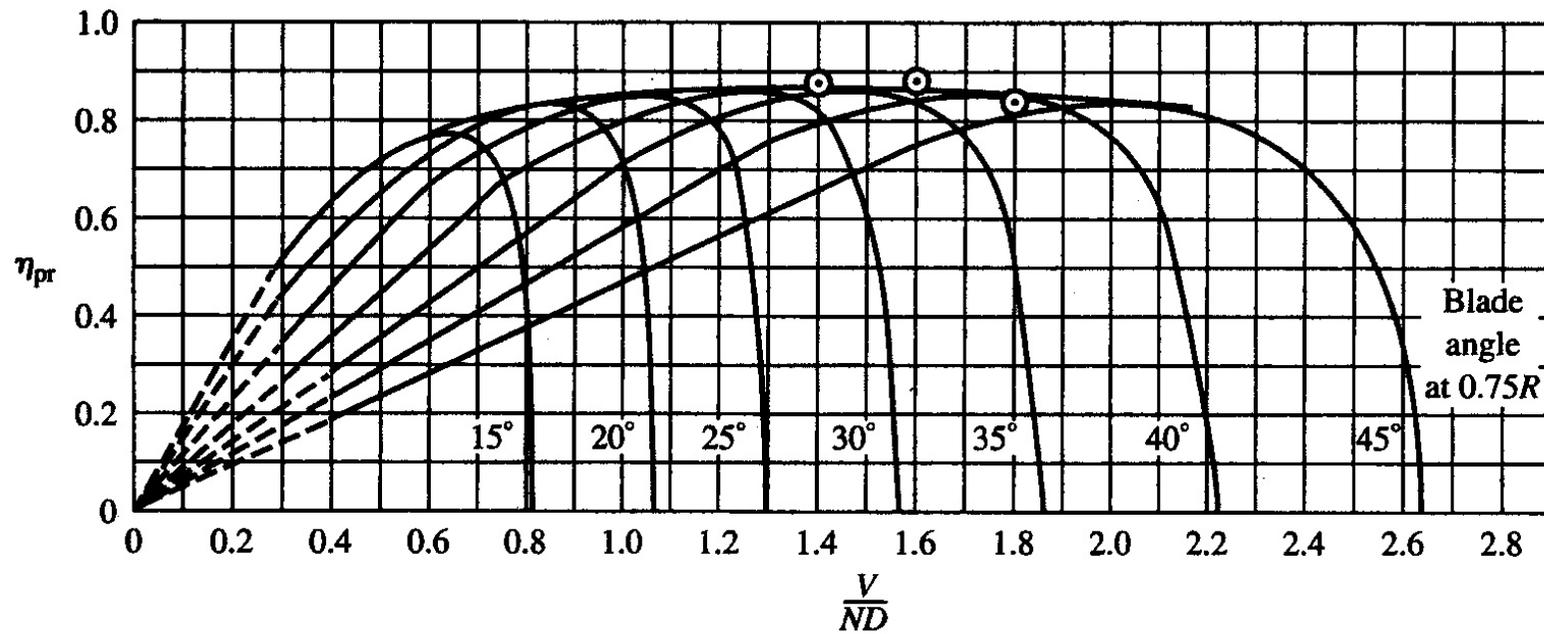
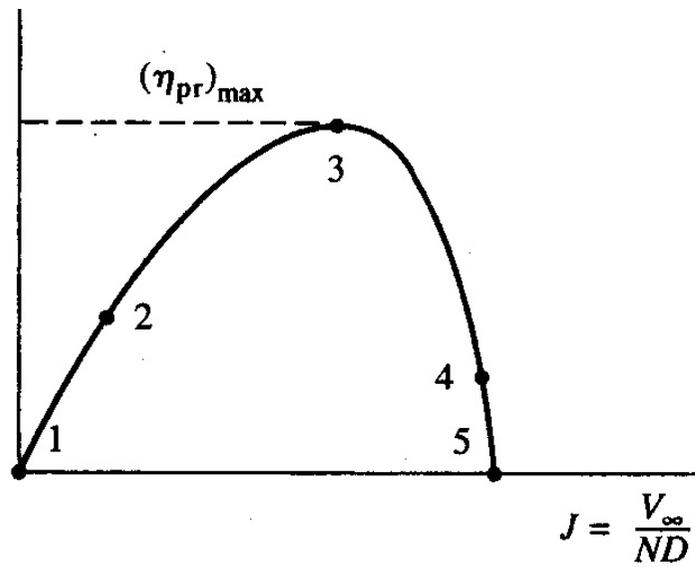
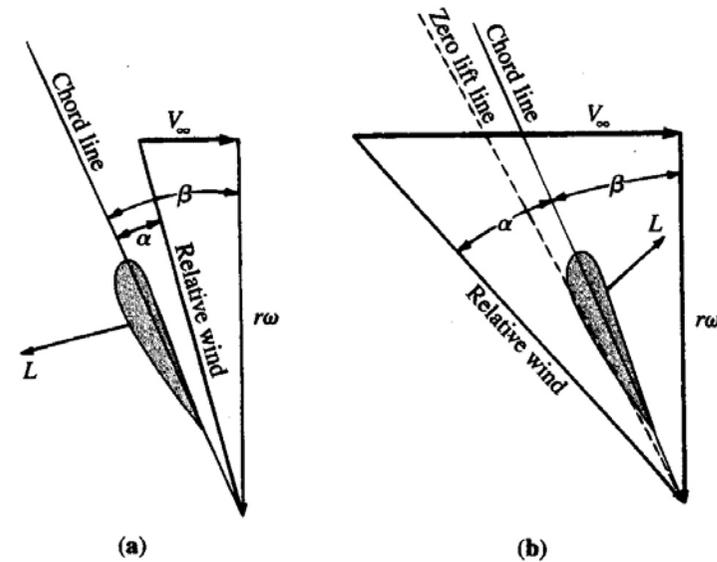


Fig. 5.5. Angle of attack of a rotating propeller.

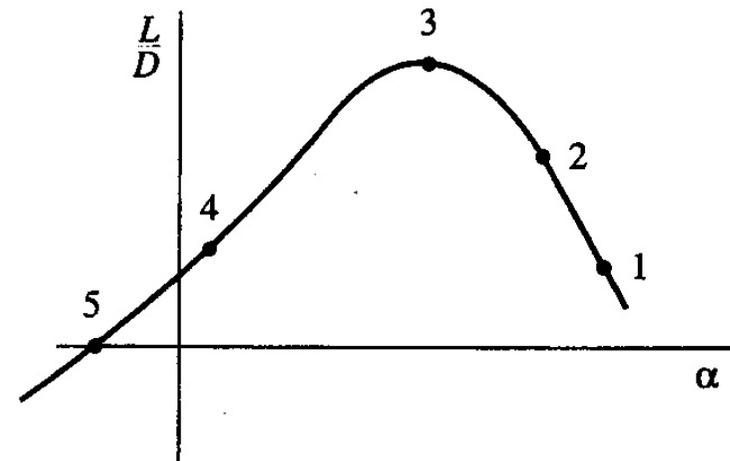
# Cap.6 – Caratteristiche propulsive ELICHE



# Cap.6 – Caratteristiche propulsive ELICHE



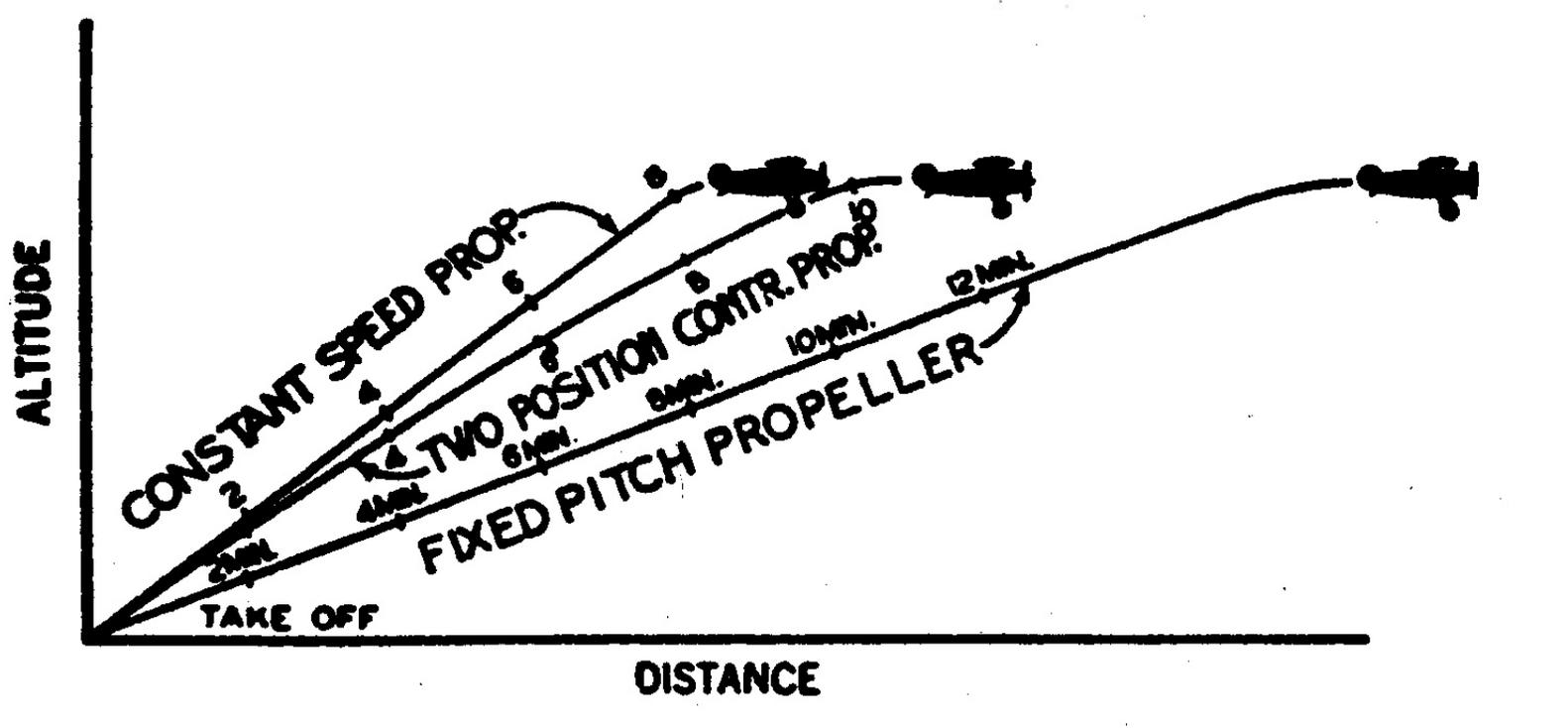
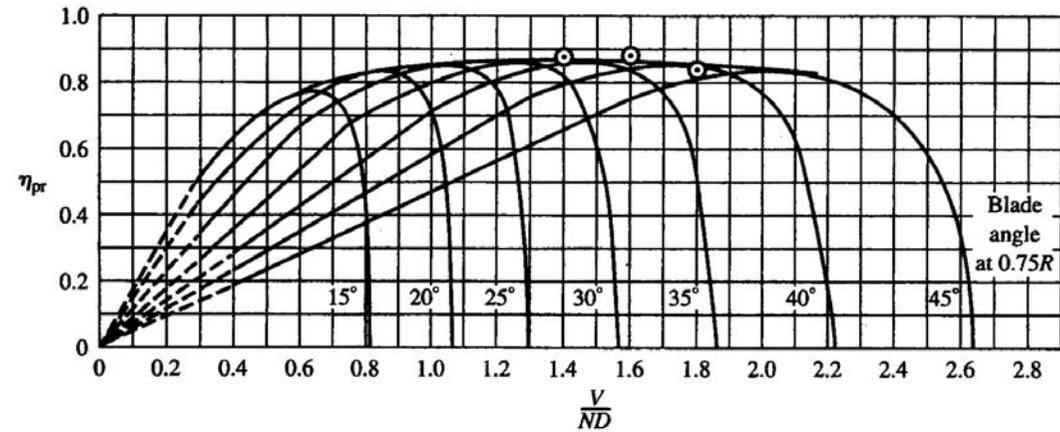
(a) Propeller efficiency



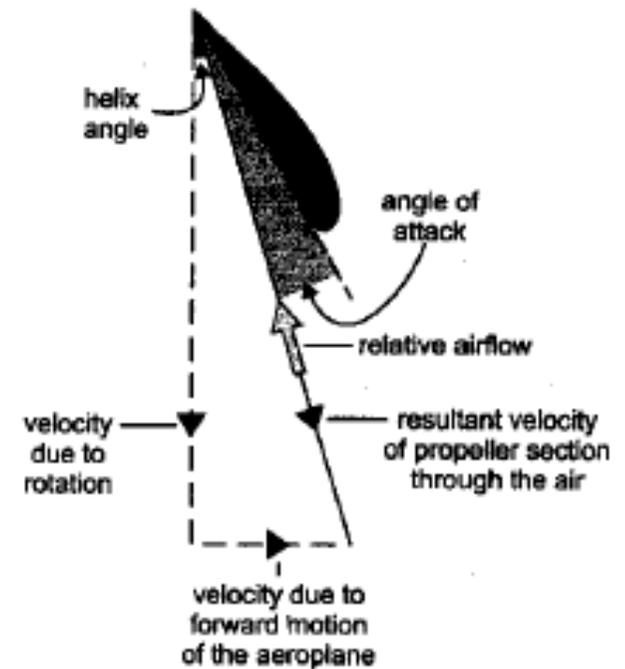
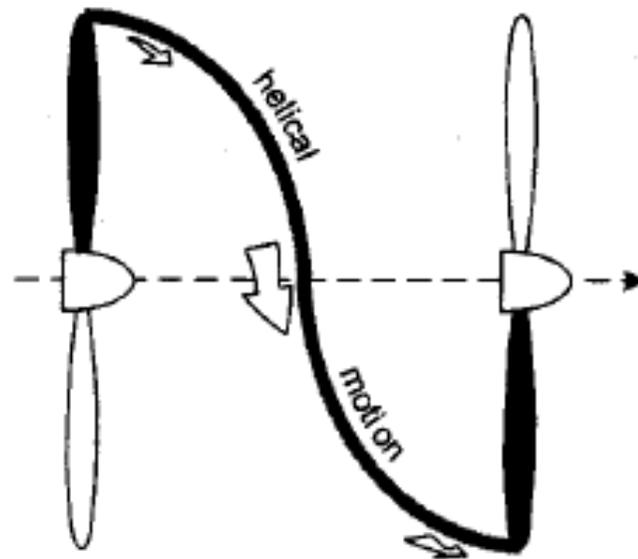
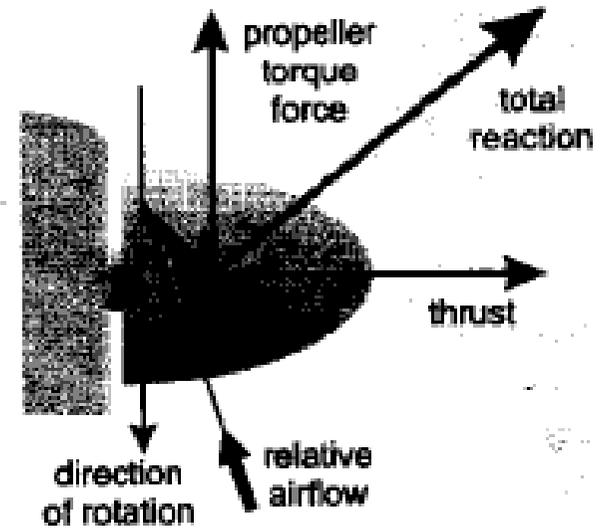
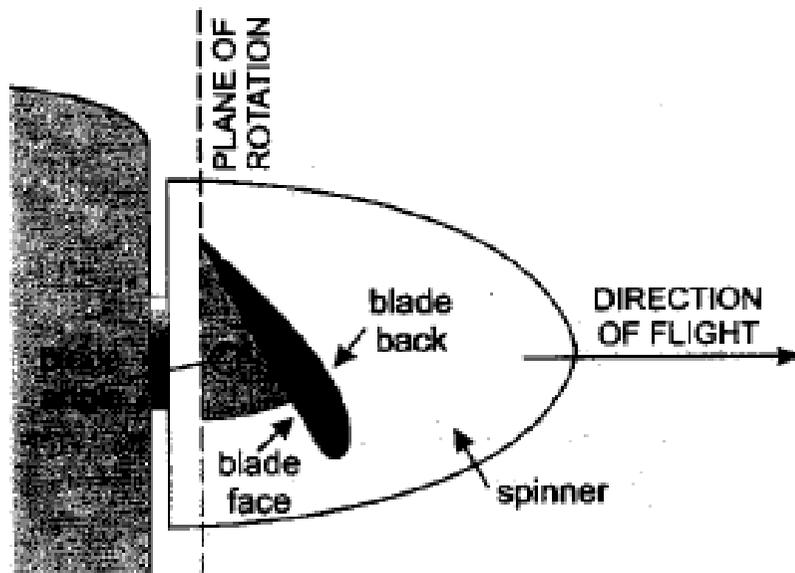
(b) Lift-to-drag ratio of a given propeller airfoil cross-section

