Propulsione Aerospaziale

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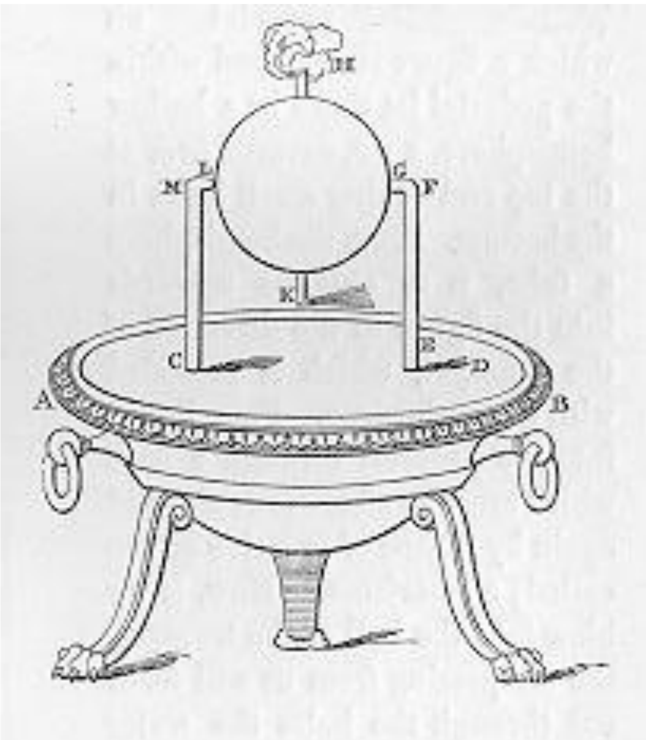
Eolipila o motore di Erone di Alessandria

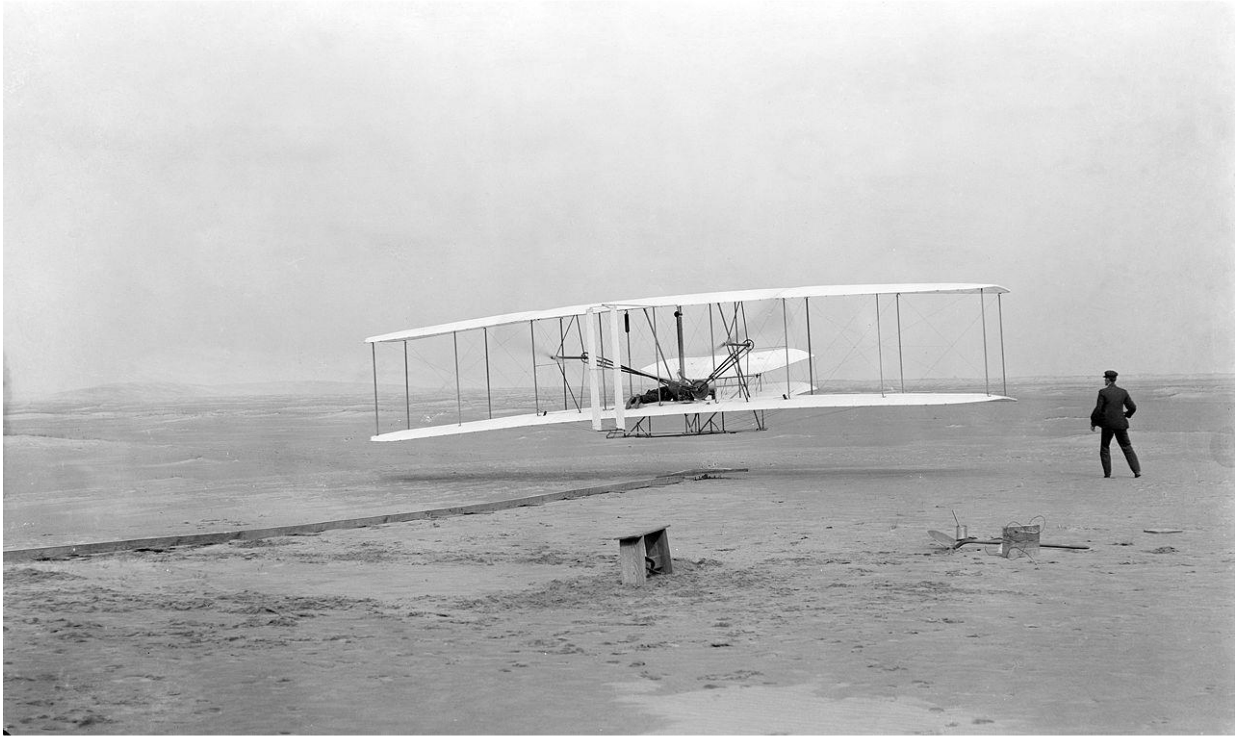


Disegno originale

Schema

Gli albori della propulsione aerospaziale

La propulsione aerospaziale è un invenzione del ventesimo secolo, nata il 17 dicembre 1903 con il primo volo dei **fratelli Wright**.

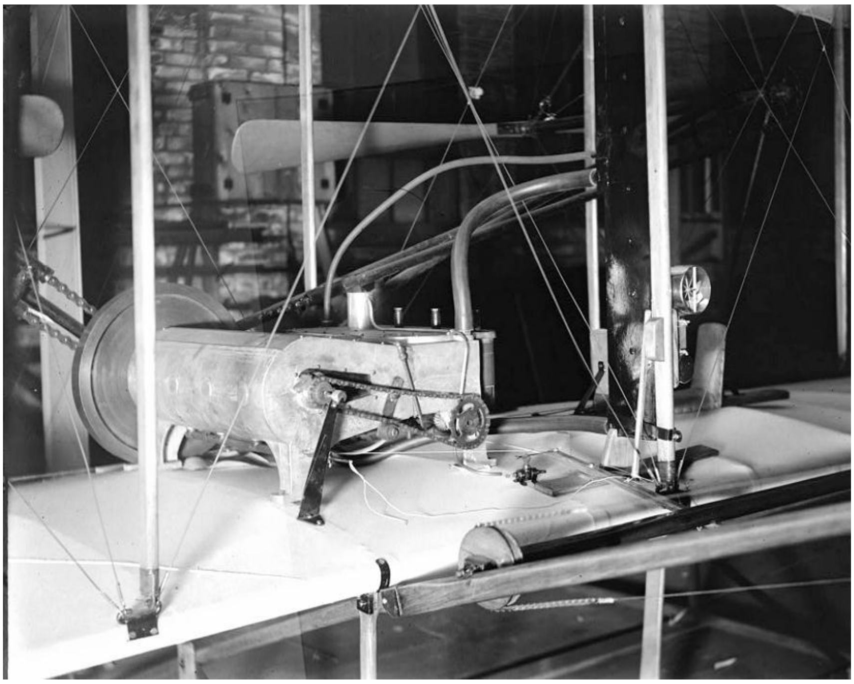


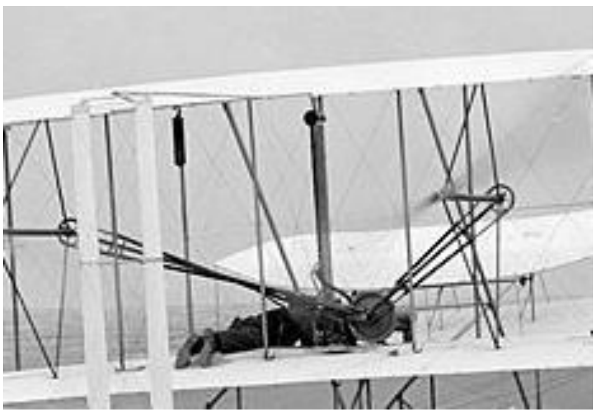
The "Flyer" in Kitty Hawk, North Carolina

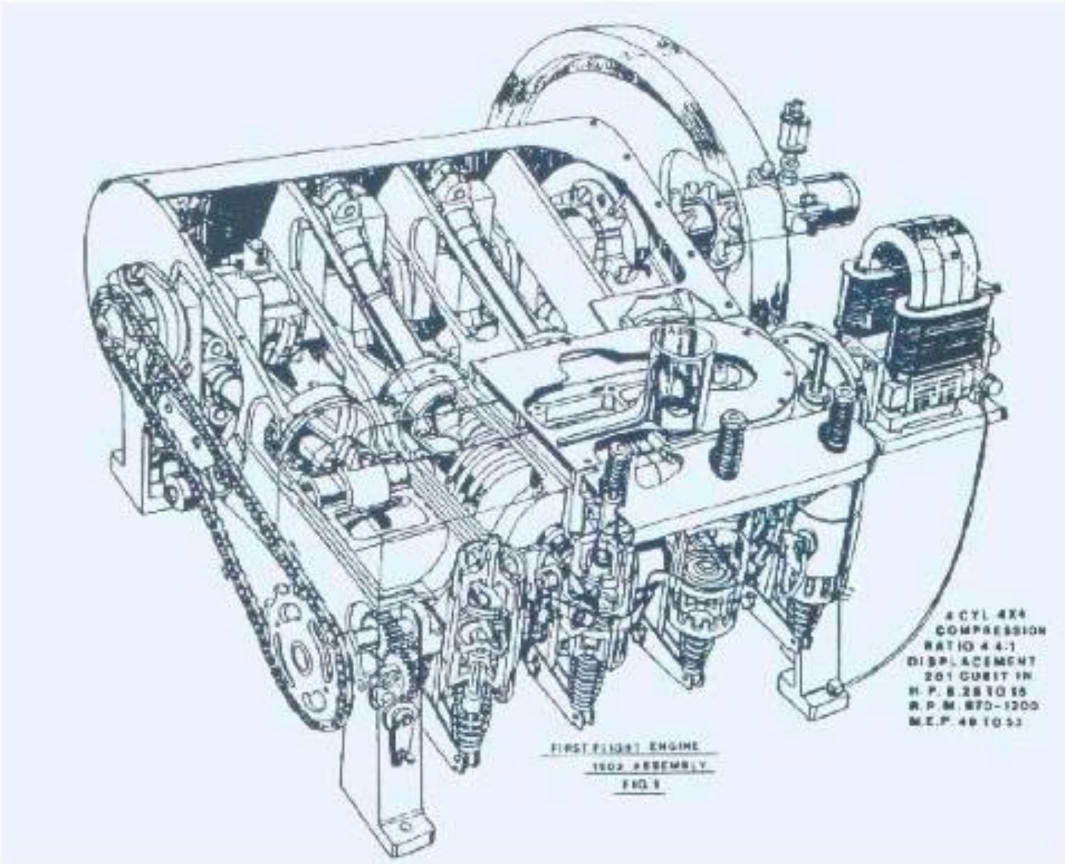
Gli albori della propulsione aerospaziale

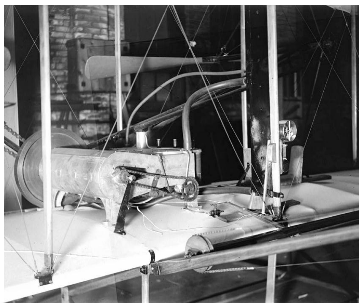
Il motore a bordo del "Flyer" era un motore a **movimento alternativo** (motore a pistoni) collegato a **due eliche** (propulsore).

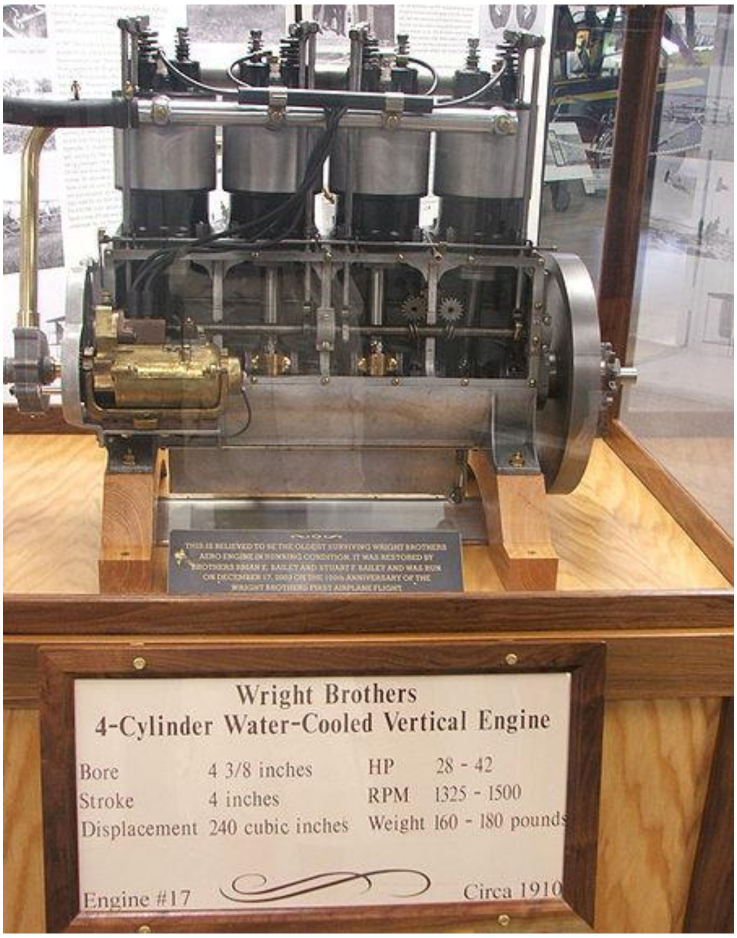
Questo tipo di sistema di propulsione è stato utilizzato fino agli anni trenta.