## Cap.6 – Caratteristiche propulsive ELICHE

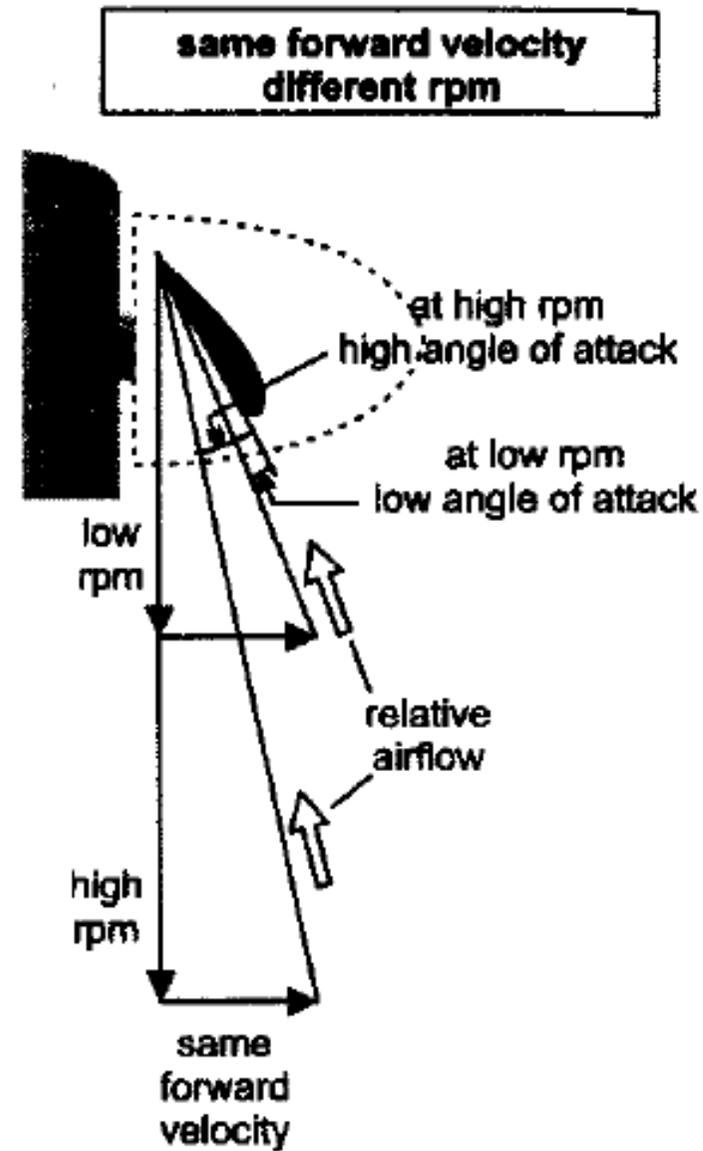
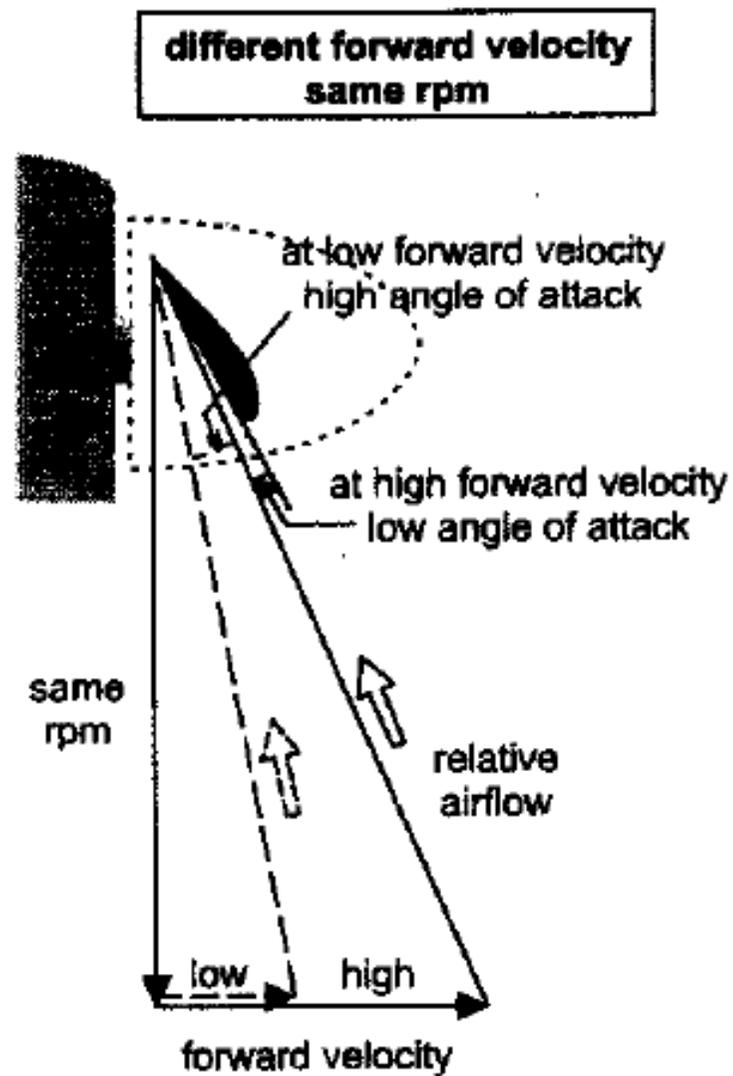
- Elica a passo variabile
- Elica a giri costanti



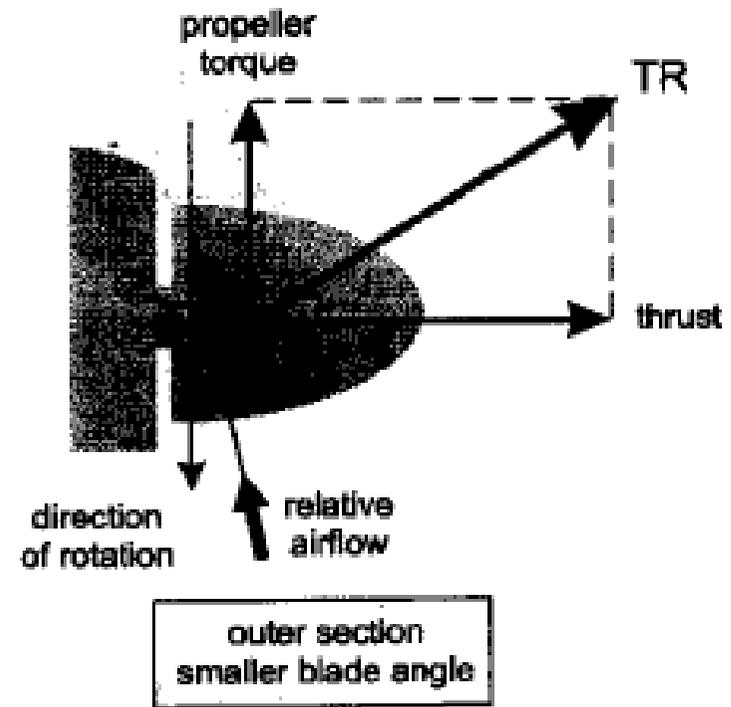
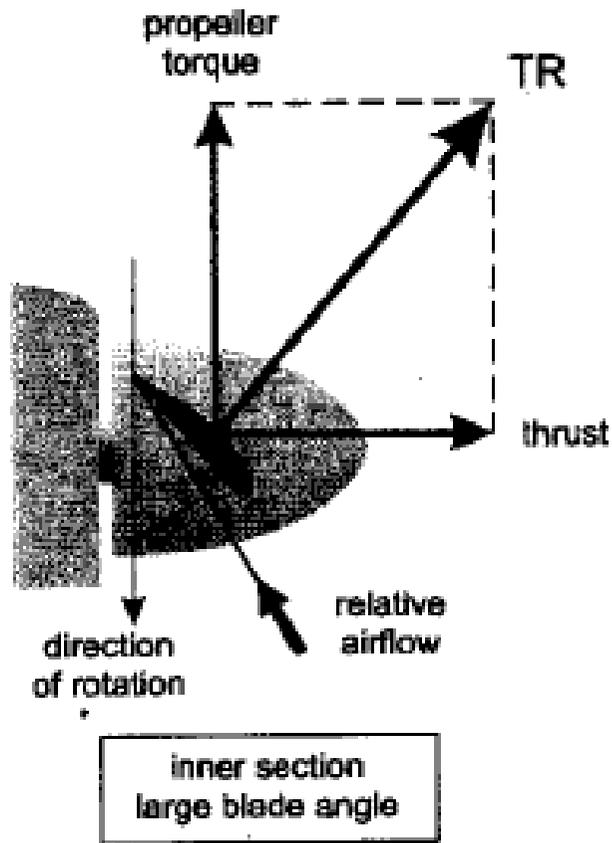
# Cap.6 – Caratteristiche propulsive ELICHE



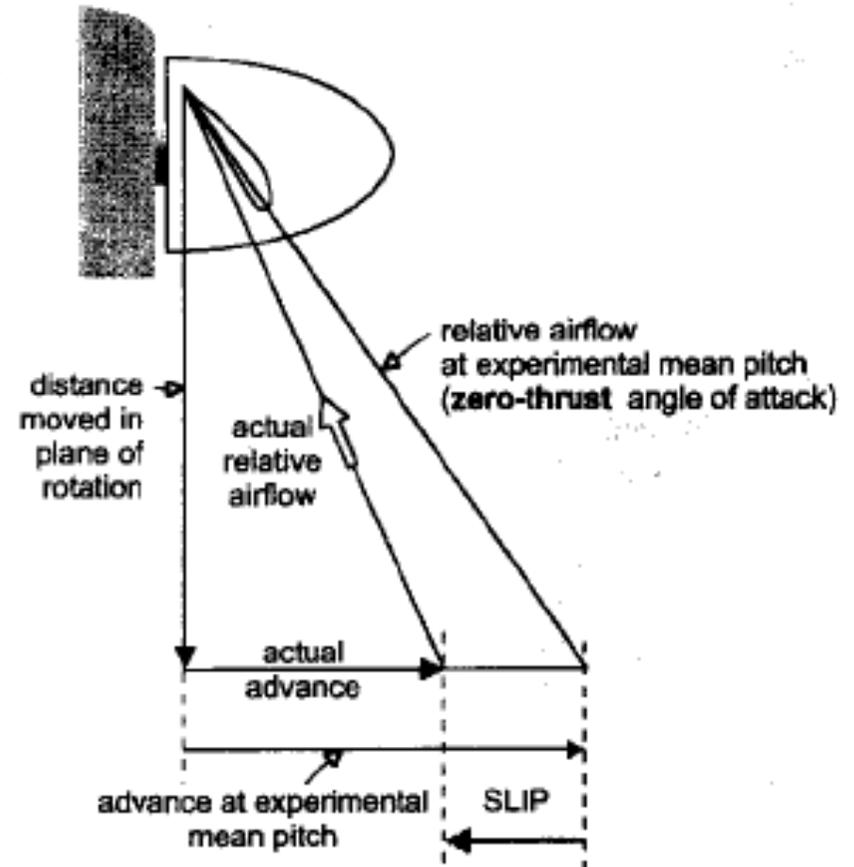
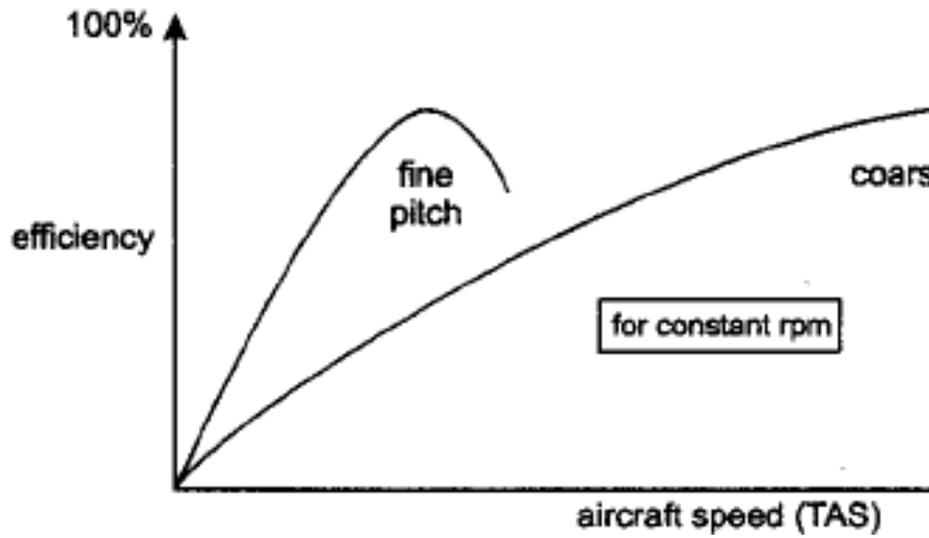
# Cap.6 – Caratteristiche propulsive ELICHE



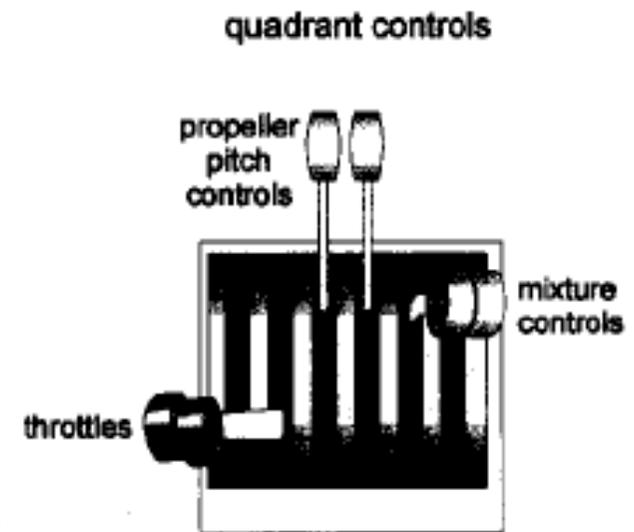
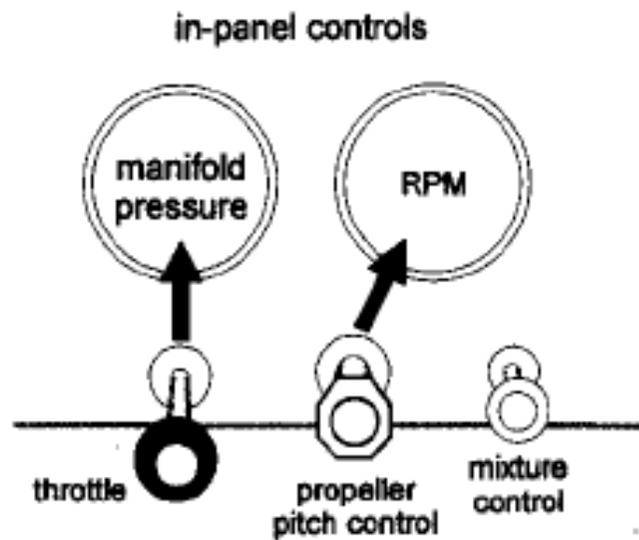
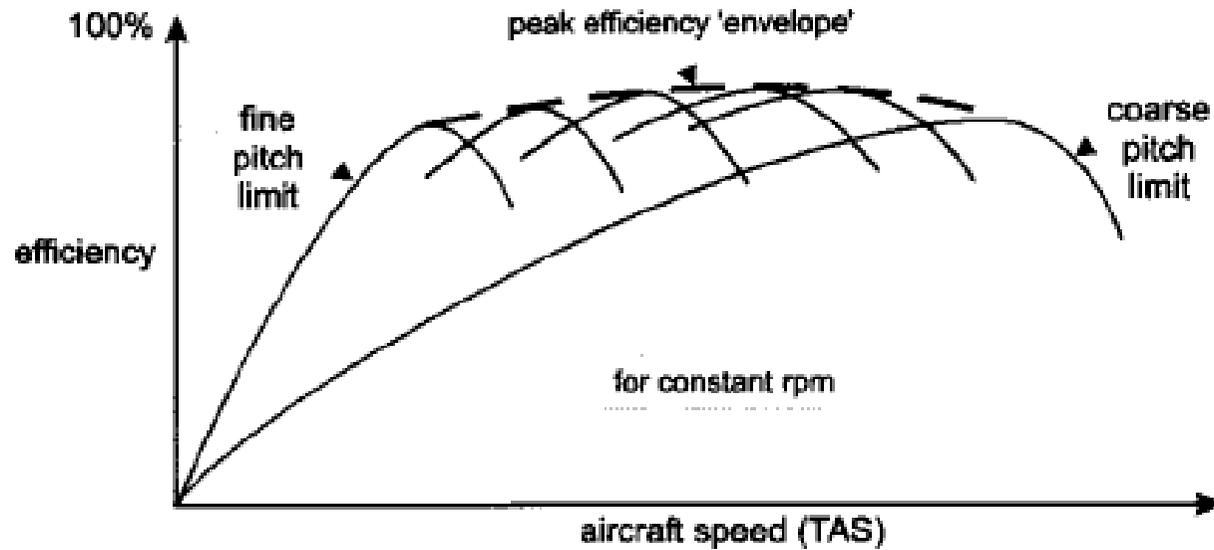
# Cap.6 – Caratteristiche propulsive ELICHE



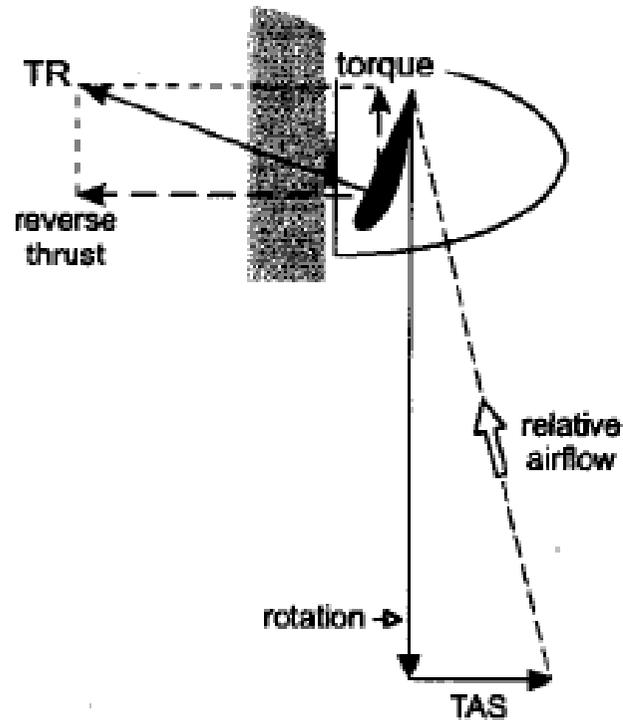
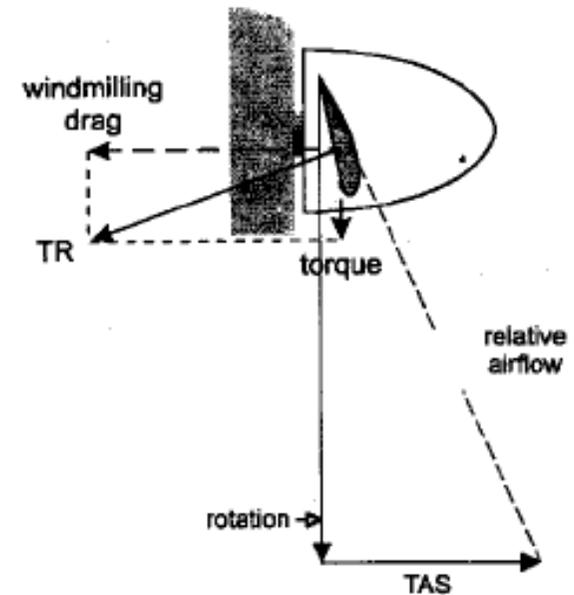
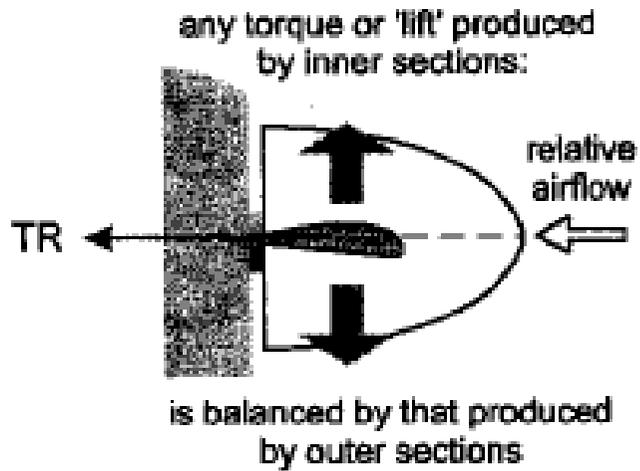
# Cap.6 – Caratteristiche propulsive ELICHE



# Cap.6 – Caratteristiche propulsive ELICHE



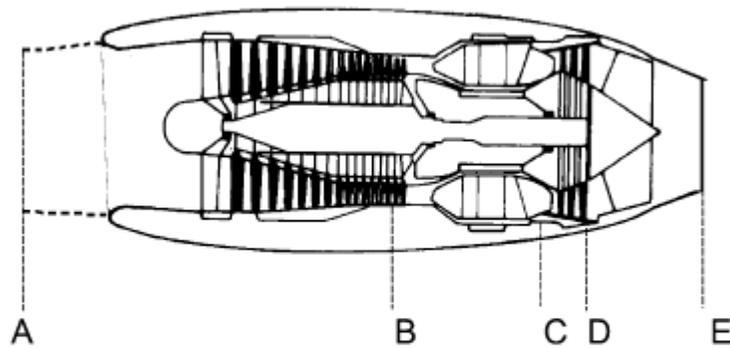
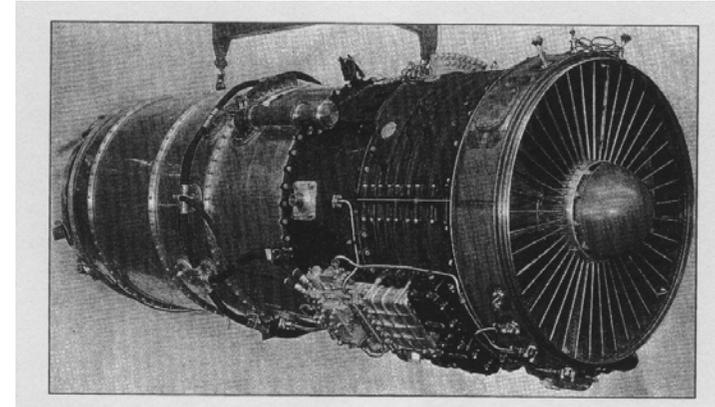
# Cap.6 – Caratteristiche propulsive ELICHE



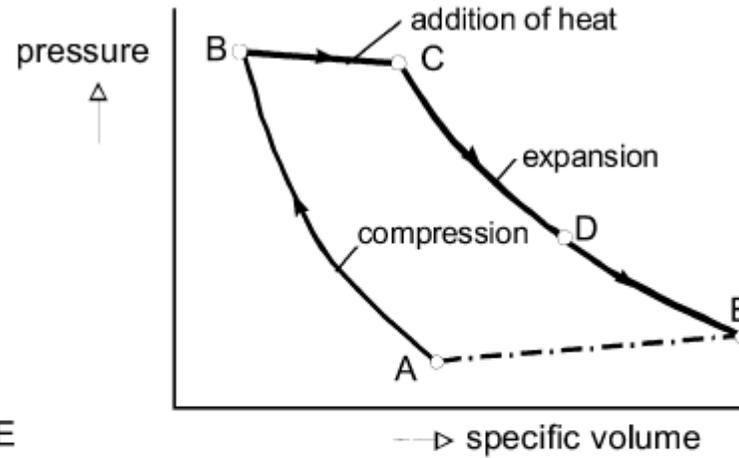
# Cap.6 – Caratteristiche propulsive

## Turbojet

$$T = (\dot{m}_{air} + \dot{m}_{fuel}) V_j - \dot{m}_{air} V_\infty + (p_e - p_\infty) A_e$$



(a) Engine components



(b) Brayton cycle

**Figure 5.17** Components and cycle of a jet engine.

# Cap.6 – Caratteristiche propulsive

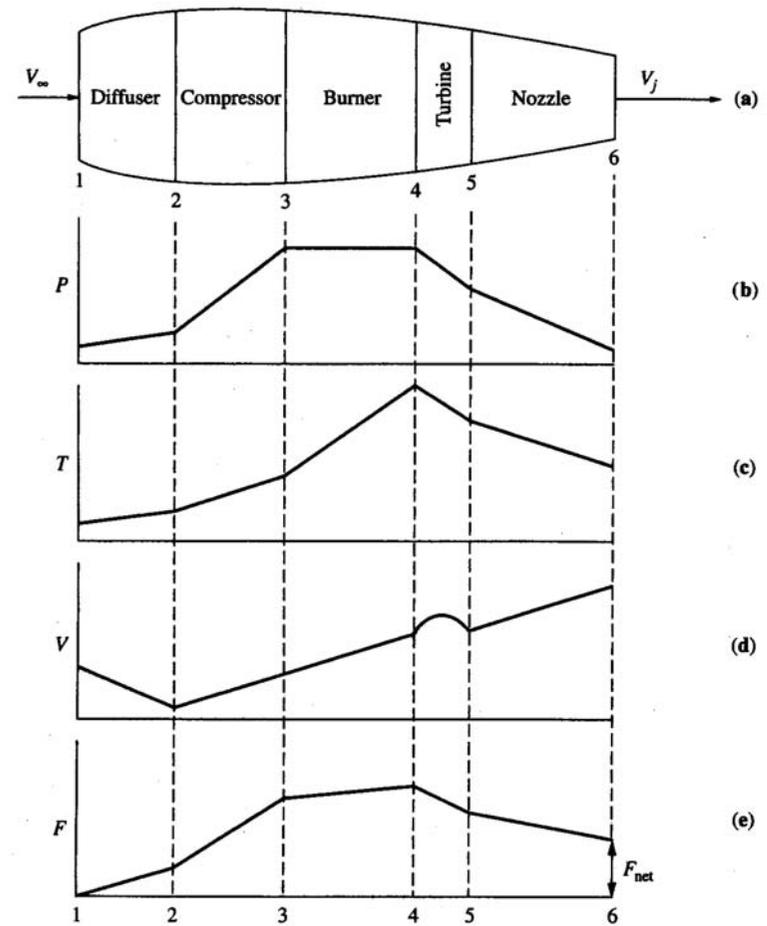
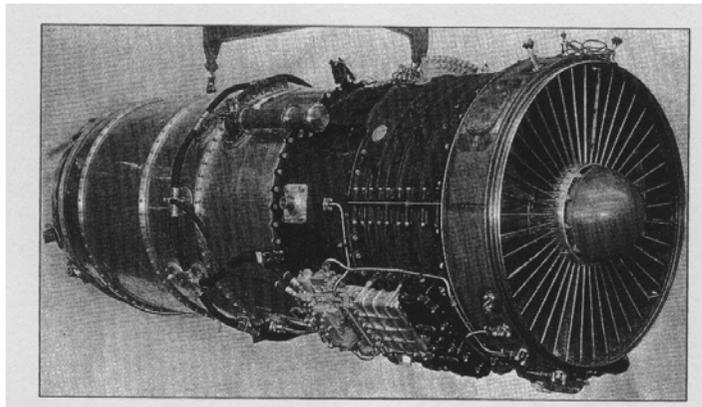
## Turbojet

$$T = (\dot{m}_{air} + \dot{m}_{fuel}) V_j - \dot{m}_{air} V_\infty + (p_e - p_\infty) A_e$$