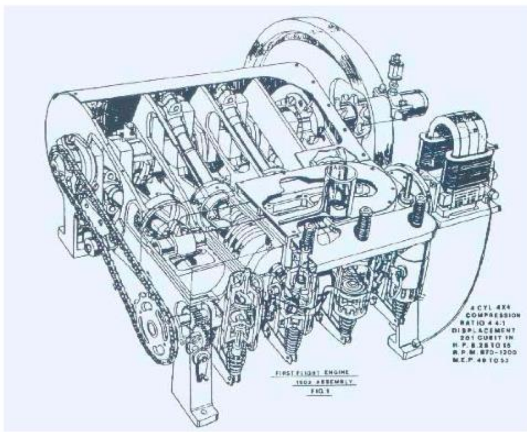





4 CYL 4X4
COMPRESSION
DISPLACEMENT
FIRST FLIGHT ENGINE
1903 ASSEMBLY
FIG. 1

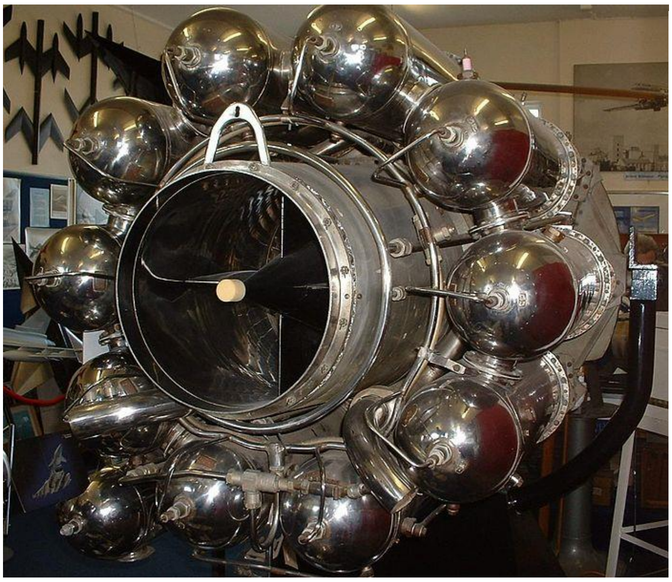


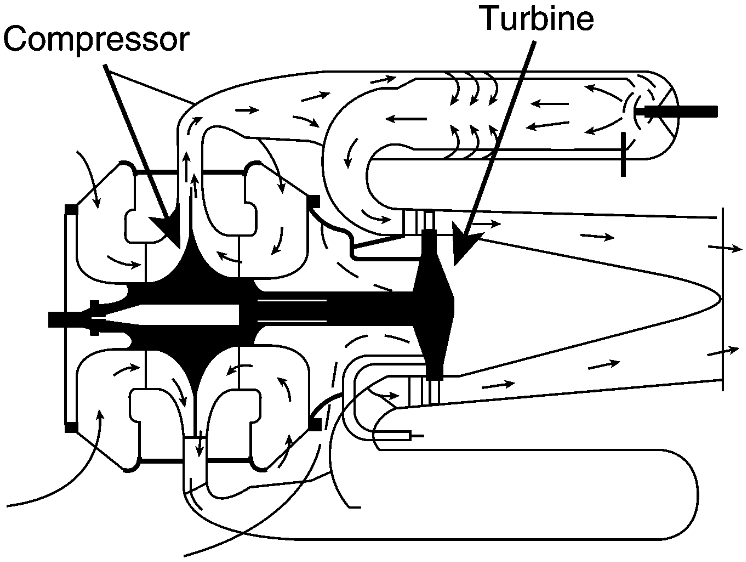

Wright Brothers
4-Cylinder Water-Cooled Vertical Engine
Bore 4 3/8 inches
Stroke 4 inches
Displacement 240 cubic inches
HP 28 - 42
RPM 1325 - 1500
Weight 160 - 180 pounds
Engine #17
Circa 1910



Gli albori della propulsione aerospaziale

Nel 1930 **Frank Whittle** brevettò il primo **motore a getto**.





Gli albori della propulsione aerospaziale

Nel 1930 **Frank Whittle** brevettò il primo **motore a getto**.

Dopo alcuni anni il motore ideato da Whittle fu montato su un aeroplano nel 1941.

Fig. 8 Gloster E28/29. (National Air and Space Museum.)

Gli albori della propulsione aerospaziale

Poco dopo (1936), ma indipendentemente, Hans-Joachim Pabst **von Ohain** brevettò anche lui un motore a getto. Nel 1939 il motore era stato completamente sviluppato e fu il primo a spingere un aeroplano.

Whittle von Ohain

Gli albori della propulsione aerospaziale

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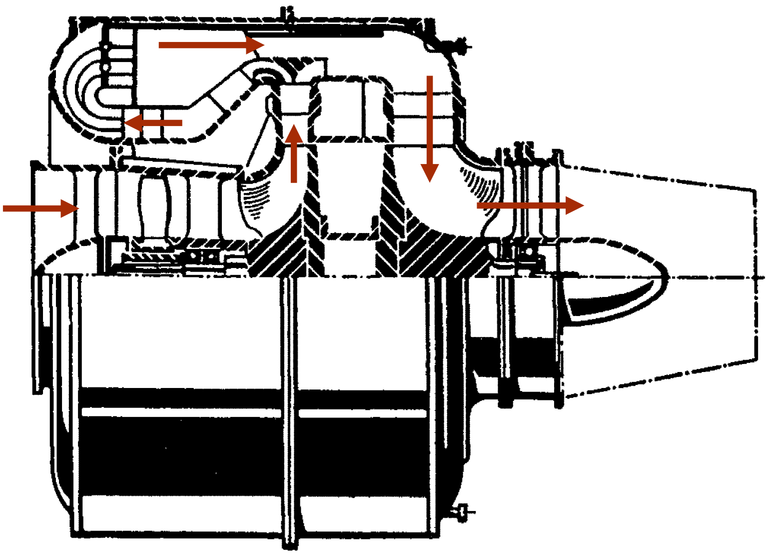
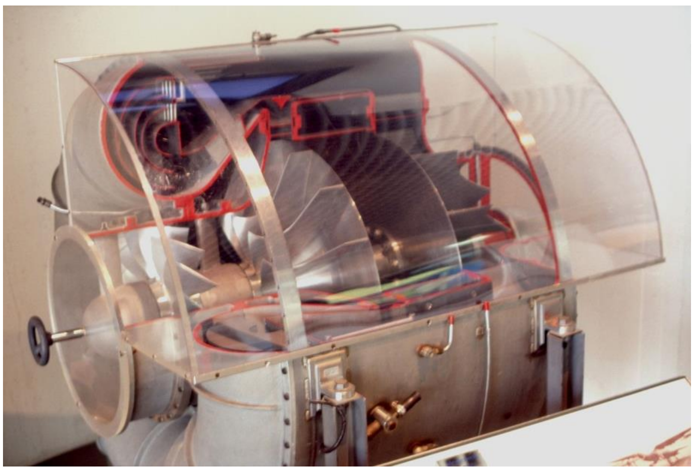


Fig. 12 1937 design of the He.S3 turbojet engine.



Gli albori della propulsione aerospaziale

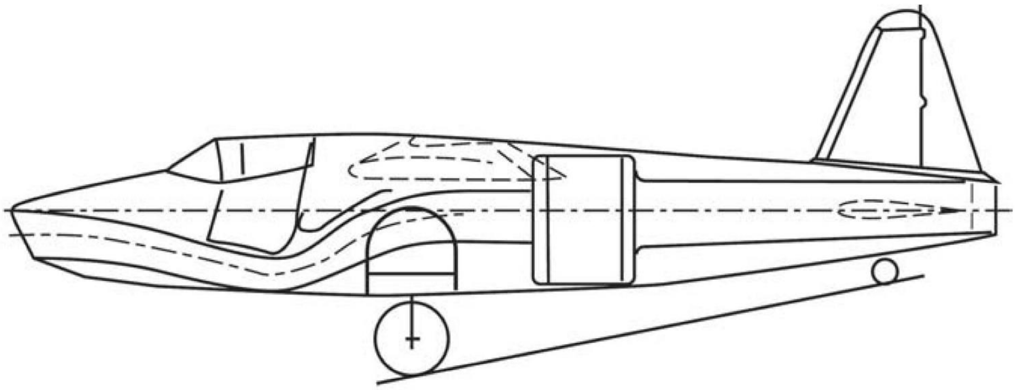
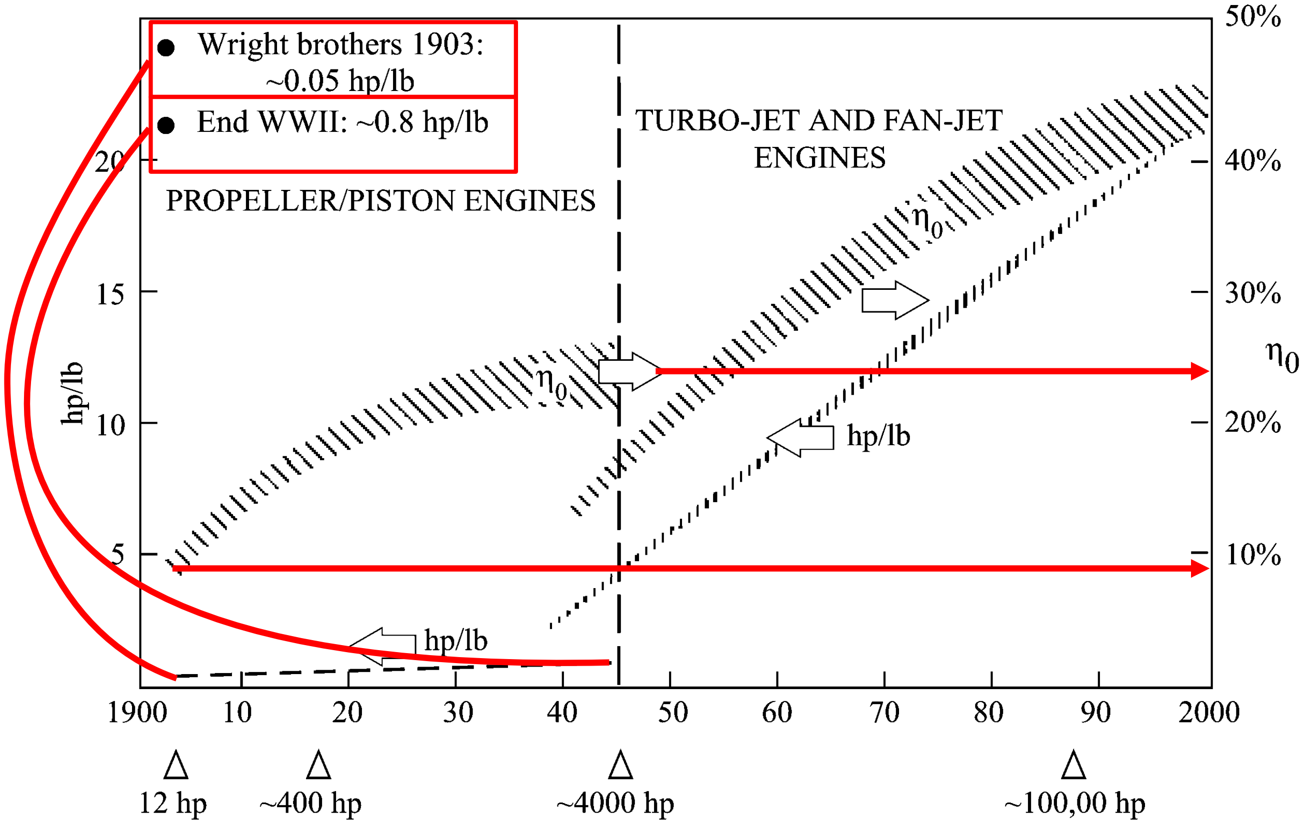