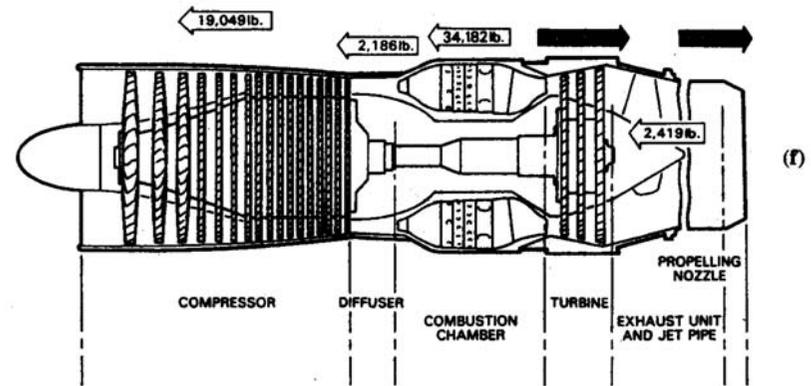
$$c_j = \frac{\text{peso del carburante consumato per dato incremento di tempo}}{(\text{spinta sviluppata})(\text{incremento di tempo})}$$

$$[c_j] = \frac{N}{N \cdot s} = \frac{1}{s}$$

$$[SFCJ] = \frac{lb}{lb \cdot h} = \frac{1}{h}$$

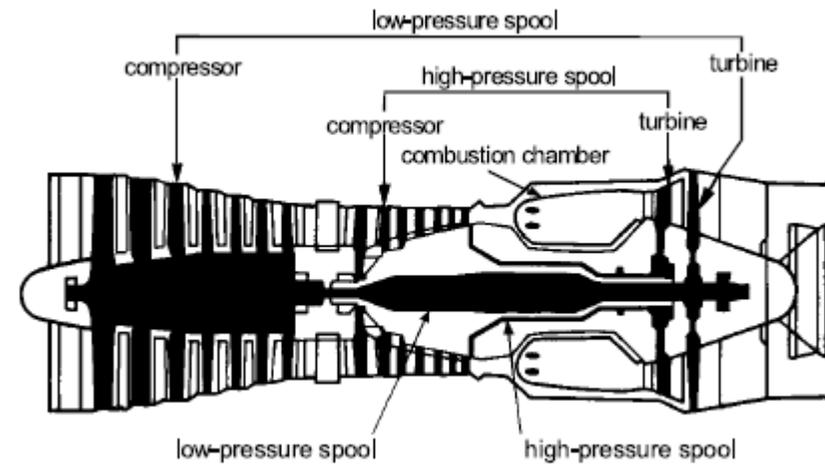
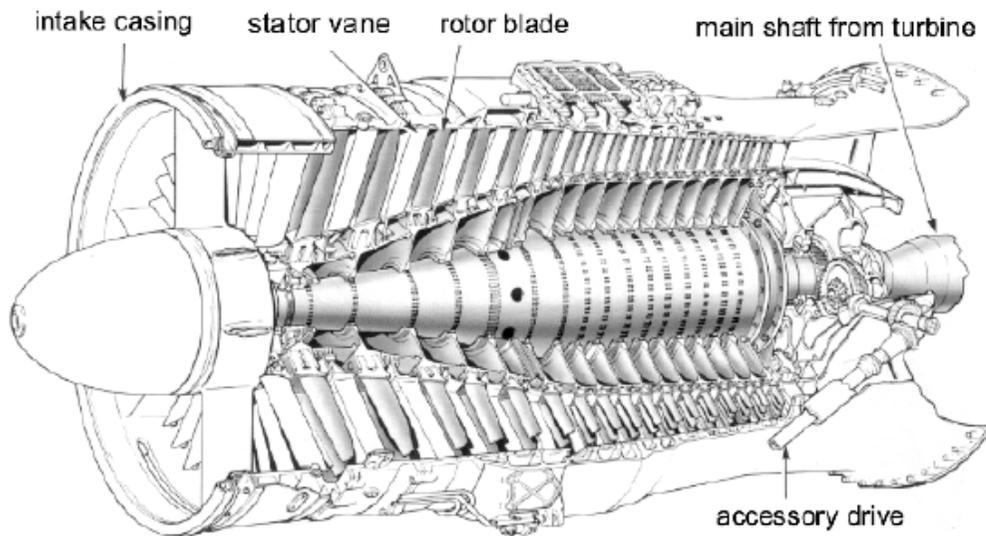
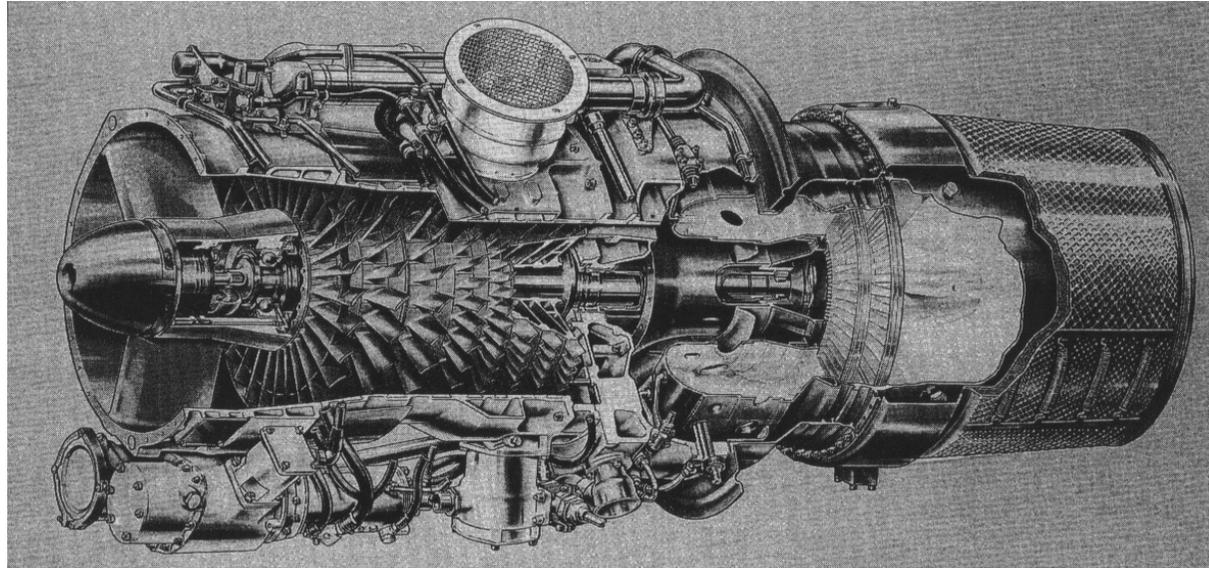


FORWARD GAS LOAD 57,836 lb.  
TOTAL THRUST 11,158 lb.



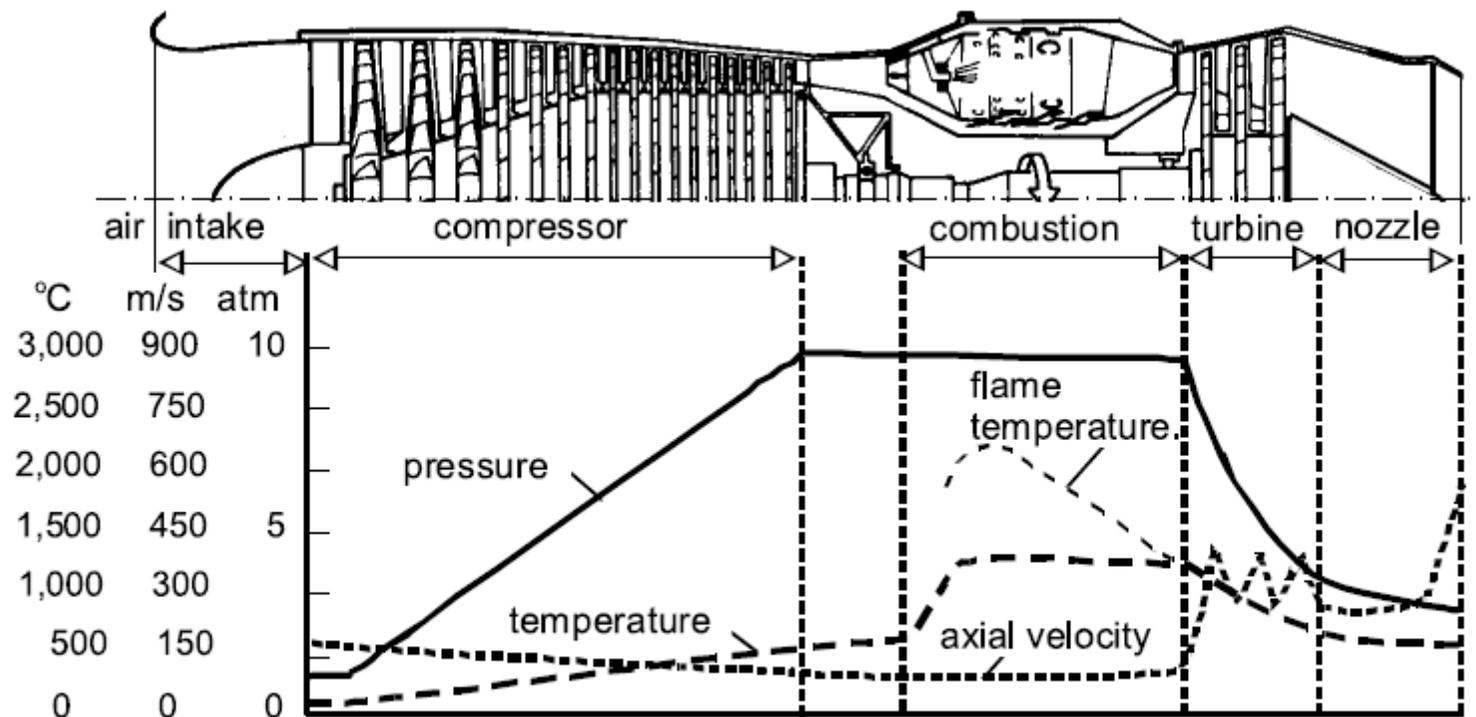
# Cap.6 – Caratteristiche propulsive

## Turbojet



# Cap.6 – Caratteristiche propulsive

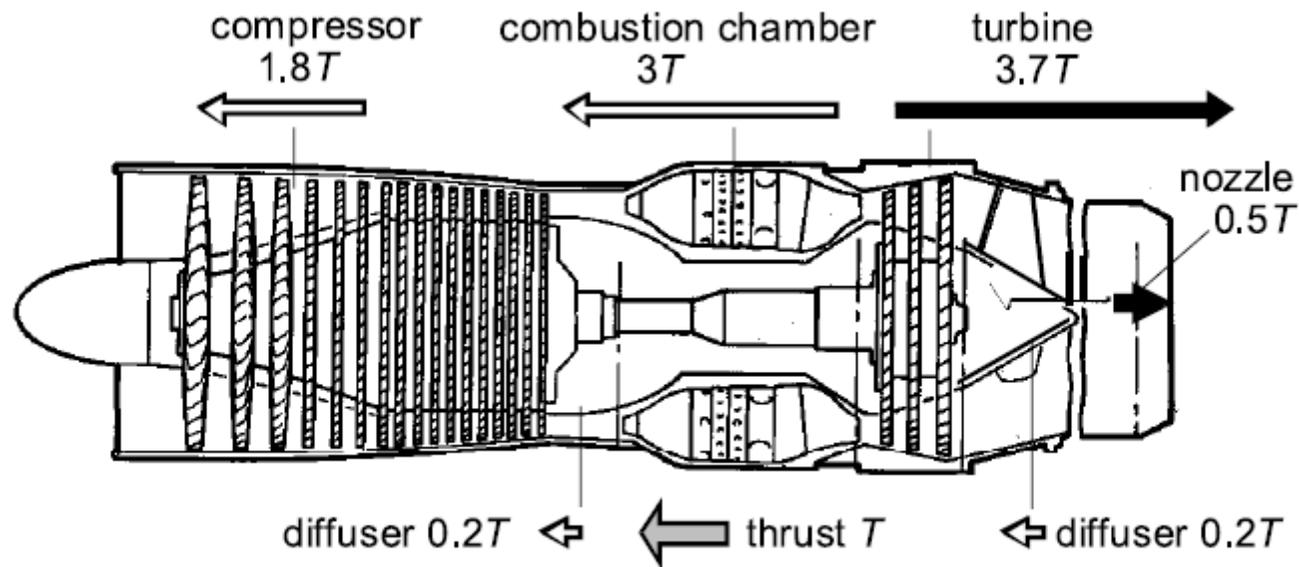
## Turbojet



**Figure 5.20** Variation of pressure, temperature and flow velocity in a jet engine (courtesy of Rolls-Royce plc).

# Cap.6 – Caratteristiche propulsive

## Turbojet

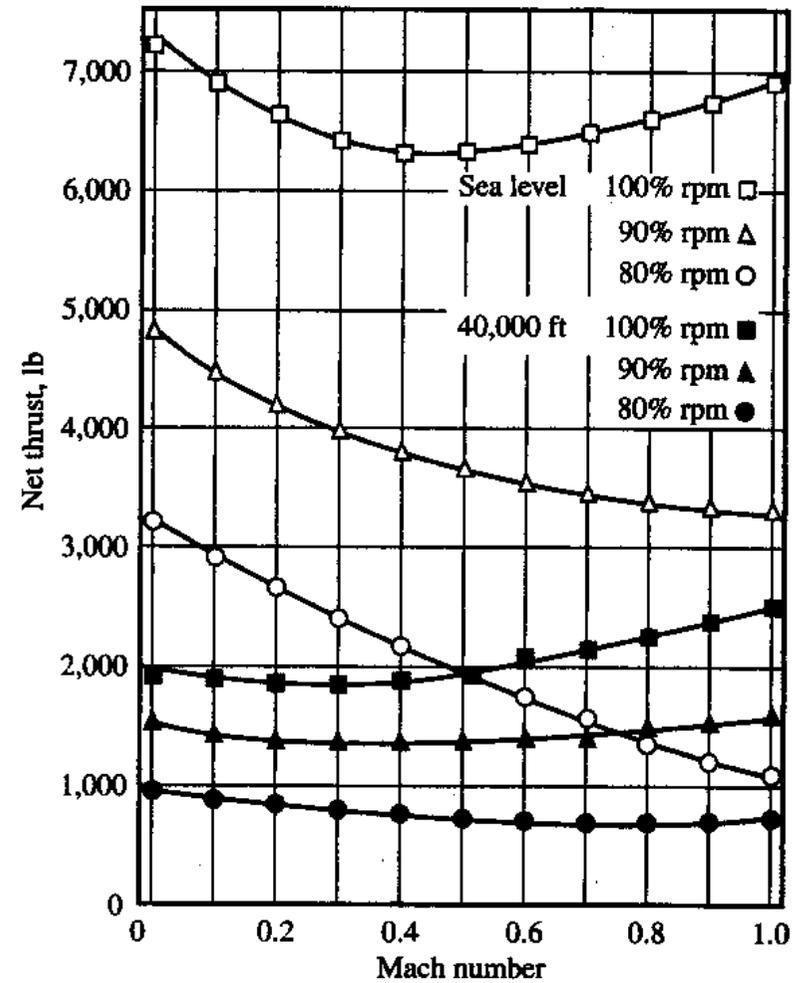
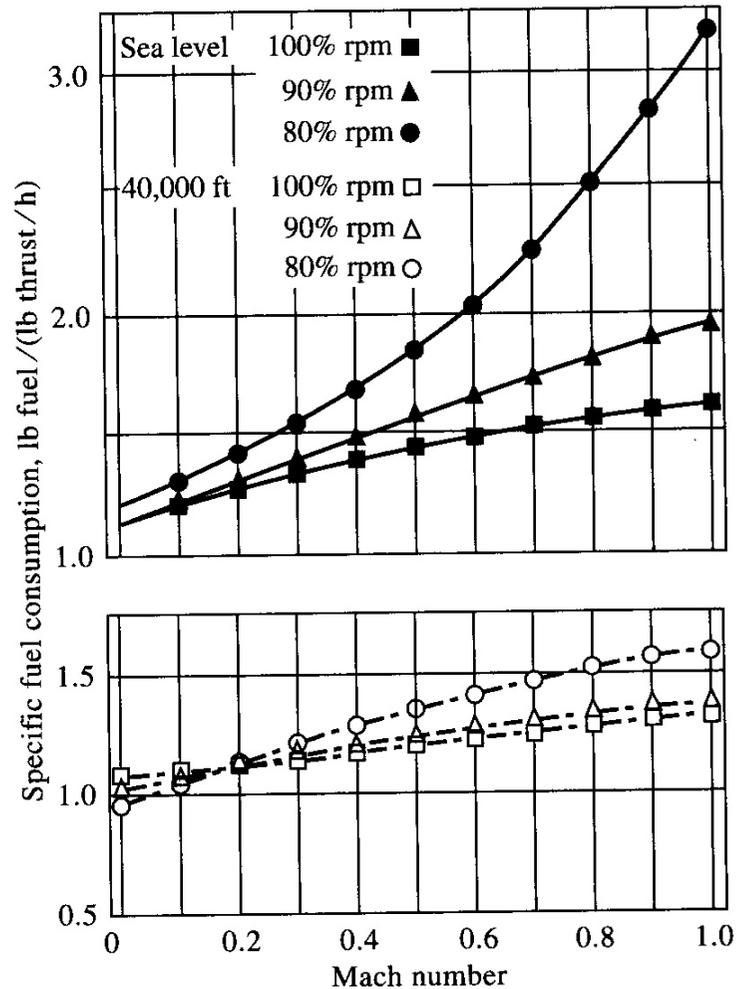