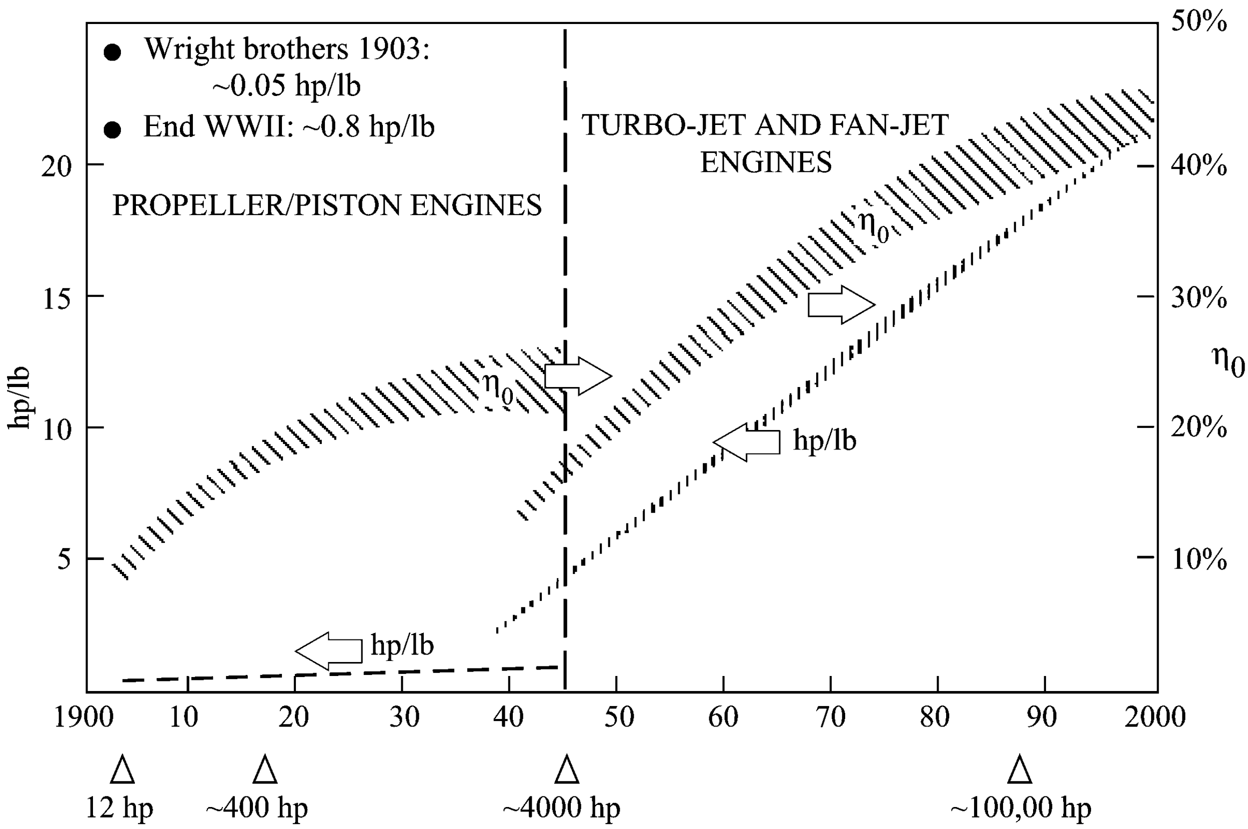
Fig. 13 The world's first jet-powered aircraft, the Heinkel He-178, was powered by the von Ohain–designed He.S3B turbojet engine. (National Air and Space Museum.)

Efficienza del sistema propulsivo



Fino alla fine della seconda guerra mondiale i motori erano a pistone.

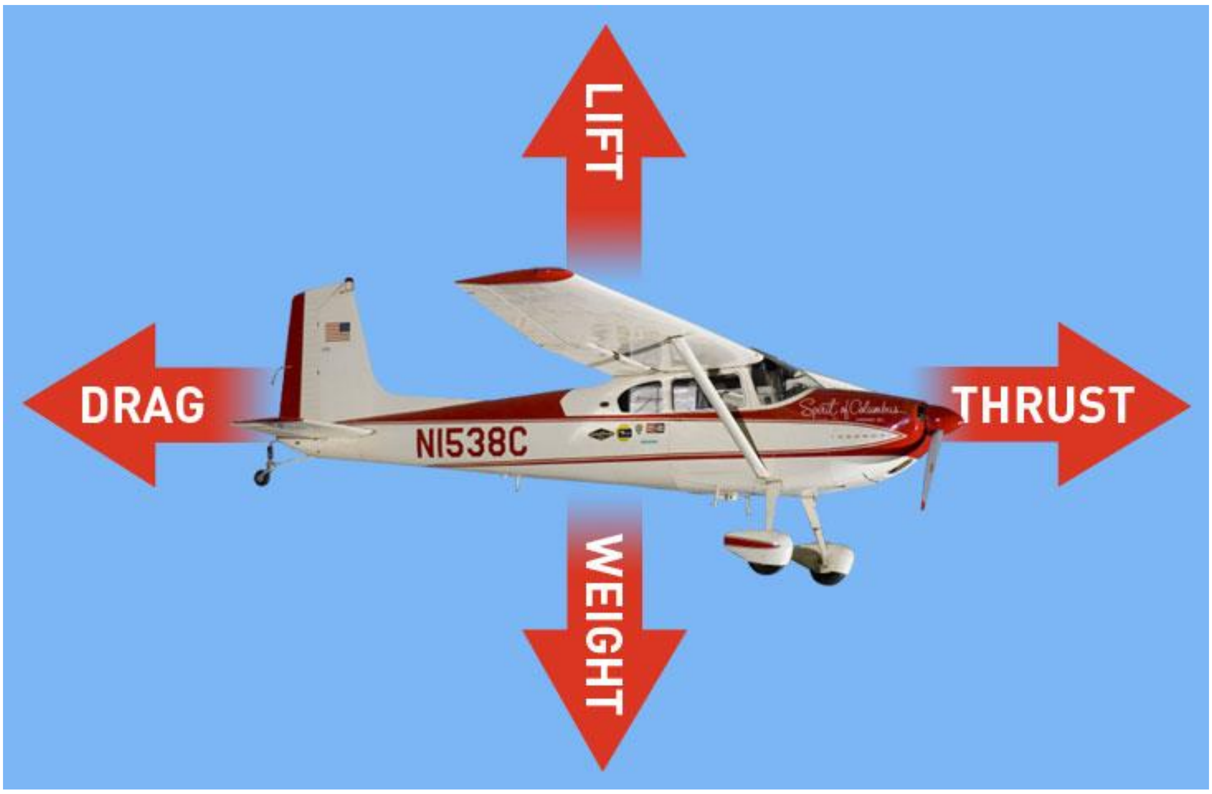
Efficienza del sistema propulsivo



Dopo la seconda guerra mondiale il quadro è completamente cambiato con l'avvento dei motori a turbina.

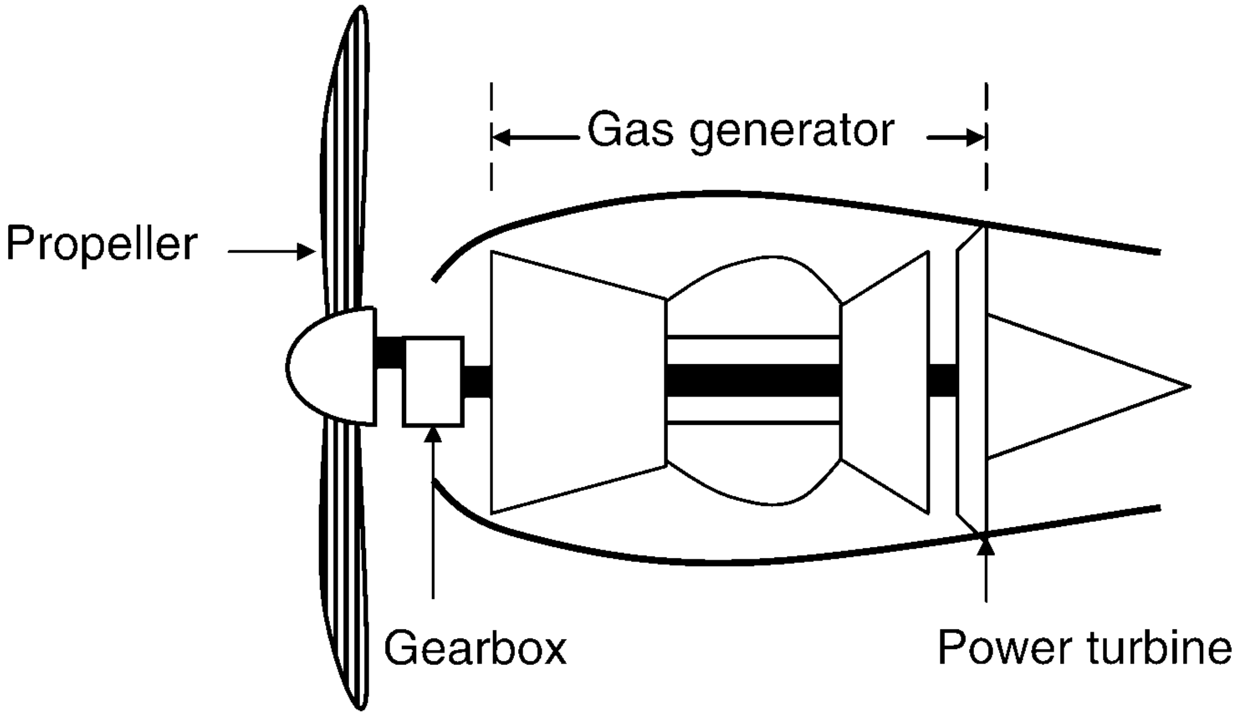
Funzione del sistema propulsivo aeronautico

Nel caso più semplice di volo livellato il sistema propulsivo serve per vincere la resistenza.



Differenze fra propulsore e motore

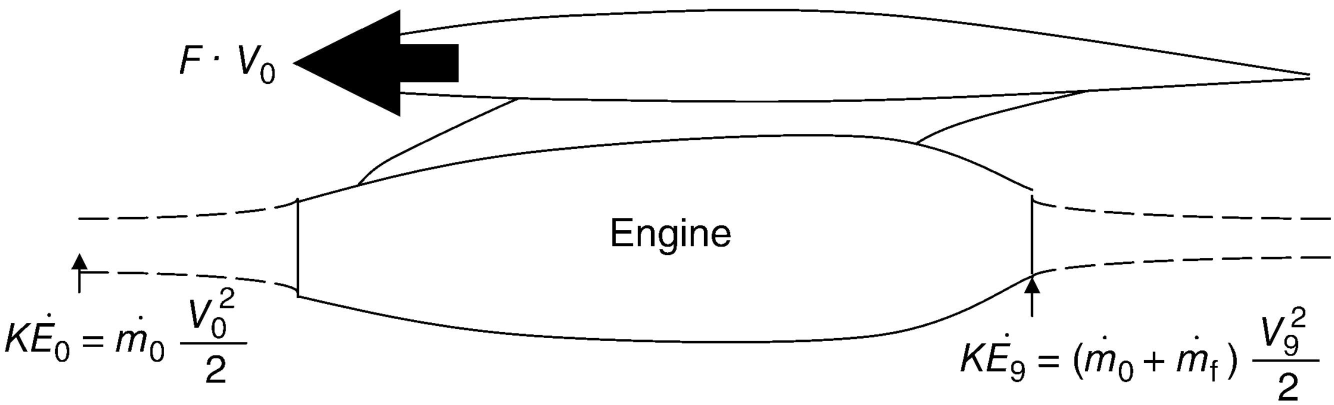
In figura è mostrato uno schema di un turboelica.