**Figure 5.21** Distribution of internal thrust components for a static turbojet.

# Cap.6 – Caratteristiche propulsive Turbojet

$$\text{TSFC} = 1.0 + kM_\infty$$

SFCJ è costante con la quota



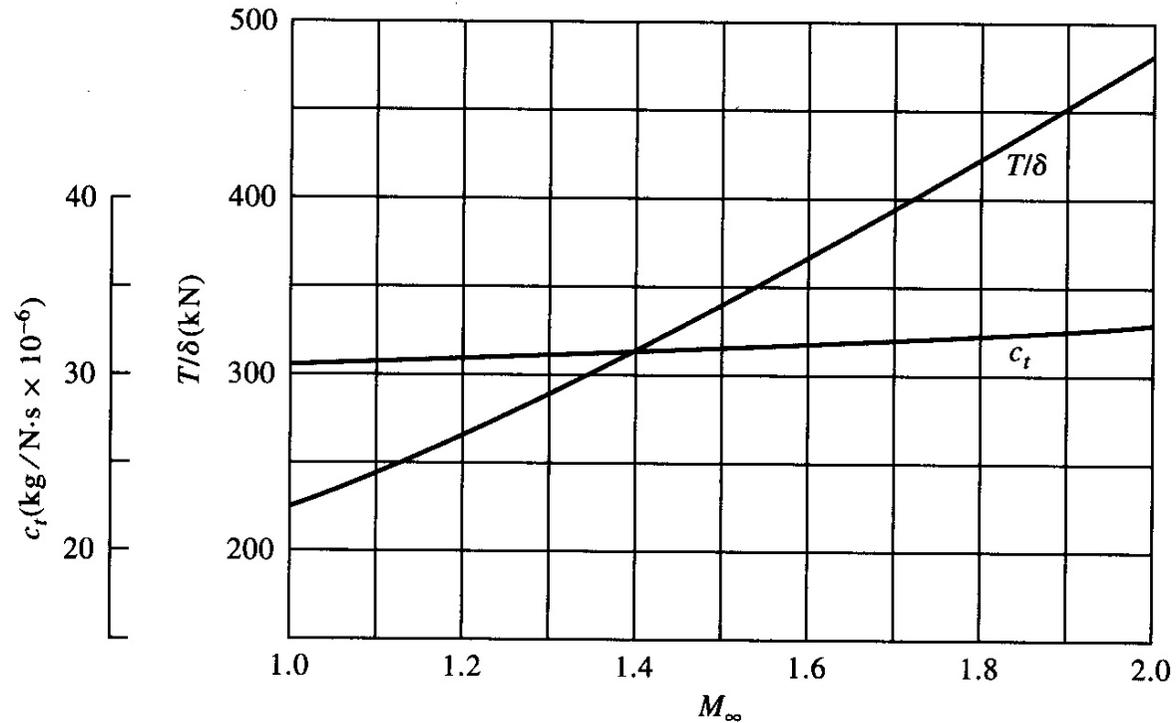
Spinta cost. con V

Effetto quota  $\frac{T}{T_0} = \frac{\rho}{\rho_0}$

## Cap.6 – Caratteristiche propulsive Turbojet

$$\frac{P_{total}}{P_{static}} = \left( 1 + \frac{\gamma - 1}{2} M^2 \right)^{\gamma/(\gamma - 1)}$$

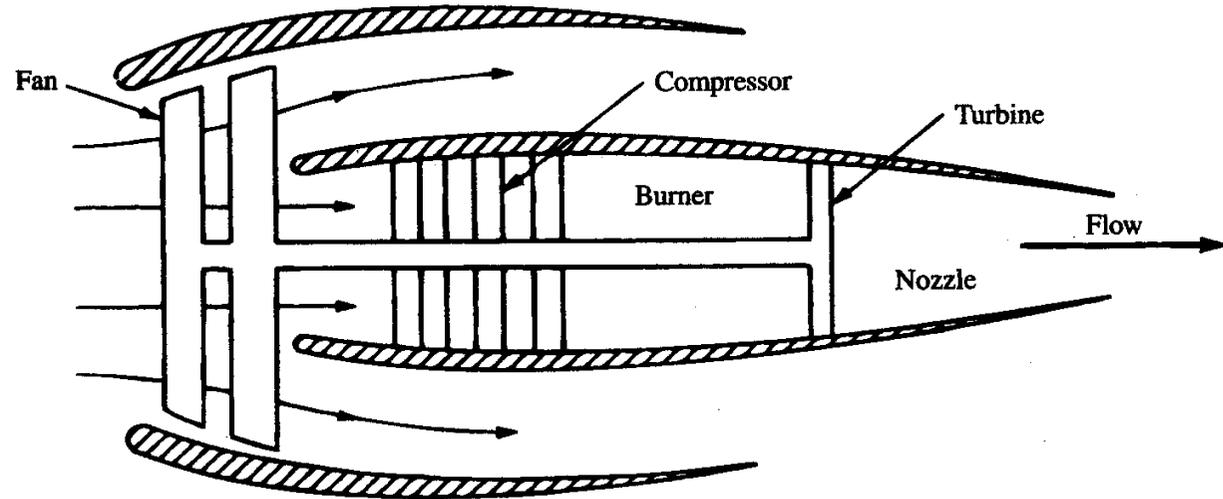
Condizioni supersoniche



$$\frac{T}{T_{Mach1}} = 1 + 1.18(M_\infty - 1)$$

## Cap.6 – Caratteristiche propulsive

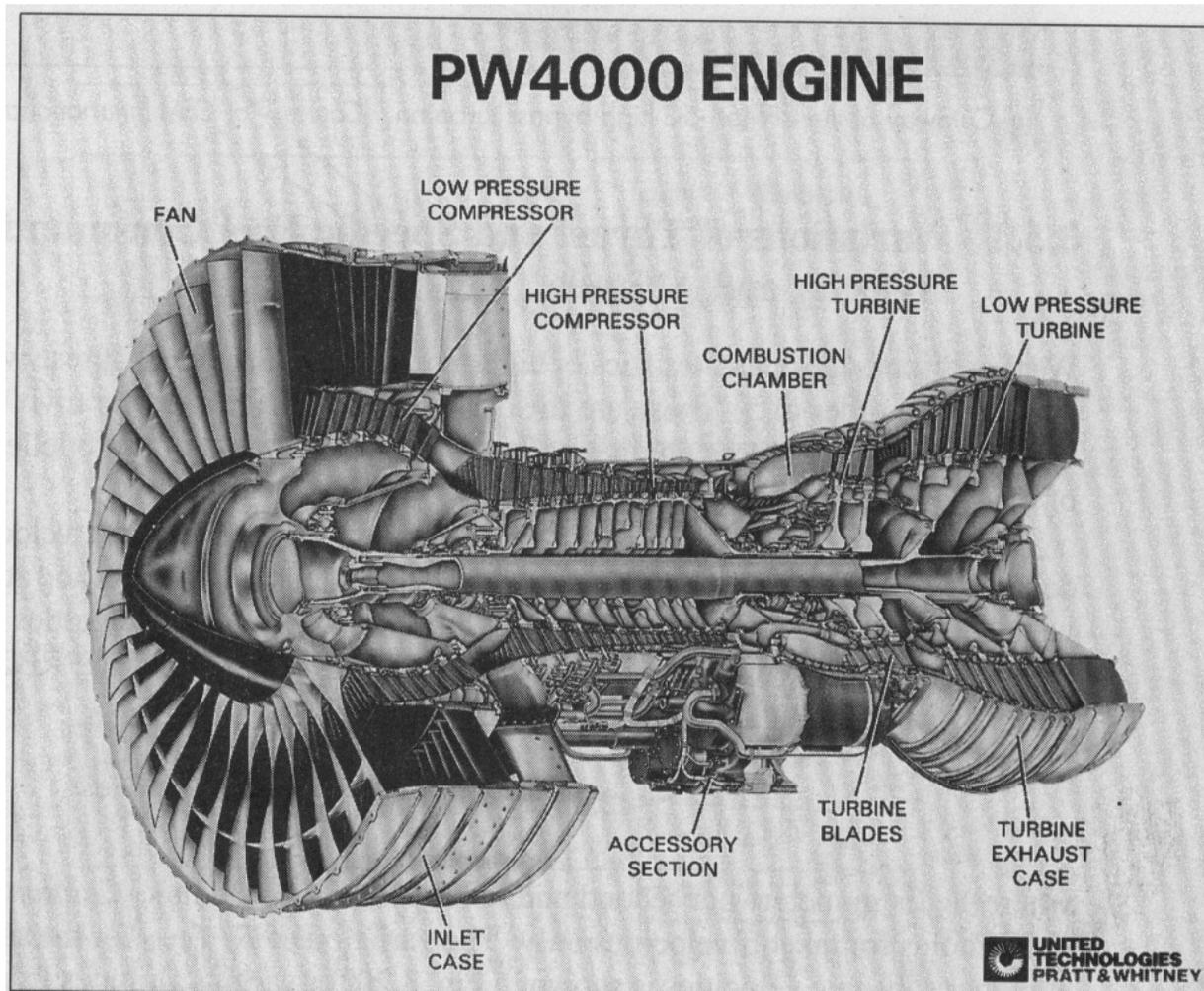
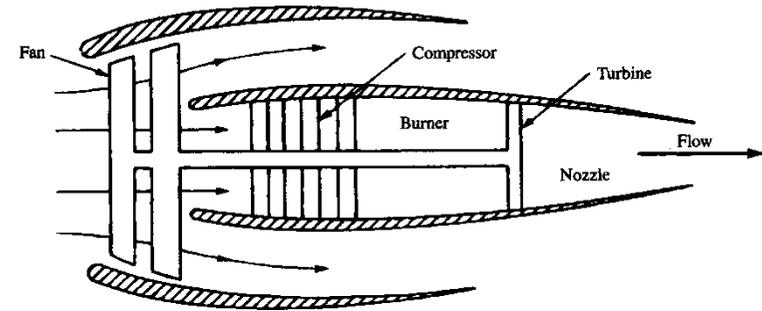
### Turbofan



BPR : apporto di By-Pass o anche rapporto di diluizione

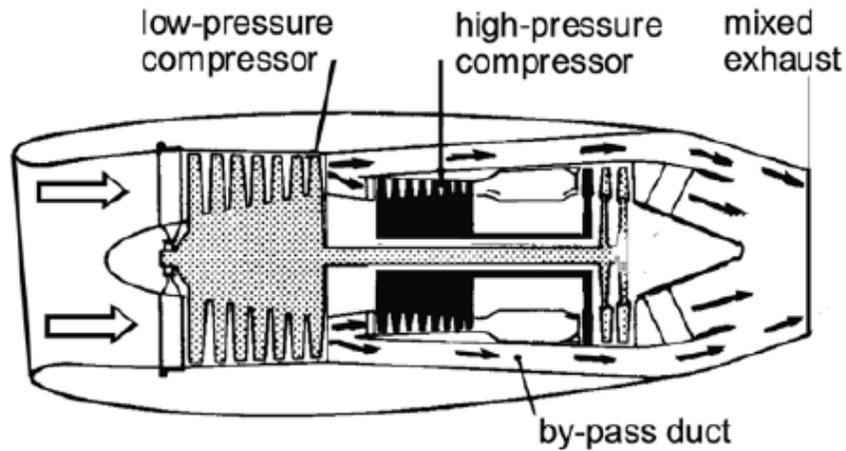
# Cap.6 – Caratteristiche propulsive

## Turbofan

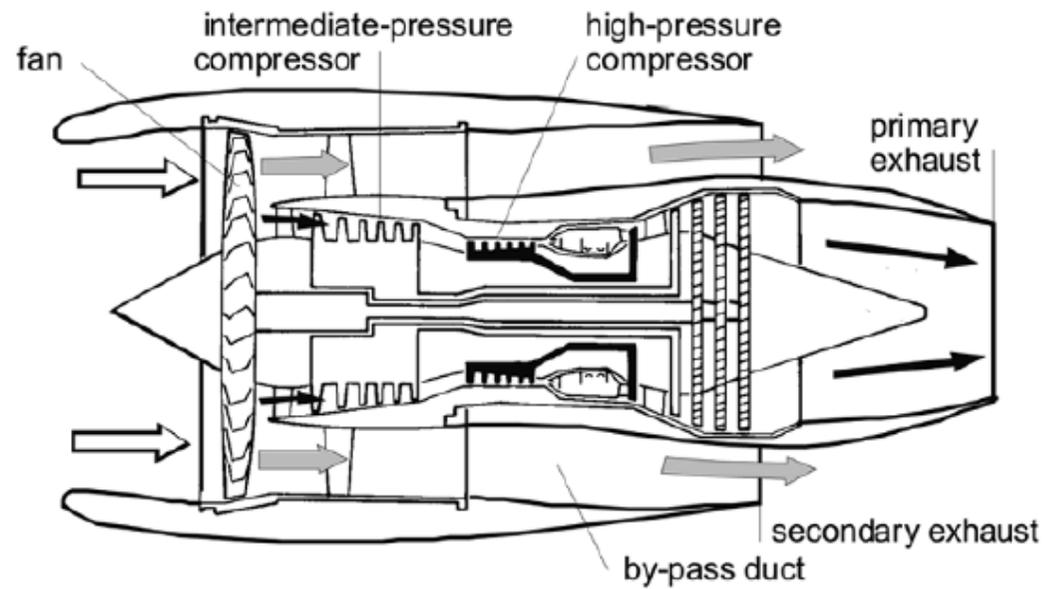


# Cap.6 – Caratteristiche propulsive

## Turbofan



(a) Low by-pass ratio turbofan



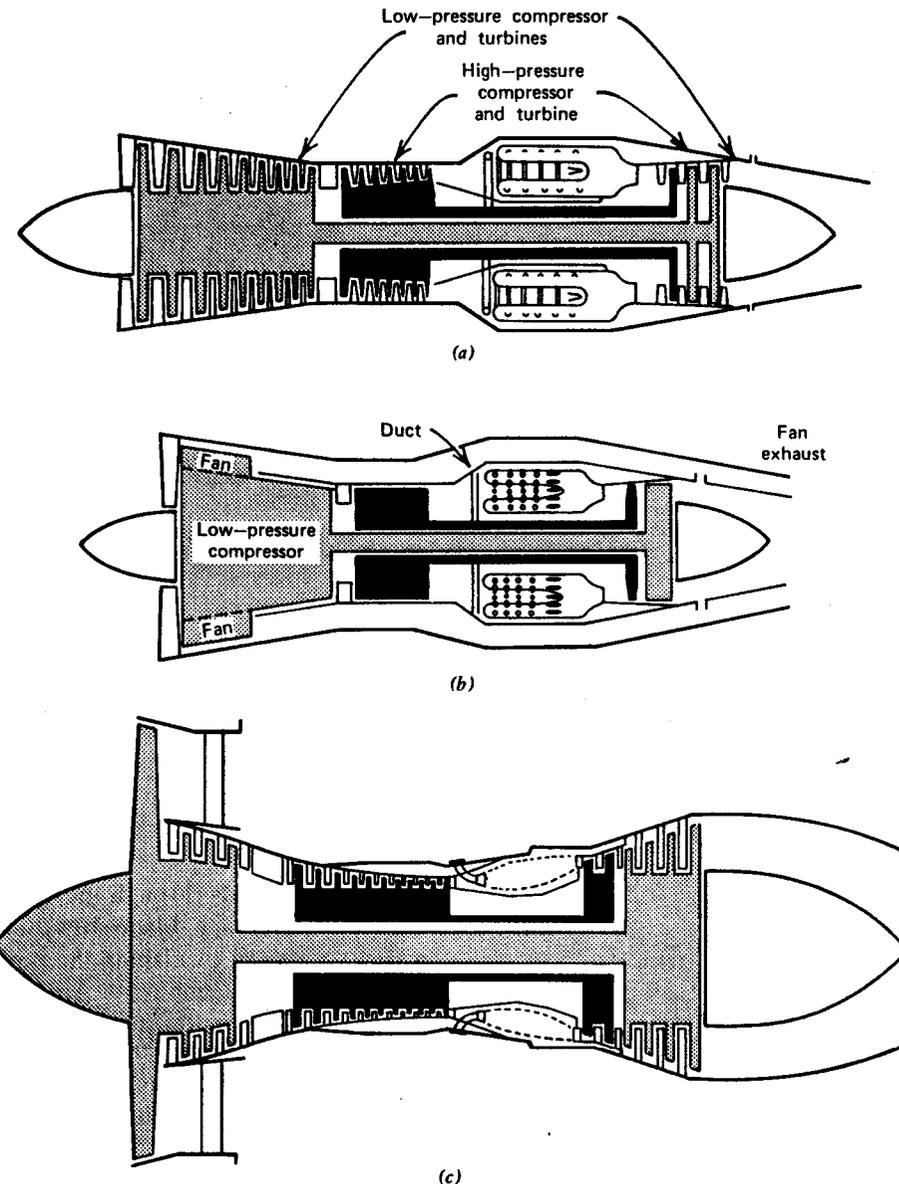
(b) Three-shaft high by-pass ratio turbofan

# Cap.6 – Caratteristiche propulsi

## Turbofan

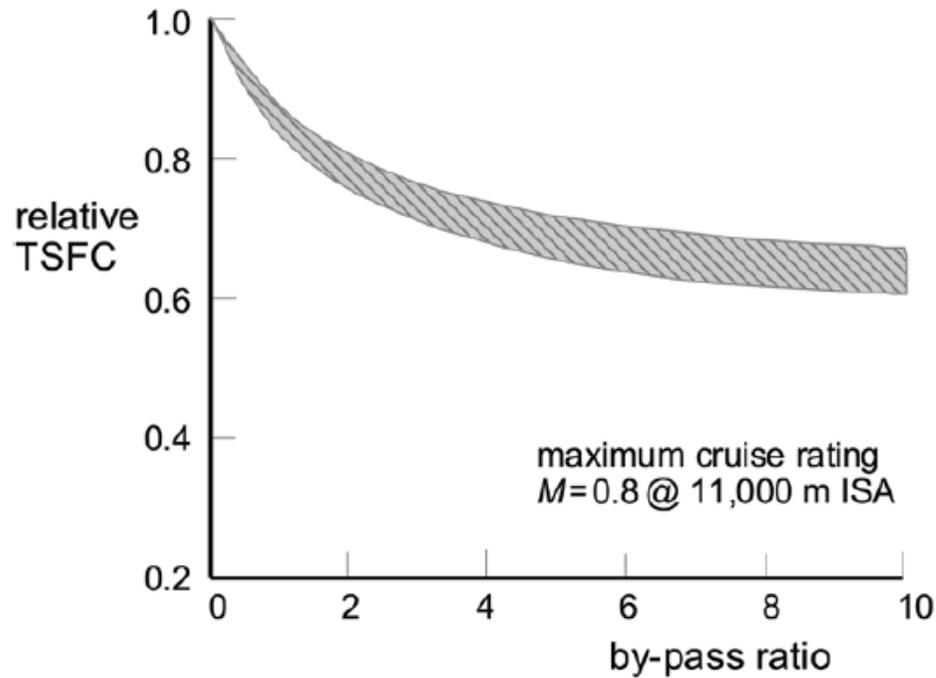
- Low BPR

- HIGH BPR

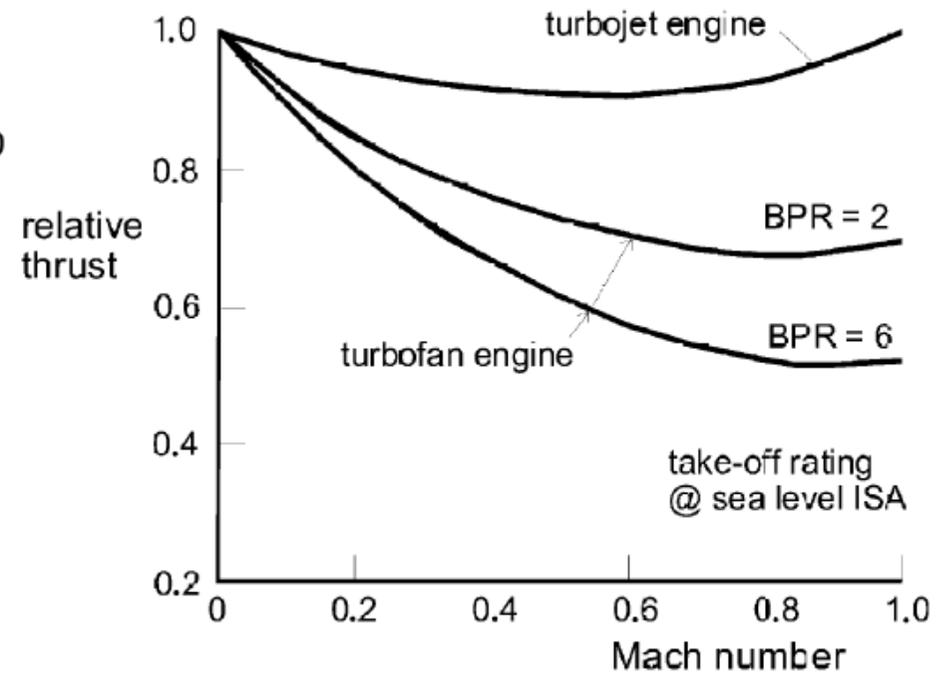


**Figure 6.26** Variations on the gas turbine. (a) Dual axial-flow compressor turbojet. (b) Dual axial-flow compressor, forward fan engine with long ducts. (c) High bypass ratio turbofan with short ducts. (d) Single axial-flow compressor, direct propeller drive turboprop. (e) Single axial-flow compressor, free turbine propeller drive turboprop. (f) Dual axial-flow compressor, turbojet with afterburner. (g) Dual axial-flow compressor, industrial turboshaft engine.

# Cap.6 – Caratteristiche propulsive



(a) Specific fuel consumption



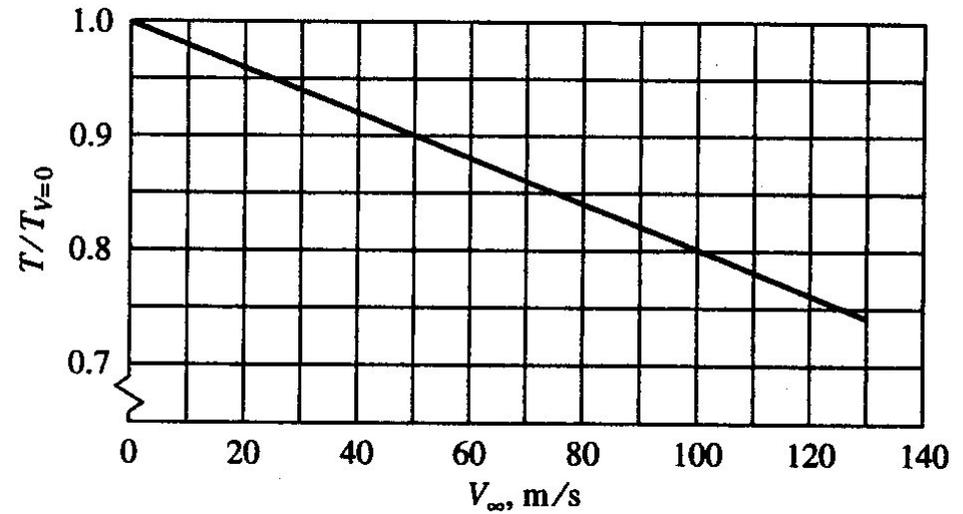
(b) Thrust lapse with speed

# Cap.6 – Caratteristiche propulsive Turbofan

## Variazione Spinta con Vel e quota

### Condizioni di decollo

$$\frac{T}{T_{V=0}} = 1 - 2.52 \times 10^{-3} V_{\infty} + 4.34 \times 10^{-6} V_{\infty}^2$$

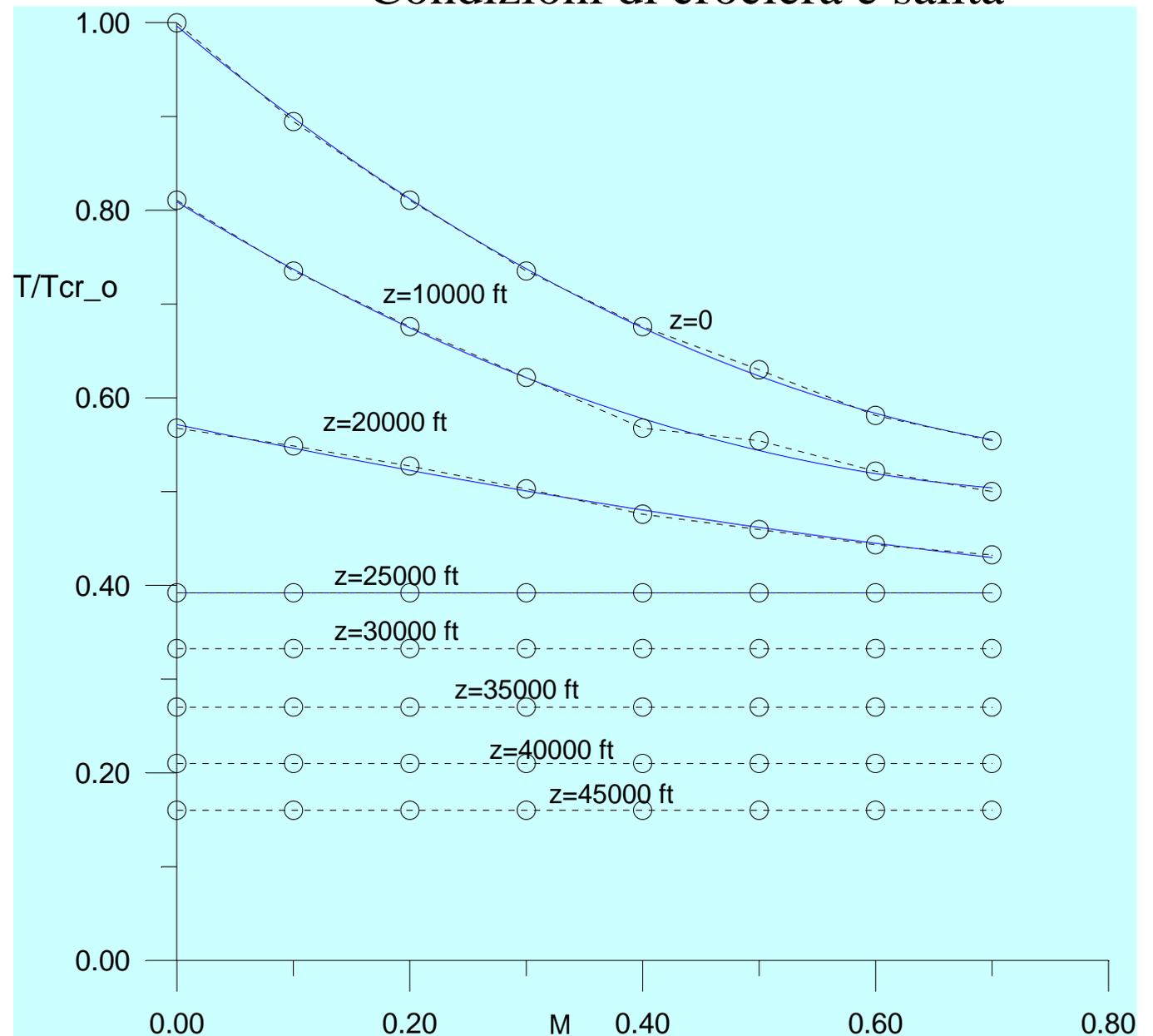


# Cap.6 – Caratteristiche propulsive Turbofan

## Variazione Spinta con Vel e quota

Condizioni di crociera e salita

$$T_{o\_cr} = T_o \cdot 0.80$$



## Cap.6 – Caratteristiche propulsive Turbofan

### Variazione Spinta con Vel e quota

### Condizioni di crociera e salita

$$K_{MZ} = \frac{T}{T_o\_cr}$$

<b>z=0 ft (S/L)</b>	<b>KMZ=T/Tcr_o = 1.00 -1.037 M + 0.582 M<sup>2</sup></b>
<b>z= 10000 ft</b>	<b>KMZ=T/Tcr_o = 0.81 -0.768 M + 0.474 M<sup>2</sup></b>
<b>z= 20000 ft</b>	<b>KMZ=T/Tcr_o = 0.57 -0.261 M + 0.084 M<sup>2</sup></b>
<b>z= 25000 ft</b>	<b>KMZ=T/Tcr_o = 0.39</b>
<b>z= 30000 ft</b>	<b>KMZ=T/Tcr_o = 0.33</b>
<b>z= 35000 ft</b>	<b>KMZ=T/Tcr_o = 0.27</b>
<b>z= 40000 ft</b>	<b>KMZ=T/Tcr_o = 0.21</b>
<b>z= 45000 ft</b>	<b>KMZ=T/Tcr_o = 0.16</b>

$$T = K_{MZ} \cdot 0.80 \cdot T_o \cdot \varphi$$

## Cap.6 – Caratteristiche propulsive Turbofan

### Variazione Spinta con Vel e quota

### Condizioni di crociera e salita

E' abbastanza valida

$$\frac{T}{T_0} = \left( \frac{\rho}{\rho_0} \right)^m$$

Alle alte quote :

$$T = T_o \cdot 0.80 \cdot \sigma \cdot \varphi = T_o \text{ - } cr \cdot \sigma \cdot \varphi$$

## Cap.6 – Caratteristiche propulsive Turbofan

### Variazione Consumo specifico con Vel e quota

$$c_t = B(1 + kM_\infty)$$

**SFCJ=0.50-0.70 lb/(lb h)**

# Cap.6 – Caratteristiche propulsive Turbofan

Table 6.1 Weight and Performance Data for Turbojet and Turbofan Engines							
Manuf./Type/ Config./B.P.R.	Weight (lbs)	Thrust at take-off s.l.s. (lbs)	s.f.c. at take-off s.l.s. (lbs/hr/lbs)	Massflow take-off s.l.s. (lbs/sec)	Alt./ M	Thrust at altitude/M (lbs)	s.f.c. at altitude/M (lbs/hr/lbs)
(1)/CF6-6D/ TBF/5.72	7,896	40,000	0.346	1,303	35K/ 0.8	7,160 (80% max)	0.616
(1)/CF6-32/ TBF/4.90	7,140	36,500	0.357	1,104	35K/ 0.8	6,630 (80% max)	0.609
(1)/CF6-50/ TBF/4.26	8,731	51,000	0.390	1,450	35K/ 0.8	8,720 (80% max)	0.628
(1)/CF6-80/ TBF/4.66	8,435	48,000	0.344	1,433	35K/ 0.8	8,260 (80% max)	0.592
(1)/CF34/ TBF/6.30	1,580	8,650	0.362	332	40K/ 0.8	1,420 (max)	0.728
(1)/CFM56-2/ TBF/6.00	4,610	24,000	???	817	35K/ 0.8	5,188 (max)	0.661
(1)/CJ610-5/ TBJ/1.00	402	2,950	0.980	44	36K/ 0.8	870 (max)	1.150
(1)/CF700/ TBF/1.93	725	4,200	0.660	126	36K/ 0.8	1,060 (max)	0.980
(1)/J79-17/ TBJ/0	3,873	17,820	1.980	170	35K/ 0.9 35K/ 2.0	2,600 (max) 18,600 (max)	0.980 2.070
(1)/TF34-400/ TBF/6.2	1,478	9,275	0.363	338	36K/ 0.8	1,896 (intermediate)	0.682
(1)/F404-402/ TBF/0.27	2,282	17,700	???	146	???	???	???
(2)/CFE738/ TBF/5.3	1,325	5,725	0.372	210	40K/ 0.8	1,464 (max)	0.640
(3)/535E4/ TBF/4.3	7,264	42,000	???	1,150	35K/ 0.8	8,700 (max)	0.598
(3)/RB211/ TBF/4.3	9,814	60,600	???	1,604	35K/ 0.85	11,813 (max)	0.570
(3)/Trent800/ TBF/???	13,133	90,000	???	???	35K/ 0.83	13,000 (max)	0.557
Type: (1) = G.E. (2) = G.E./Allied Signal (3) = Rolls Royce Manuf./Type/ Config./B.P.R. = Manufacturer/Type/ Configuration/By-pass Ratio							