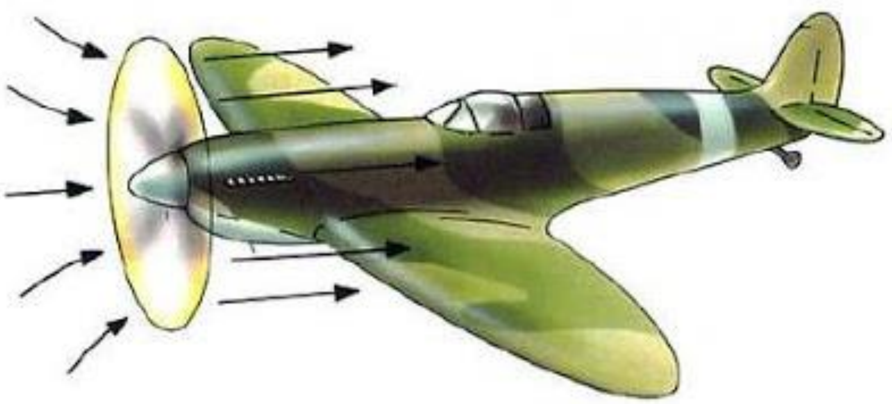
Genesi della spinta

La **differenza** fra la di **quantità di moto** entrante ed uscente dal volume di controllo è la causa della generazione della spinta. Il sistema propulsivo al suo interno accelera l'aria (ed aggiunge dei gas combusti). Per il **terzo principio della dinamica** il propulsore è accelerato in direzione opposta generando la spinta.

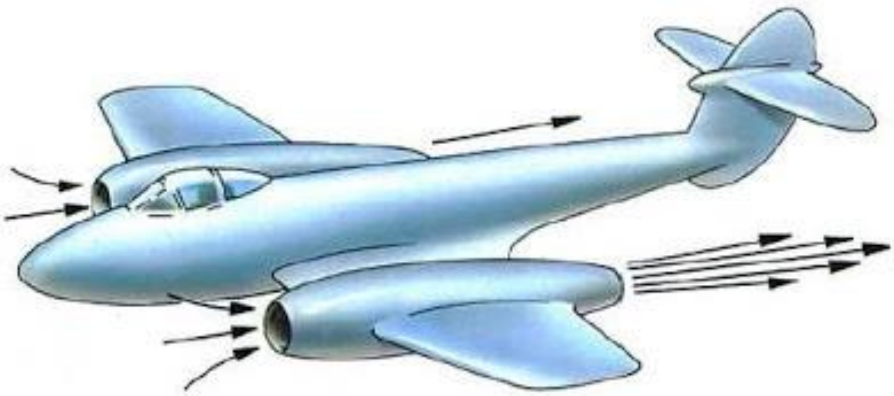
La variazione di quantità di moto è essenzialmente causata da un **accelerazione del flusso**.



Genesi della spinta



Grande portata d'aria e piccole accelerazioni.



Piccola portata d'aria e grandi accelerazioni.

Classificazione dei sistemi propulsivi

La classificazione dei sistemi propulsivi può essere fatta in base:

- al fluido propulsivo:
  - **Motori respiranti** (Airbreathing) anche detti **esoreattori** o aeroreattori;
  - **Endoreattori** (non-Airbreathing) o **razzi** (rockets)

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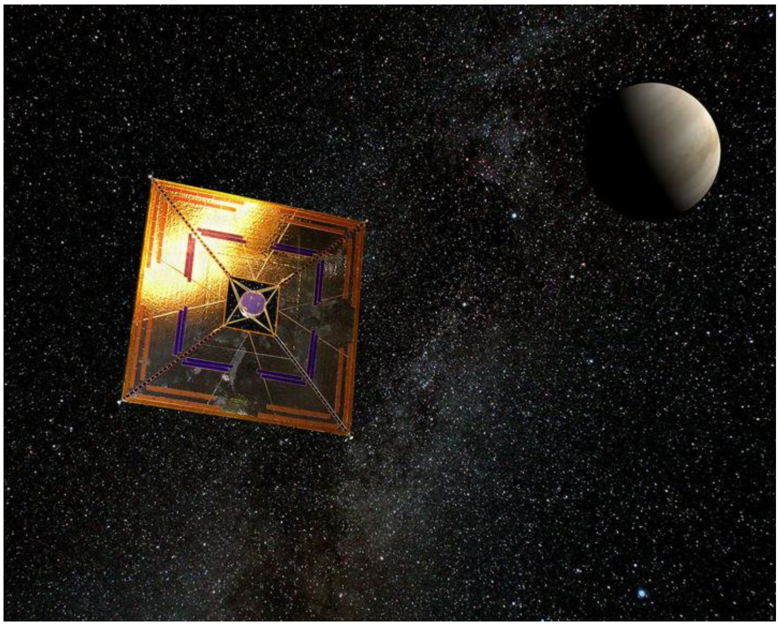

- alla sorgente energetica;

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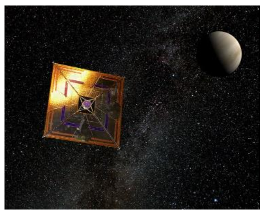
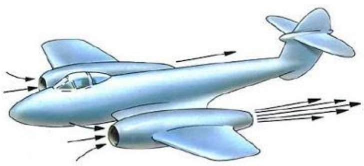
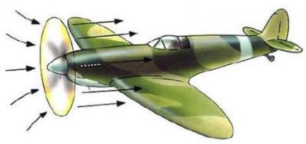
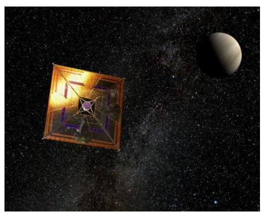
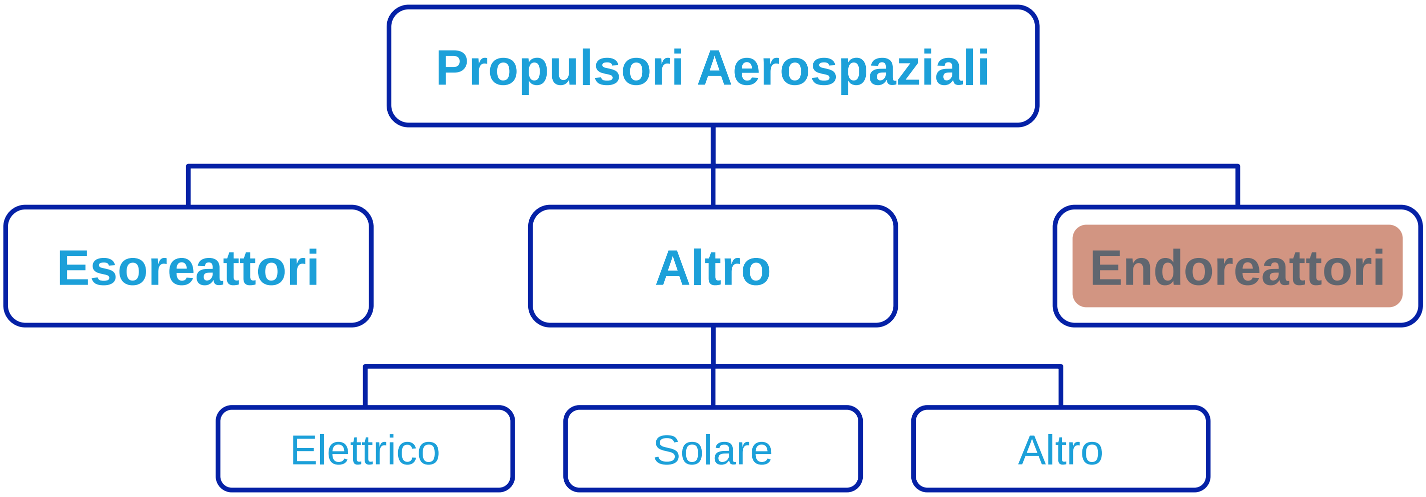


- alla sorgente energetica;

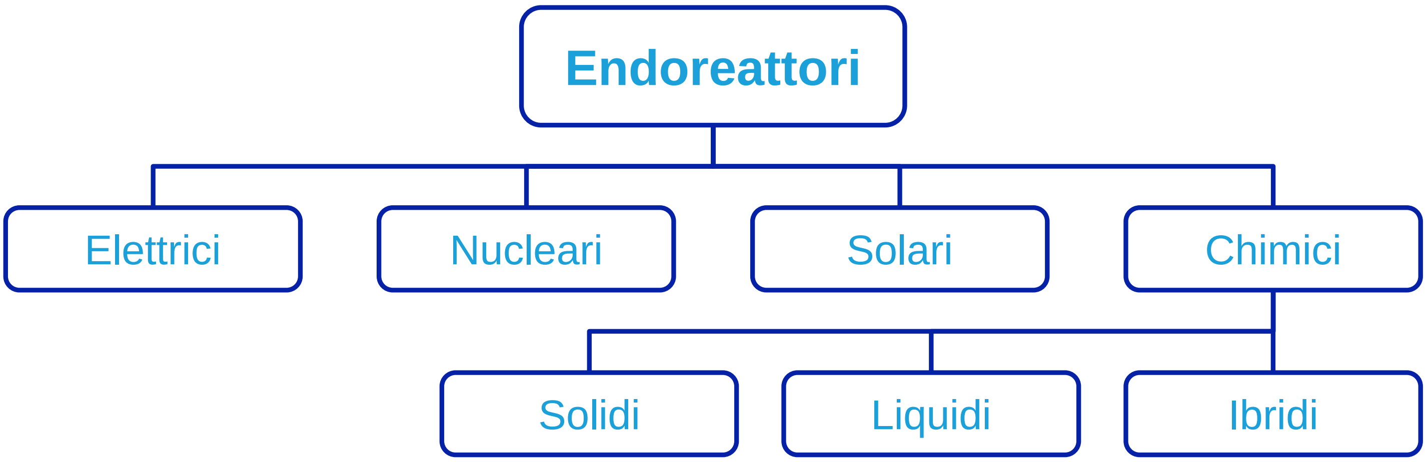
- al generatore di spinta.

Classificazione in base al fluido propulsivo

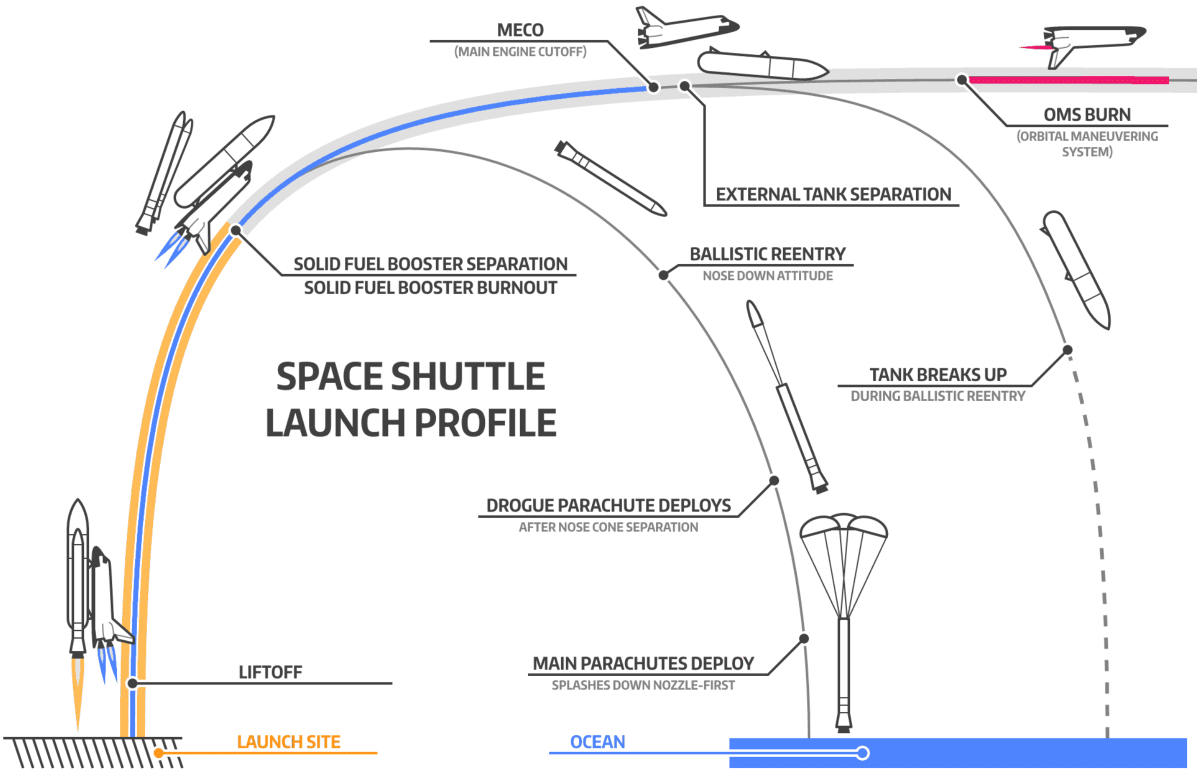


Classificazione in base al fluido propulsivo



Funzione del sistema propulsivo aerospaziale

Nelle missioni spaziali è necessario fornire una differenza di velocità…



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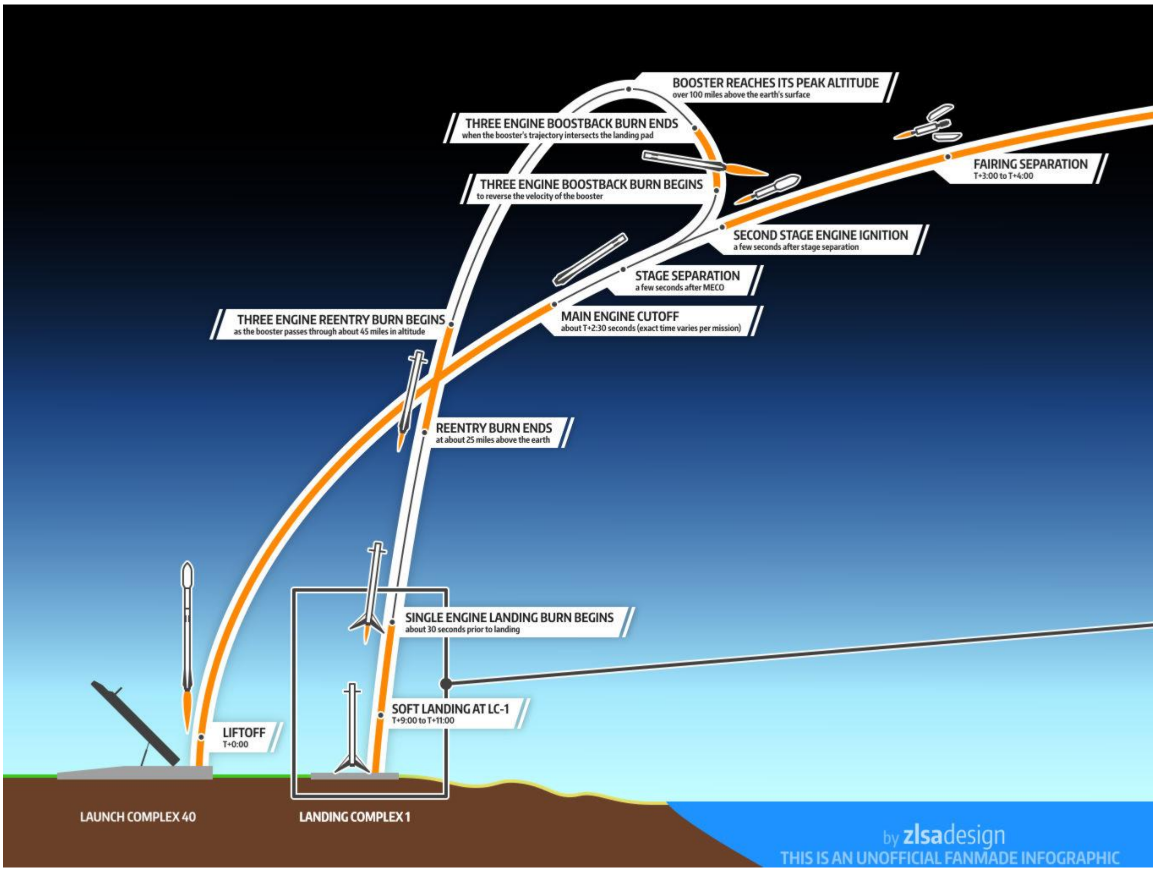

Funzione del sistema propulsivo aerospaziale

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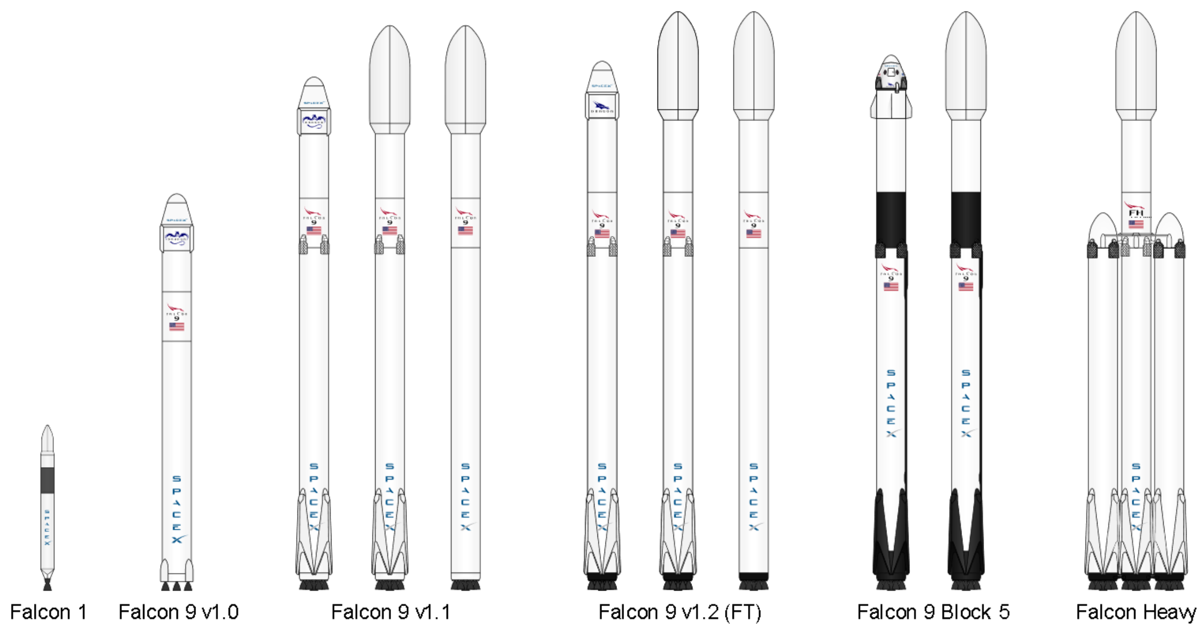
Funzione del sistema propulsivo aerospaziale

SpaceX Falcon family:

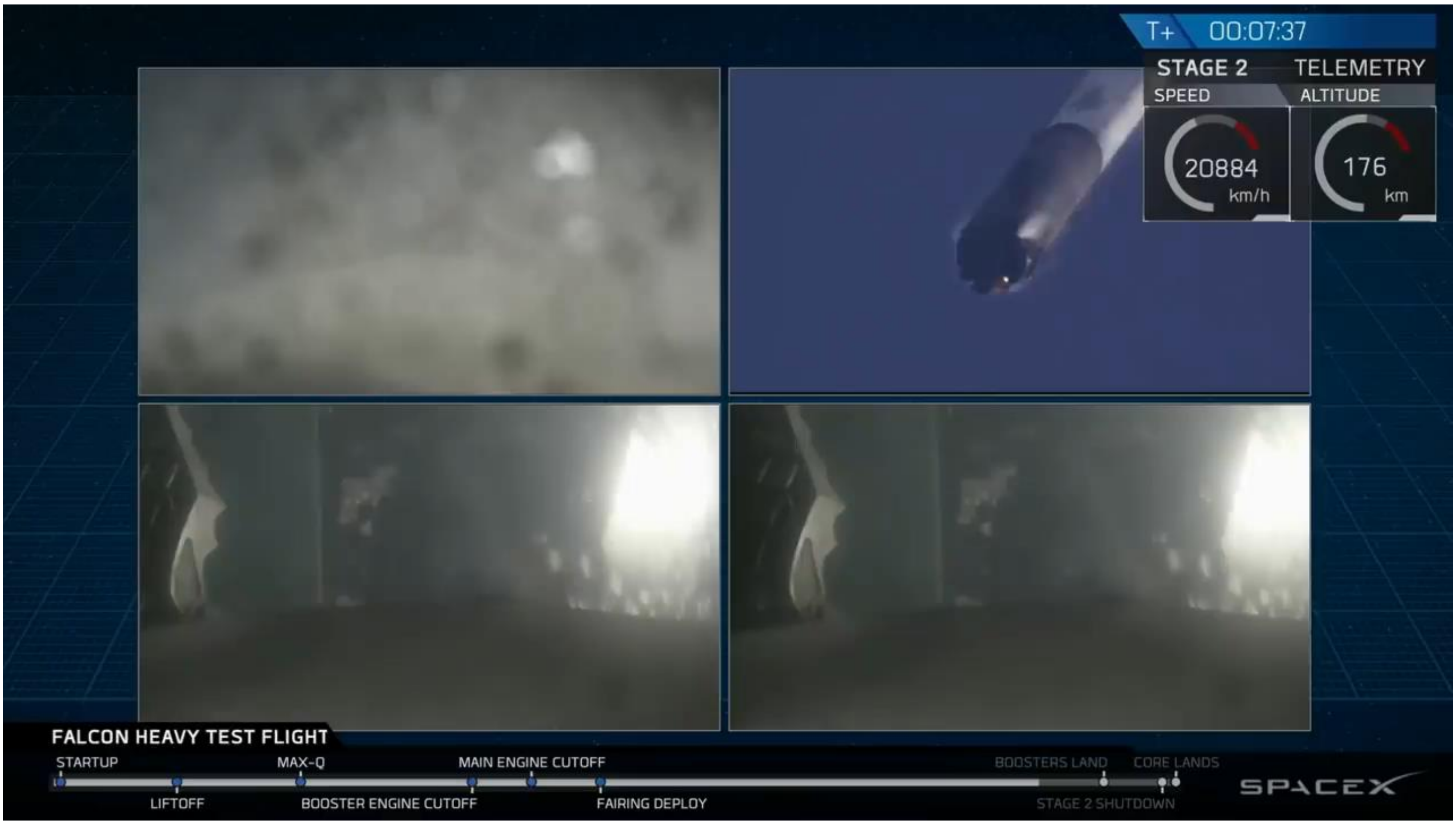


Funzione del sistema propulsivo aerospaziale

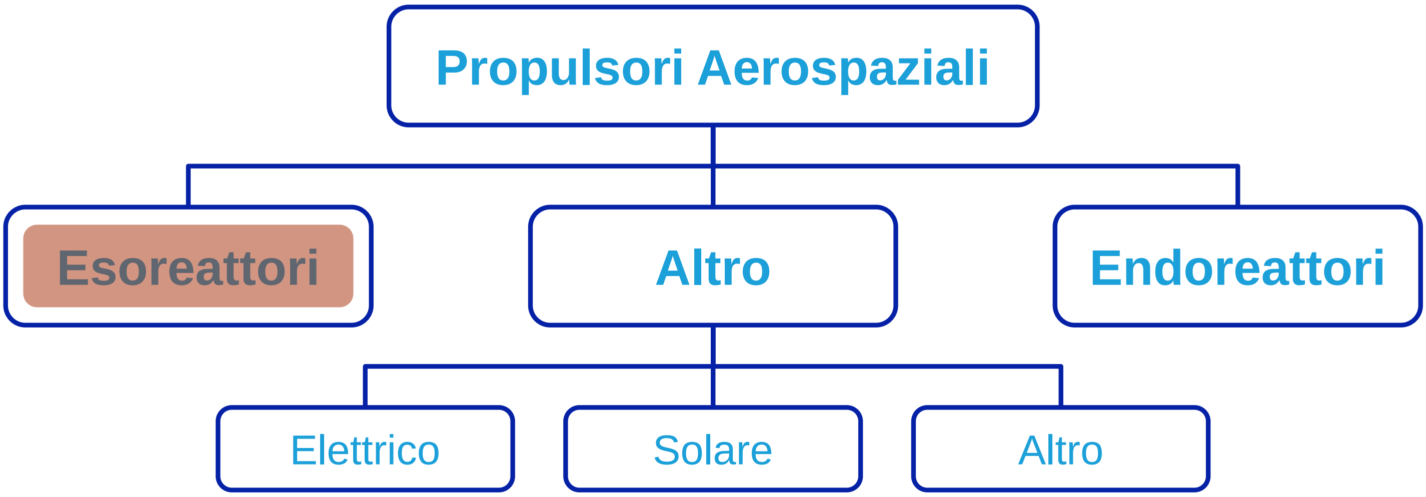
SpaceX **Falcon Heavy**:

Funzione del sistema propulsivo aerospaziale

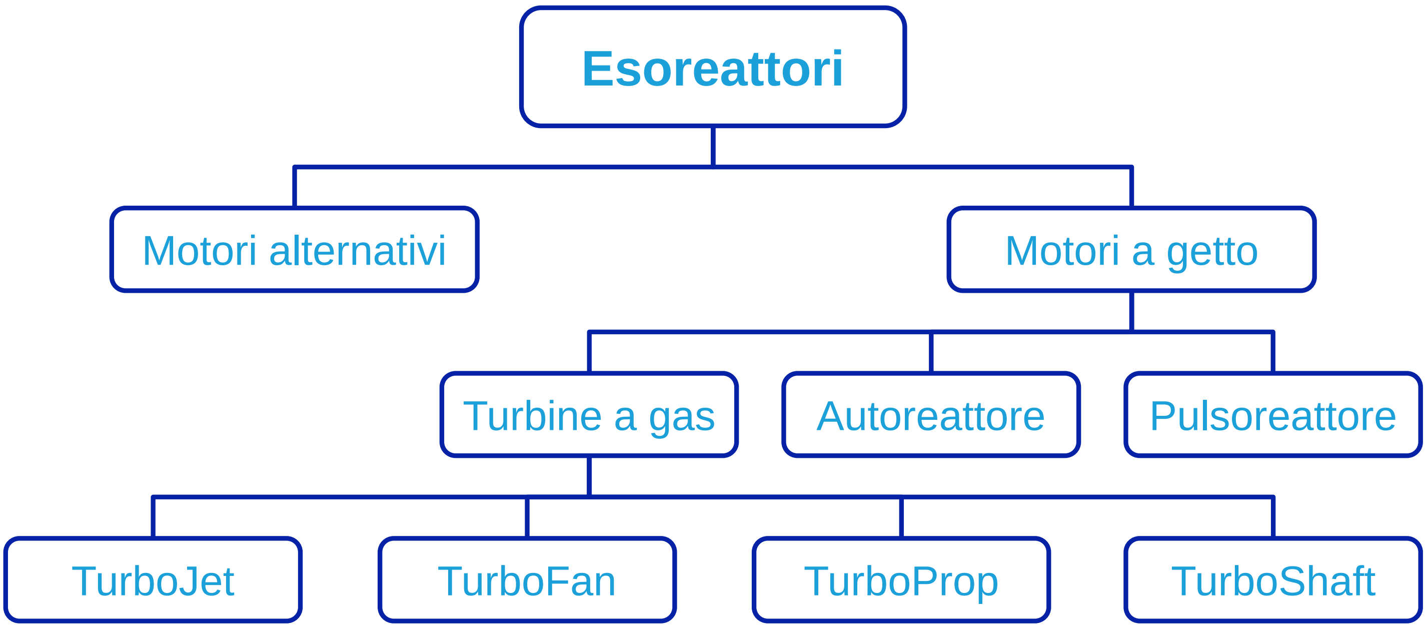
SpaceX **Falcon Heavy**:



Classificazione in base al fluido propulsivo

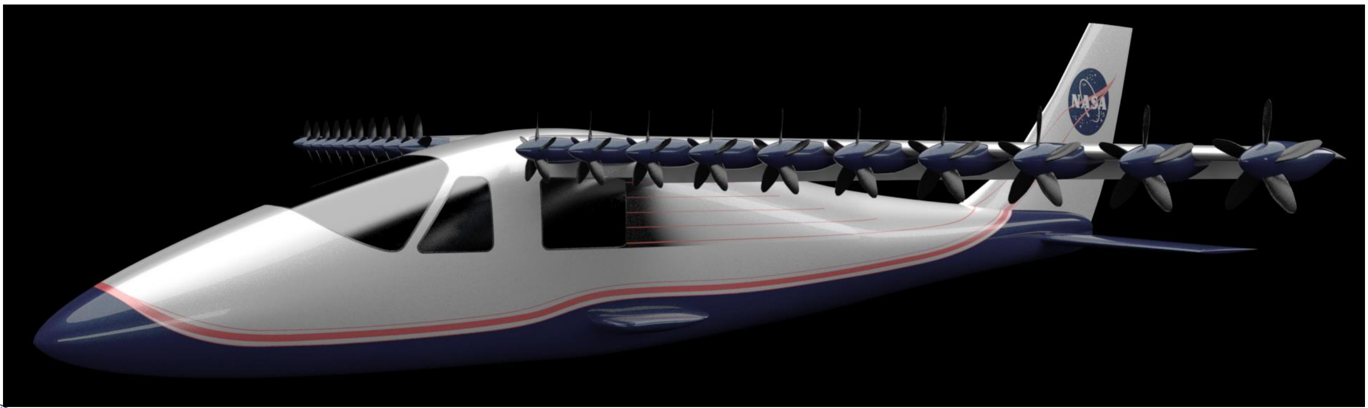


Classificazione in base al fluido propulsivo



Classificazione in base al generatore di spinta

- **Propulsori Aerospaziali**
  - Elica
    - Motori alternativi
    - Elettrico
    - TurboProp
    - TurboShaft
  - Getto
  - Non Conv.



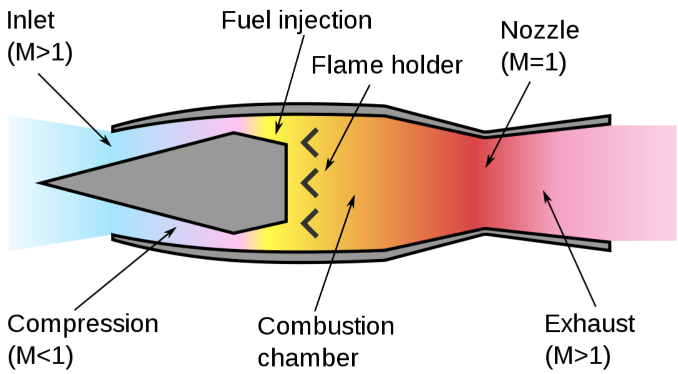
Classificazione in base al fluido propulsivo

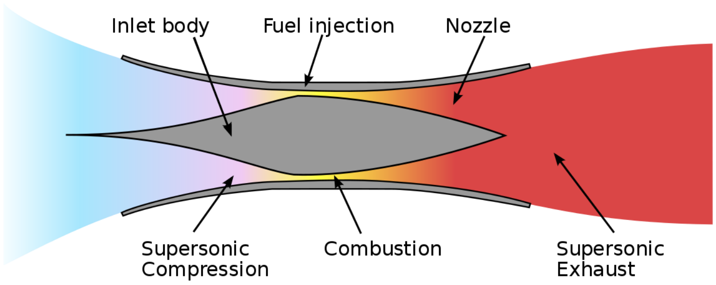
- **Esoreattori**
  - Motori alternativi
  - Motori a getto
    - Turbine a gas
      - TurboJet
      - TurboFan
      - TurboProp
      - TurboShaft
    - Autoreattore
    - Pulsoreattore

Autoreattori o statoreattori

Autoreattore

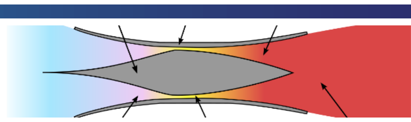
Ramjet | SCRamjet



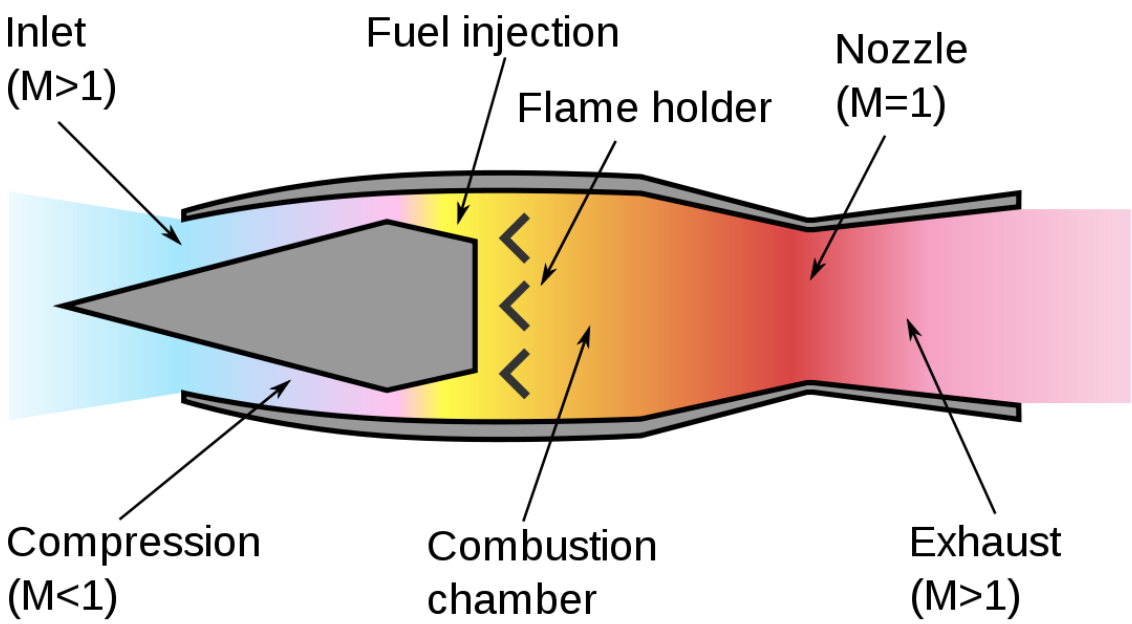


Ramjet

Autoreattore

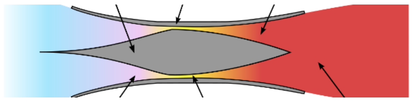


Gli **autoreattori** in linea di principio, non avendo parti rotanti, sono i **sistemi di propulsione più semplici**. Sono formati solamente da presa d'aria, camera di combustione ed ugello e possono funzionare solo ad alta velocità normalmente in regime supersonico (non può funzionare al punto fisso).



Ramjet

Autoreattore



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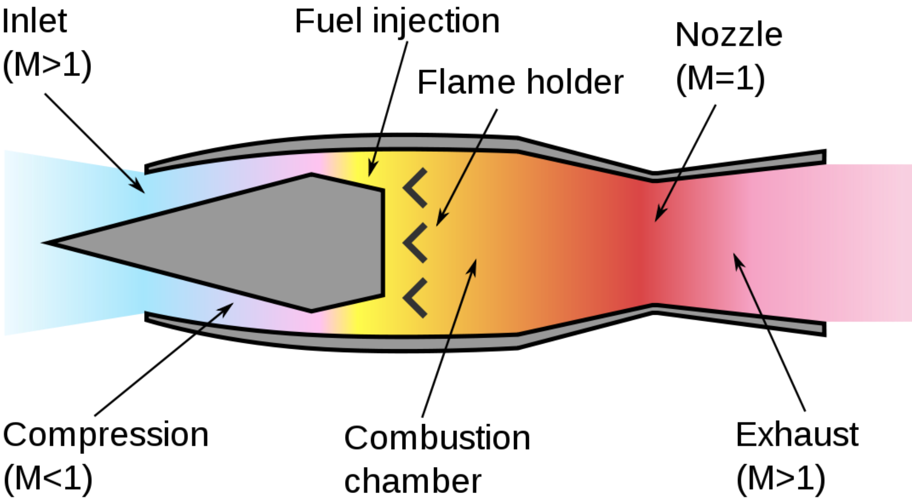
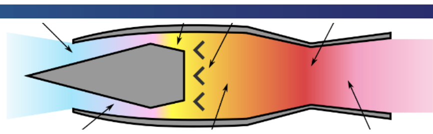
La **compressione** generata dalla **presa d'aria** è sufficiente per avere una **buona combustione** quindi il fluido caldo espande nell'ugello producendo la spinta.