# Cap.6 – Caratteristiche propulsive Turbofan

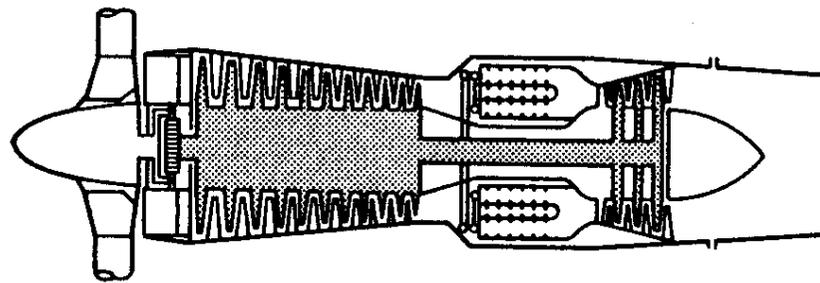
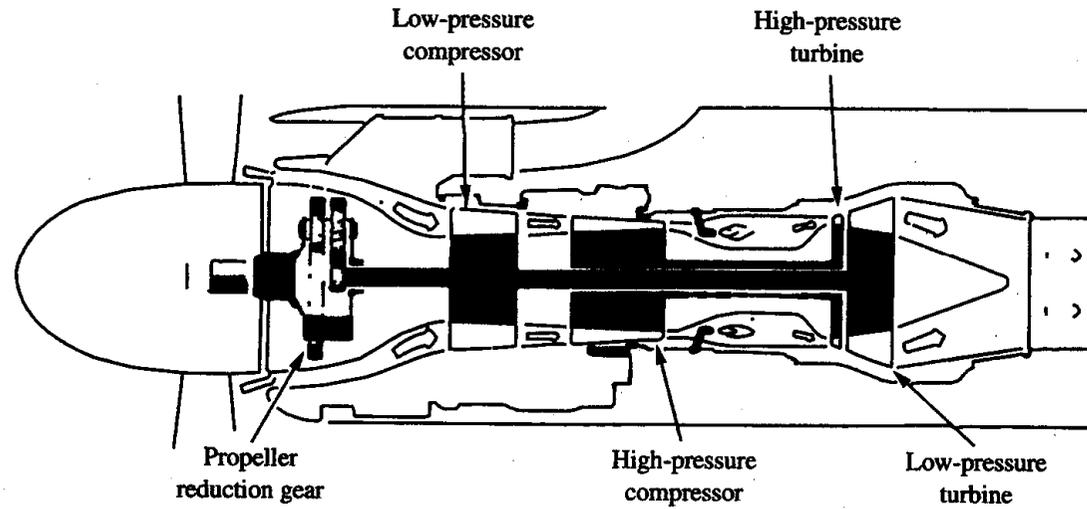
Table 6.2 Weight and Performance Data for Turbojet and Turbofan Engines							
Manuf./Type/ Config./B.P.R.	Weight  (lbs)	Thrust at take-off s.l.s. (lbs)	s.f.c. at take-off s.l.s. (lbs/hr/lbs)	Massflow take-off s.l.s. (lbs/sec)	Alt./ M	Thrust at altitude/M  (lbs)	s.f.c. at altitude/M  (lbs/hr/lbs)
(4)/TFE731-2/ TBF/2.66	743	3,500	???	113	40K/ 0.8	755 (max)	0.815
(4)/TFE731-5/ TBF/3.48	890	4,600	???	143	40K/ 0.8	1,000 (max)	0.760
(4)/ALF502L/ TBF/5.0	1,311	7,500	0.428	???	???	???	???
(5)/JT8D-219/ TBF/1.77	4,612	21,000	???	488	35K/ 0.8	5,250 (max)	0.737
(5)/PW4000/ TBF/4.85	9,400	56,000	???	1,705	35K/ 0.8	???	0.537
(5)/PW2000/ TBF/6.00	7,300	38,250	???	1,340	35K/ 0.8	???	0.563
(5)/PW300/ TBF/4.3	993	4,679	0.388	???	40K/ 0.8	1,155 (max)	0.681
(6)/CFM56-2A2/ TBF/6.0	4,820	24,000	???	817	35K/ 0.8	5,188 (max)	0.661
(7)/IAEV2500/ TBF/4.6	5,224	30,000	???	848	35K/ 0.8	5,752 (max)	0.575
(8)/Larzac 04/ TBF/1.13	639	2,966	0.710	63	35K/ 0.8	772 (max)	???
(9)/FJ44/ TBF/3.28	447	1,900	0.475	???	36K/ 0.7	506 (max. cont.)	0.758
(10)/Adour 871/ TBF/0.80	1,330	5,900	0.740	???	39K/ 0.8	???	0.955

Type: (4) = Allied Signal  
 (5) = Pratt & Whitney  
 (6) = CFM International (G.E./SNECMA)  
 (7) = International Aero Engines  
 (8) = Turbomeca  
 (9) = Williams/Rolls Royce  
 (10) = Rolls Royce/Turbomeca

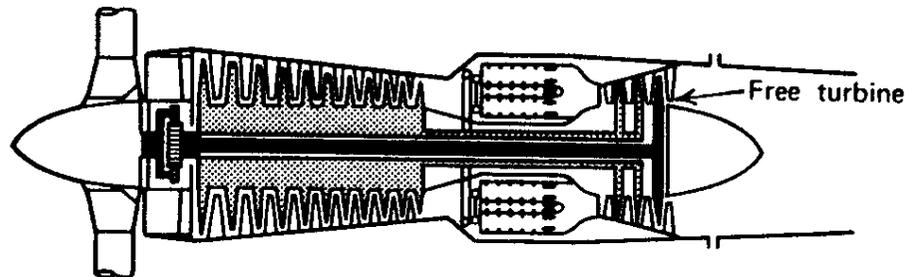
Manuf./Type/  
Config./B.P.R. = Manufacturer/Type/  
Configuration/By-pass Ratio

# Cap.6 – Caratteristiche propulsive

## Turboelica



(d)



(e)

## Cap.6 – Caratteristiche propulsive

### Turboelica

$$\Pi_d = (T_p + T_j)V_\infty$$

$$\Pi_d = \eta_p \Pi_a + T_j V_\infty$$

Equivalent Shaft Horsepower (Pot all'albero equivalente)

$$\Pi_d = \eta_p \Pi_{ea}$$

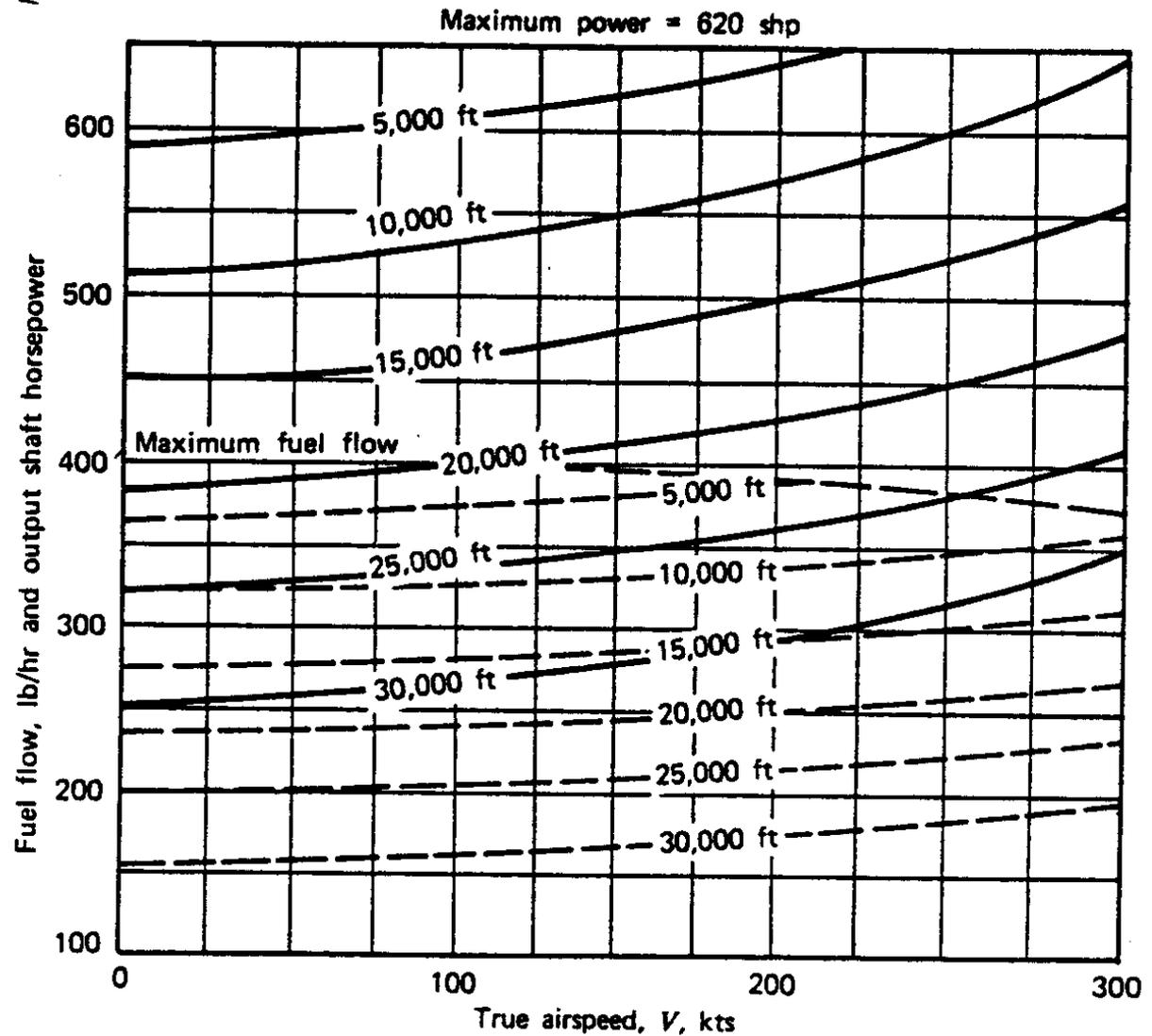
$$\eta_p \Pi_{ea} = \eta_p \Pi_a + T_j V_\infty$$

$$\Pi_{ea} = \Pi_a + \frac{T_j V_\infty}{\eta_p}$$

In ultimo forniamo una utile regola basata sull'esperienza pratica: in condizioni statiche (motore che opera con l'aeroplano a velocità nulla al suolo) una turboelica produce circa 2.5 lb di spinta per cavallo vapore all'albero. Questa osservazione va utilizzata se dobbiamo considerare la spinta di un motore turboelica in decollo.

# Cap.6 – Caratteristiche propulsive Turboelica

EFFETTO RAM !! - -



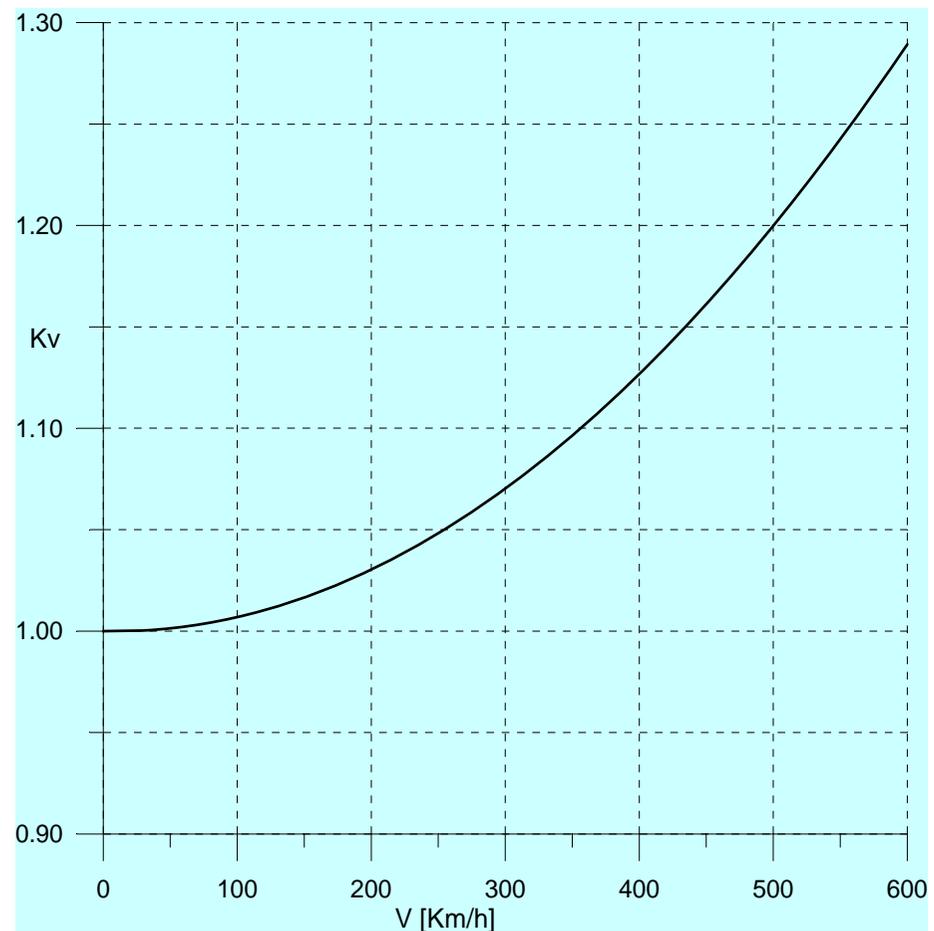
**Figure 6.46a** PT6A-27 maximum cruise performance. Prop speed—2200 rpm. (Courtesy, Pratt & Whitney of Canada.)

## Cap.6 – Caratteristiche propulsive Turboelica

EFFETTO RAM !!

$$K_v = 1.00 - 0.0014 * (V/100) + 0.00827 * (V/100)^2$$

con  $V$  espressa in Km/h



## Cap.6 – Caratteristiche propulsive Turboelica

EFFETTO Quota

$$\frac{\Pi_a}{\Pi_{a,0}} = \left( \frac{\rho}{\rho_0} \right)^n \quad n = 0.7$$

O anche ...

$$\frac{\Pi_a}{\Pi_{a0}} = \left( \frac{\rho}{\rho_0} \right) = \sigma$$

$$\Pi_a = \Pi_{a0} \cdot \varphi \cdot \sigma \cdot K_v$$



## Cap.6 – Caratteristiche propulsive

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### PISTONI /ELICA

Potenza all'albero

$$\Pi_a = \Pi_{ao} \cdot \sigma \cdot \varphi$$

Potenza disponibile

$$\Pi_d = T \cdot V = \Pi_a \cdot \eta_p = \Pi_{ao} \cdot \sigma \cdot \varphi \cdot \eta_p$$

Spinta disponibile

$$T_d = \Pi_d / V$$

Potenza all'albero sempre costante con la velocità di volo e dipendente dalla potenza di targa e dalla quota e dal grado di ammissione.