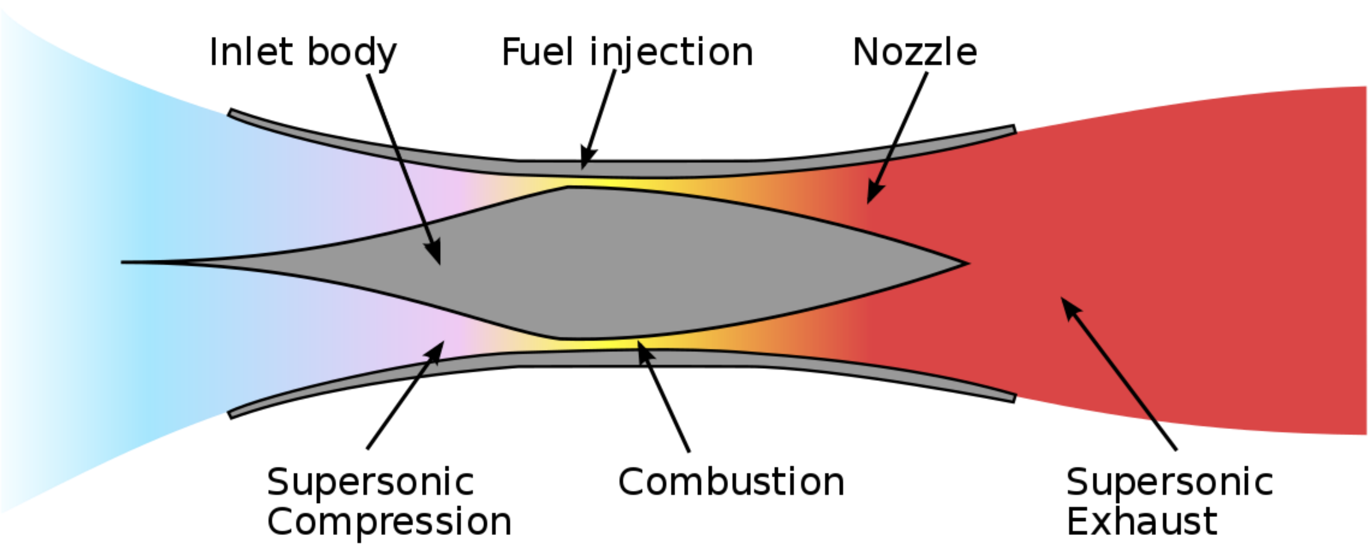


Scramjet

Autoreattore

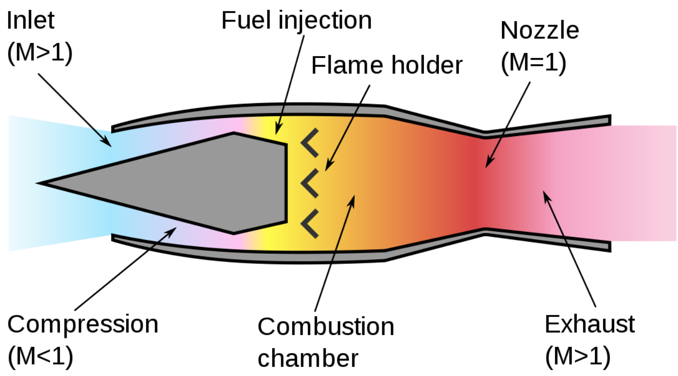


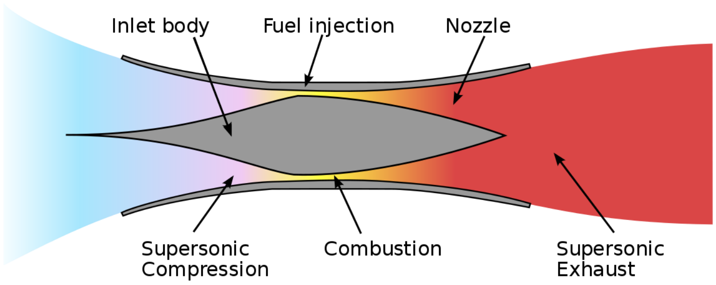
Se la **combustione** avviene in regime **supersonico** si parla di **SCRamjet** (Supersonic Combustion Ramjet). Mantenere stabile la combustione in regime supersonico non è banale.



Autoreattori o statoreattori

- Autoreattore
  - Ramjet
  - SCRamjet





Classificazione in base al fluido propulsivo

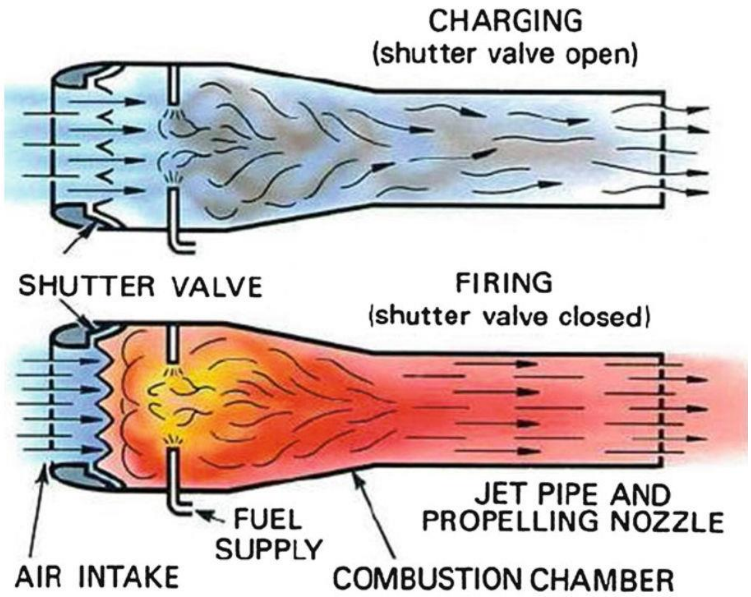
- **Esoreattori**
  - Motori alternativi
  - Motori a getto
    - Turbine a gas
      - TurboJet
      - TurboFan
      - TurboProp
      - TurboShaft
    - Autoreattore
    - Pulsoreattore

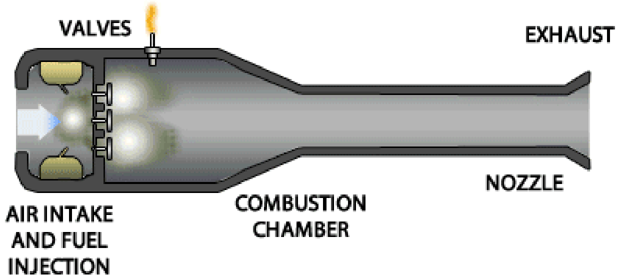
Pulsoreattore

Nel **pulsoreattore** la **combustione** è **intermittente**. Il canale d'ingresso è dotato di una serie di valvole di non ritorno che si chiudono durante la **deflagrazione** che provoca un **aumento di pressione** e la formazione di un **getto propulsivo**.

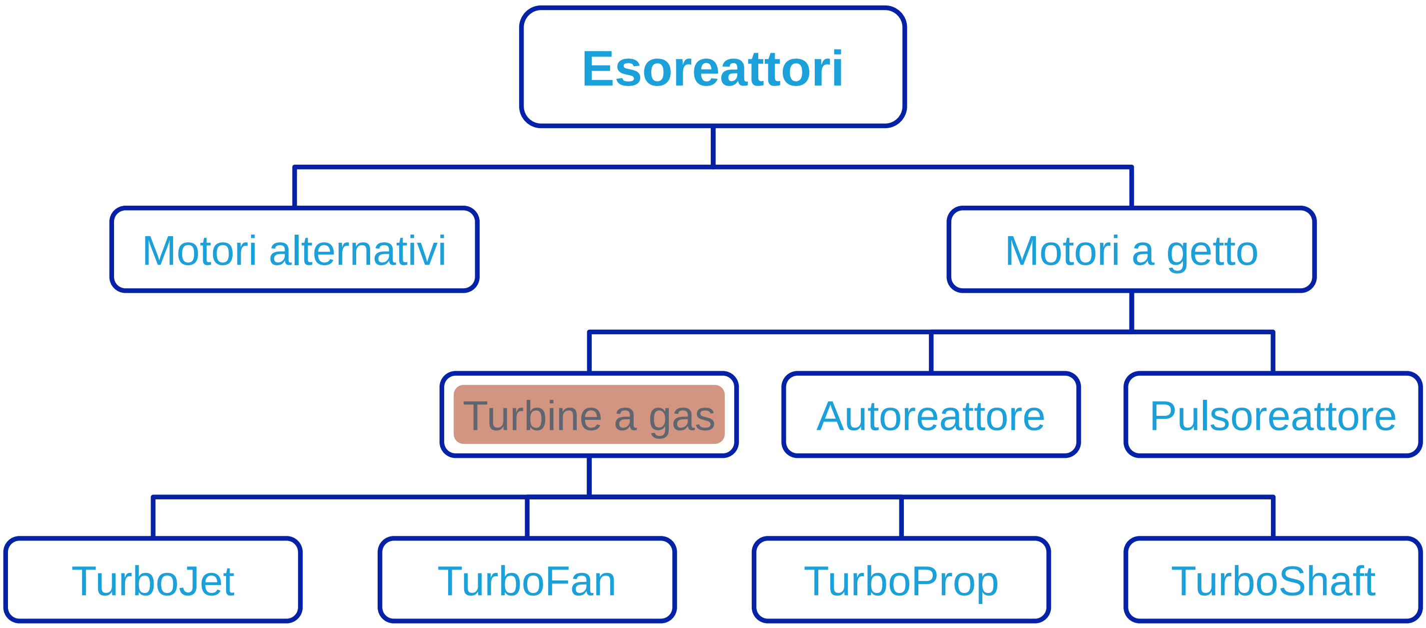
Successivamente si genera una **depressione** all'ingresso e che provoca l'apertura delle valvole durante la fase d'aspirazione.

Se la geometria del condotto è ben disegnata è possibile operare anche in assenza di valvole.





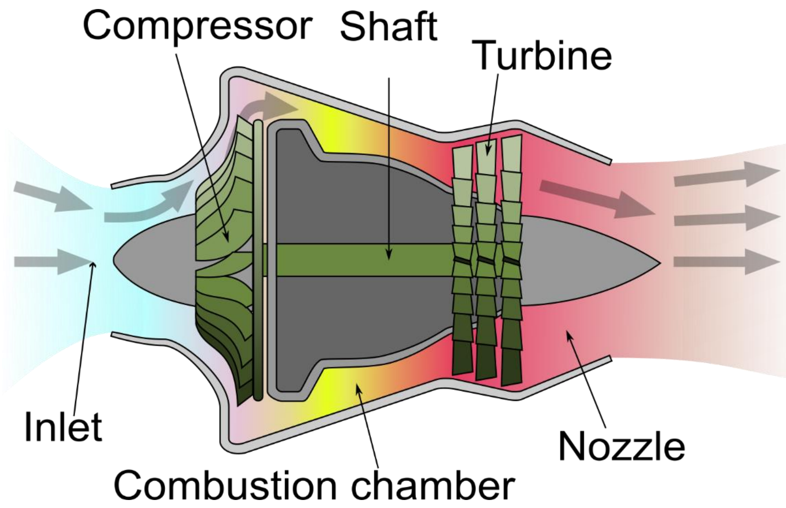
Classificazione in base al fluido propulsivo