Potenza disponibile costante con V nell'ipotesi di considerare un'elica a passo variabile (o giri costanti).

Consumo specifico

$$SFC = 0.40 \div 0.50 \frac{\text{lb}}{\text{hp} \cdot \text{h}}$$

Consumo specifico costante con la quota e la velocità di volo e dipendente solo dal motore.

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## Cap.6 – Caratteristiche propulsive

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### TURBOELICA /ELICA

Potenza all'albero  $\Pi_a = \Pi_{a0} \cdot \sigma \cdot \varphi \cdot K_v$

$K_v$  effetto *ram*  $K_v = 1.00 - 0.0014 \cdot (V/100) + 0.00827 \cdot (V/100)^2$  [V in Km/h] fig. 6.24

Potenza disponibile  $\Pi_d = T \cdot V = \Pi_a \cdot \eta_p = \Pi_{a0} \cdot \sigma \cdot \varphi \cdot K_v \cdot \eta_p$

Spinta disponibile  $T_d = \Pi_d / V$

Potenza all'albero variabile con la velocità di volo e dipendente dalla potenza di targa e dalla quota e dal grado di ammissione. Sempre accoppiato con elica a passo variabile(giri costanti), quindi  $\eta_p$  costante con la velocità di volo.

NB : Per analisi di prestazioni di velocità non al calcolatore anziché assumere la legge per il  $K_v$  data sopra, si può semplicemente assumere un valore di potenza all'albero incrementata di :

- + 5% per V all'incirca di 250 Km/h
- + 7% per V all'incirca di 300 Km/h (monorotori veloci)
- + 10% per V all'incirca di 350 Km/h
- + 13% per V all'incirca di 400 Km/h (velivoli bimotori tipo Cessna)
- + 17% per V all'incirca di 450 Km/h
- + 20% per V all'incirca di 500 Km/h (velivoli tipo ATR 42)

### Consumo specifico

$$SFC = 0.60 \div 0.70 \frac{\text{lb}}{\text{hp} \cdot \text{h}}$$

Consumo specifico costante con la quota e la velocità di volo e dipendente solo dal motore.

## Cap.6 – Caratteristiche propulsive

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### TURBOGETTO

Spinta disponibile

$$T_d = 0.80 \cdot T_o \cdot \sigma \cdot \varphi$$

Potenza disponibile

$$\Pi_d = T_d \cdot V$$

Spinta disponibile costante con la velocità (con il Mach) di volo.

Variazione con la quota data da  $\sigma$ . Dipendenza dal grado di ammissione  $\varphi$ .

Solo l'80% della spinta  $T_o$  (spinta massima al decollo del motore) può essere utilizzata in volo (crociera o salita, cioè condizioni continuative).

Consumo specifico

$$\text{SFCJ} = 1.00 \div 2.00 \frac{\text{lb}}{\text{lb} \cdot \text{h}}$$

Consumo specifico costante con la quota e la velocità di volo e dipendente solo dal motore.

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## Cap.6 – Caratteristiche propulsive

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### TURBOFAN

Spinta disponibile

$$T_d = 0.80 \cdot T_o \cdot K_{MZ} \cdot \varphi$$

Con  $K_{MZ}$  variazione della spinta massima utilizzabile in volo in funzione di Mach e quota di volo, cioè  $K_{MZ}$ =funzione di (Mach, quota)

*Relazione più semplice da utilizzare nell'analisi di prestazioni*

$$T_d = 0.80 \cdot T_o \cdot \sigma \cdot \varphi$$

Potenza disponibile

$$\Pi_d = T_d \cdot V$$

La relazione approssimata fornisce una spinta disponibile costante con la velocità (con il Mach) di volo e variazione con la quota data da  $\sigma$ . Dipendenza dal grado di ammissione  $\varphi$ .

Solo l'80% della spinta  $T_o$  (spinta massima al decollo del motore) può essere utilizzata in volo (crociera o salita, cioè condizioni continuative).

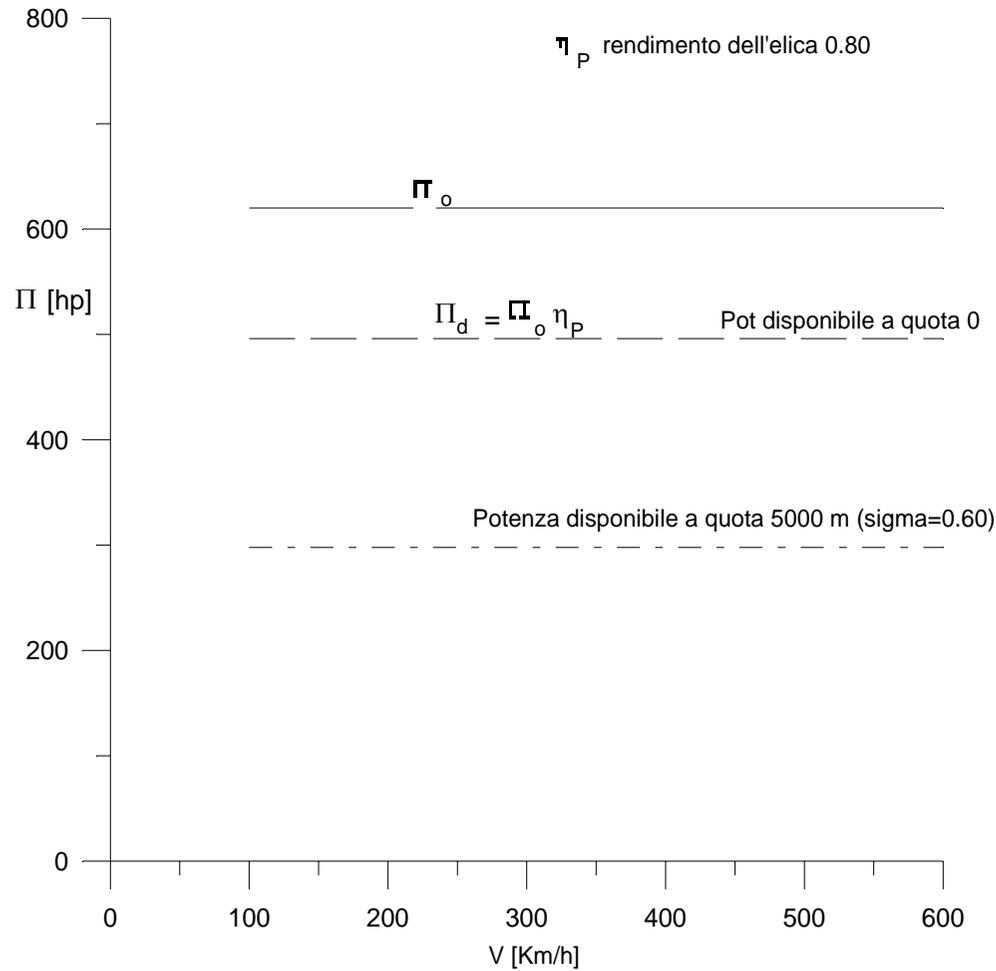
Consumo specifico

$$SFCJ = 0.60 \div 0.70 \frac{\text{lb}}{\text{lb} \cdot \text{h}}$$

Consumo specifico costante con la quota e la velocità di volo e dipendente solo dal motore.

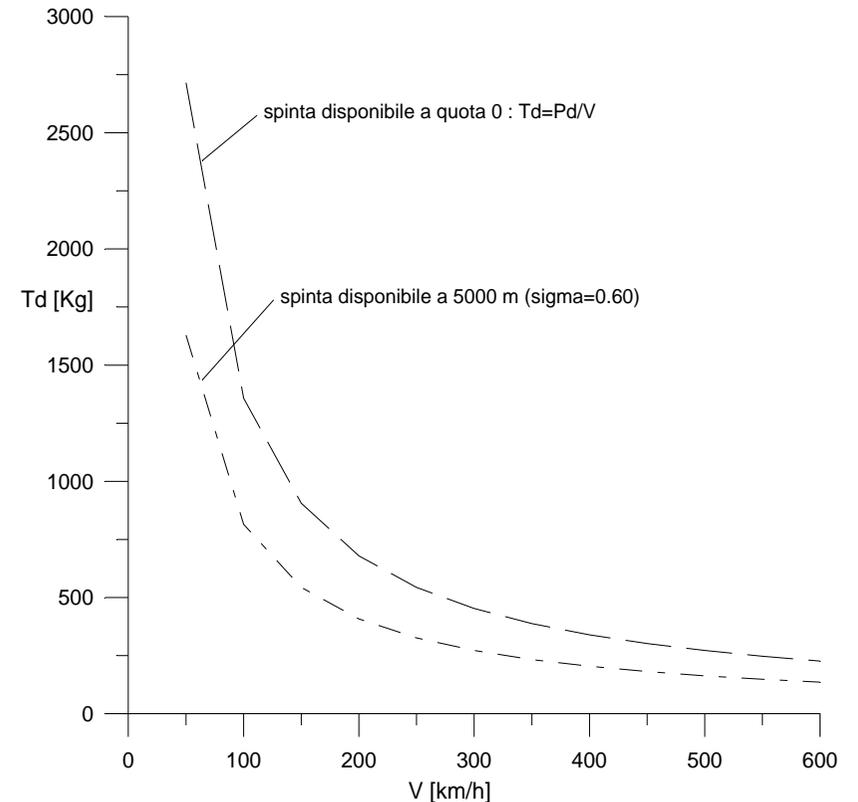
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# Cap.6 – Caratteristiche propulsive

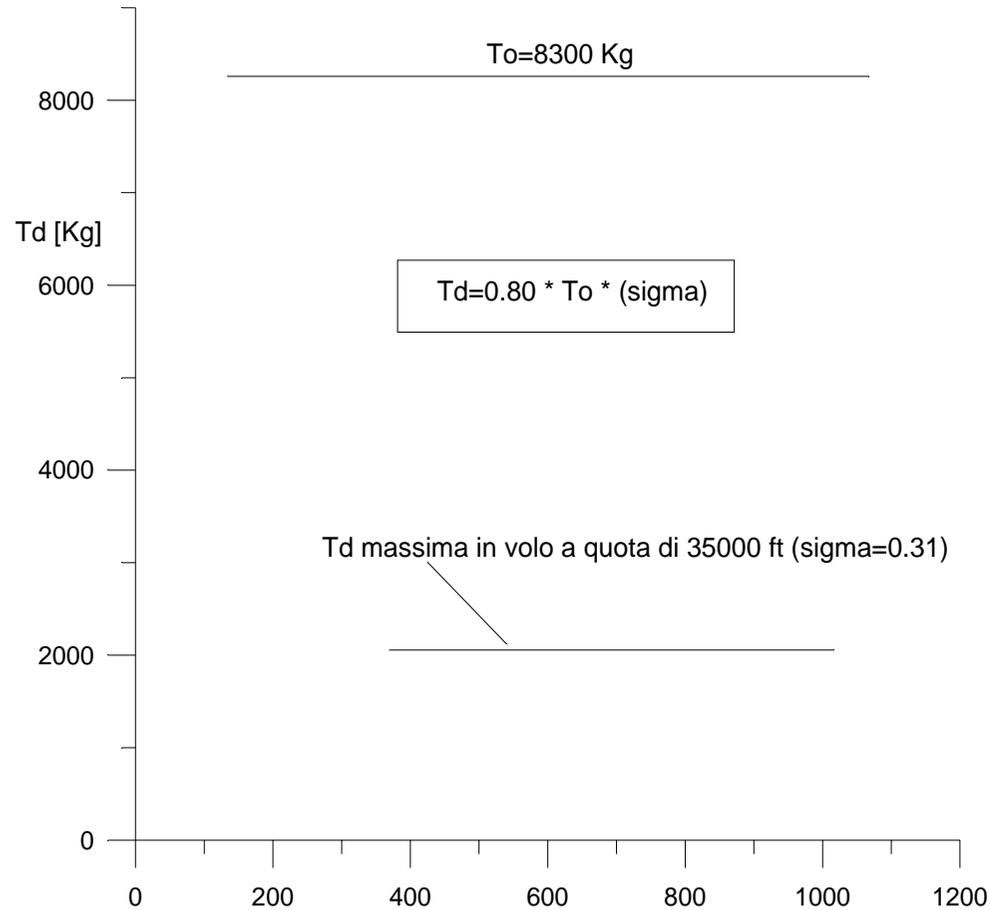


# ELICA

Motore Pratt&Whitney PT6A-27. (Potenza di targa, cioè potenza al decollo, o anche massima a quota 0=620 hp). Rendimento dell'elica a passo variabile  $\eta_P = 0.80$ . Tener presente che  $T_d = P_d/V$  fornisce  $T_d$  in [N] se  $P_d$  è in [Watt] e  $V$  in [m/s].

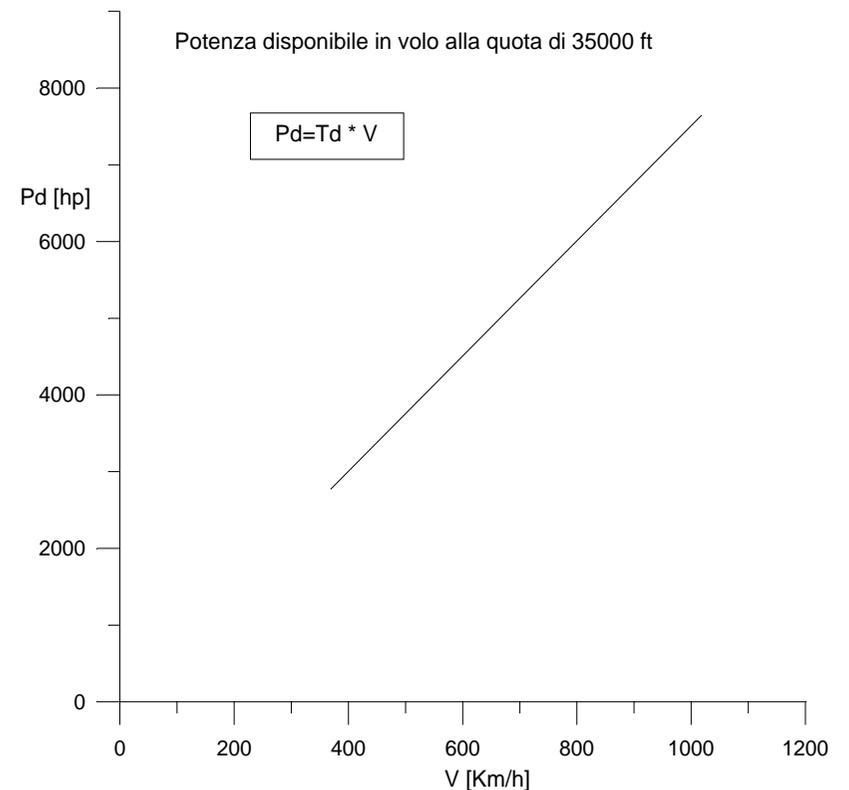


# Cap.6 – Caratteristiche propulsive



## TURBOFAN

Motore turbofan JT9-D (Motore del velivolo MD-80). Spinta massima al decollo  $T_o = 8300$  Kg.



## Cap.6 – Caratteristiche propulsive