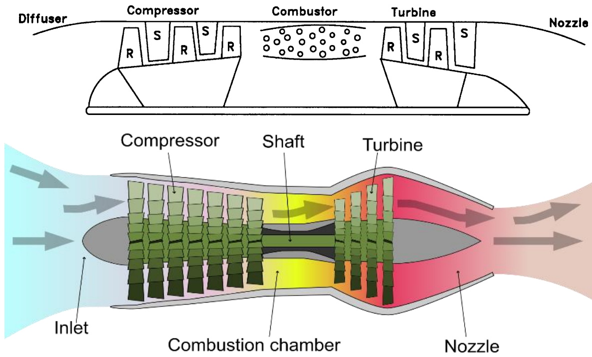


Turbogetto

Turbine a gas

- TurboJet
- TurboFan
- TurboProp
- TurboShaft



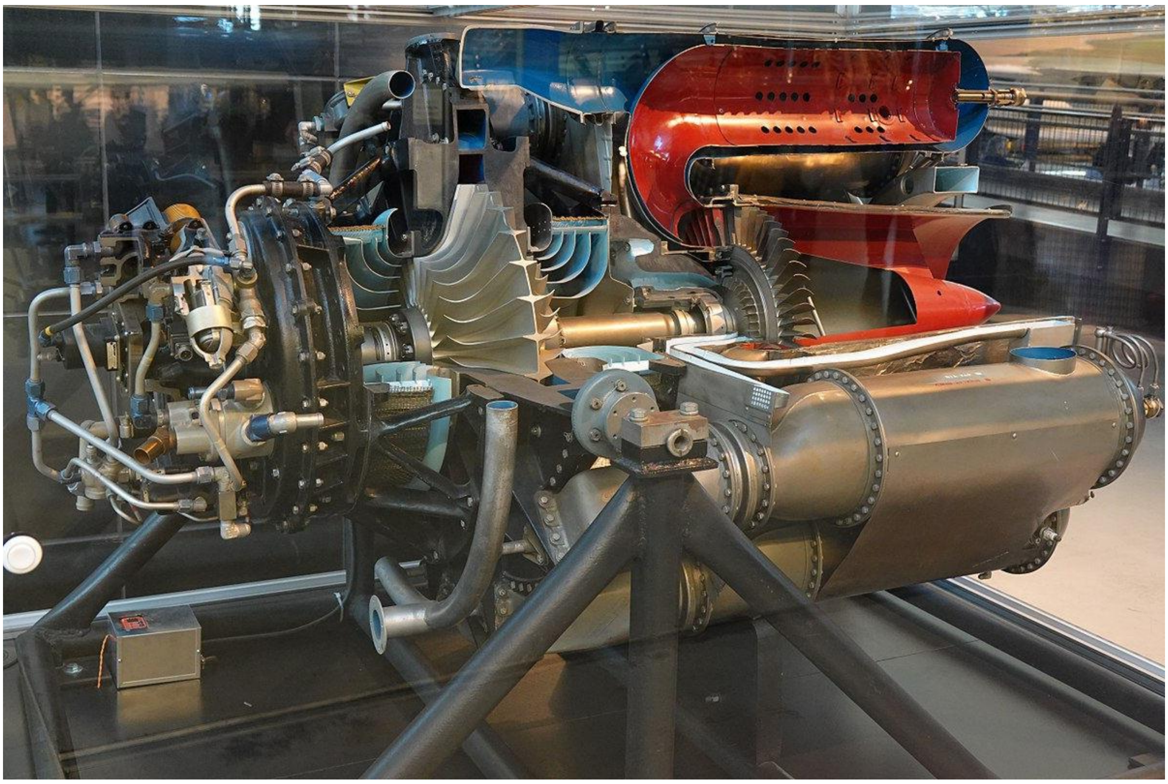


Compressore centrifugo

Compressore assiale

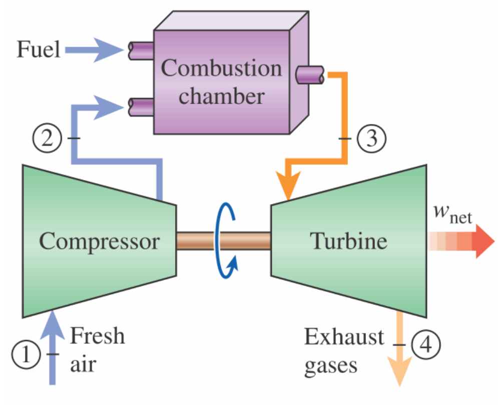
Turbogetto

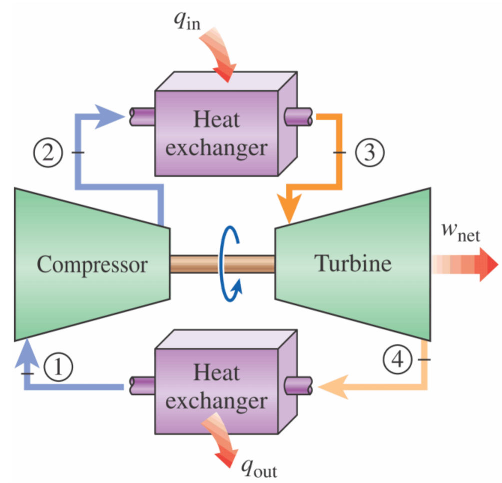
TurboJet

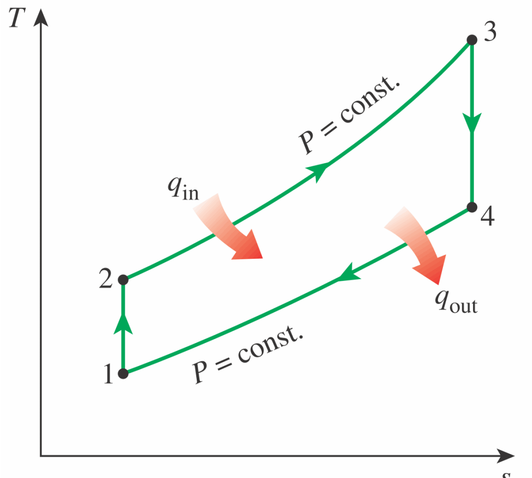


Ge J31. Peso 386*kg*, *L*=1.80*m*, *D*=1.05*m*, Fmax=7.33*kN*, $\dot{m}_a$=15*kg/s*, π_c=3.8, TSFC=0.12*kg/kNh.*

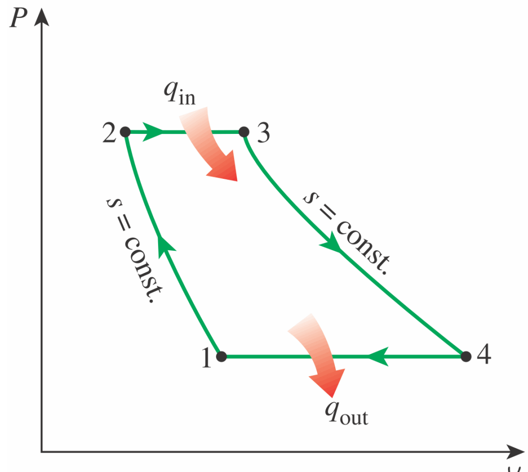
Ciclo Brayton







(*a*) *T*-*s* diagram



(*b*) *P*-*v* diagram

Rendimento del Ciclo Brayton

Il **rendimento** del ciclo si valuta come:

$$\eta_{th} = \frac{W_{net}}{Q_{in}} = \frac{Q_{in} - Q_{out}}{Q_{in}} = 1 - \frac{Q_{out}}{Q_{in}} =$$

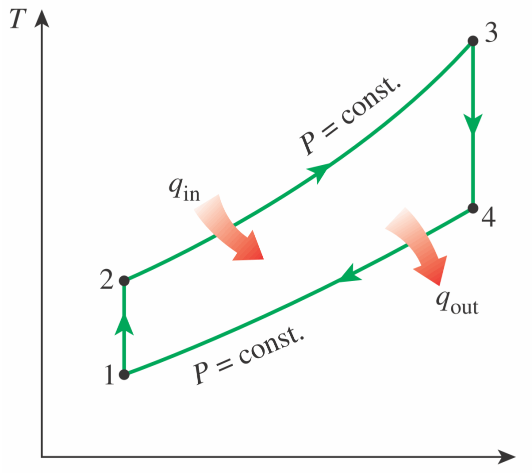
$$\eta_{th} = 1 - \frac{c_p(T_4 - T_1)}{c_p(T_3 - T_2)} = 1 - \frac{T_1(T_4/T_1 - 1)}{T_2(T_3/T_2 - 1)}$$

ma ($\tau_c = T_2/T_1, \ \pi_c = p_2/p_1$):

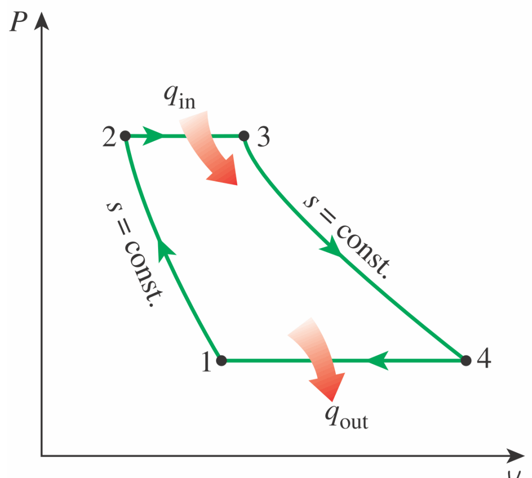
$$\tau_c = \frac{T_2}{T_1} = \left(\frac{p_2}{p_1}\right)^{\frac{\gamma-1}{\gamma}} = \left(\frac{p_3}{p_4}\right)^{\frac{\gamma-1}{\gamma}} = \frac{T_3}{T_4}$$

$$\frac{T_3}{T_2} = \frac{T_4}{T_1}$$

$$\eta_{th} = 1 - \frac{T_1}{T_2} = 1 - \frac{1}{\tau_c} = 1 - \frac{1}{\pi_c^{\frac{\gamma-1}{\gamma}}}$$



(*a*) *T*-*s* diagram

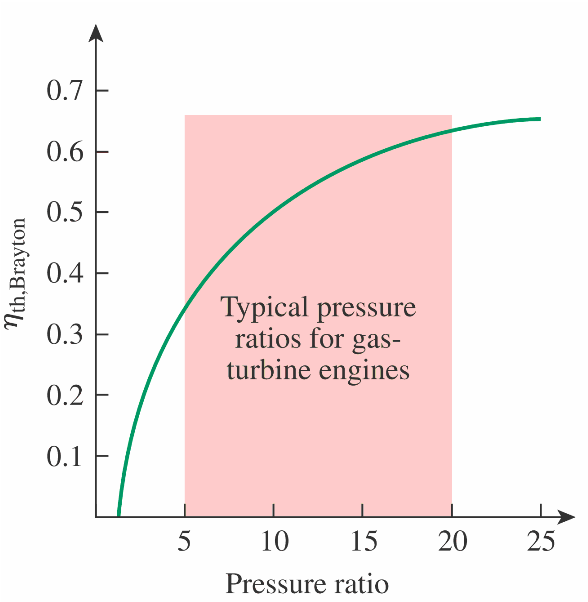


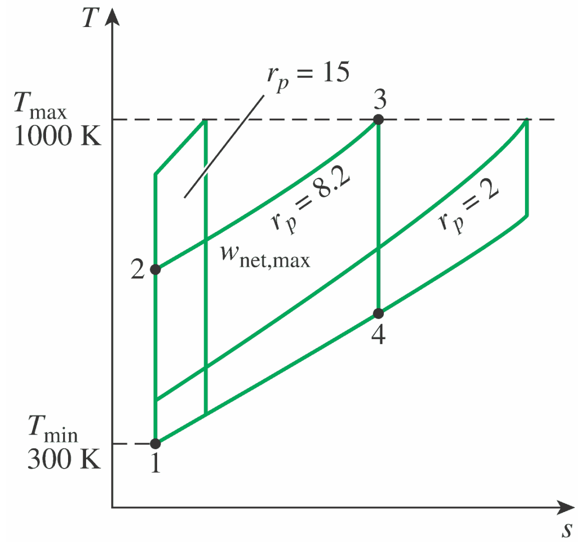
(*b*) *P*-*v* diagram

Rendimento del Ciclo Brayton

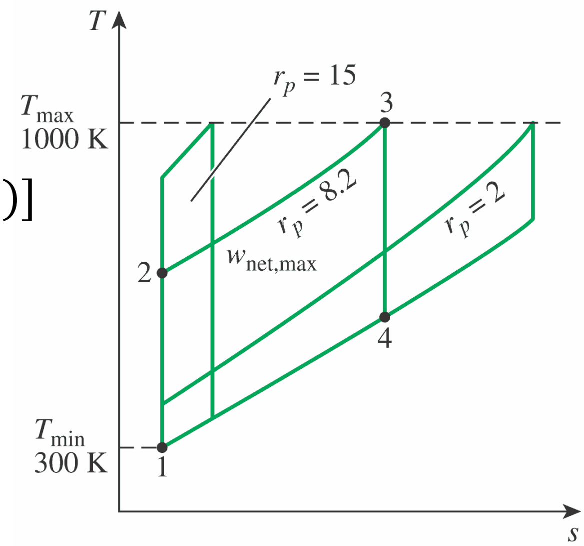
Il rendimento del ciclo è una funzione strettamente crescente del rapporto di pressioni nel compressore:

$$\eta_{th} = 1 - \frac{T_1}{T_2} = 1 - \frac{1}{\tau_c} = 1 - \frac{1}{\pi_c^{\frac{\gamma-1}{\gamma}}}$$





Rendimento del Ciclo Brayton



Il lavoro netto è:

$$W_{net} = Q_{in} - Q_{out} = c_p[(T_3 - T_2) - (T_4 - T_1)]$$

$$W_{net} = c_p T_1 \left[\frac{T_3}{T_1} - \tau_c - \frac{T_4}{T_1} + 1\right]$$

ma: $\frac{T_4}{T_1} = \frac{T_3}{T_2} = \frac{T_3}{T_1}\frac{T_1}{T_2} = \frac{T_3}{T_1}\frac{1}{\tau_c}$

$$W_{net} = c_p T_1 \left[\frac{T_3}{T_1}(1 - \tau_c^{-1}) + 1 - \tau_c\right]$$

$$W_{net} = c_p T_1 \left[\frac{T_3}{T_1}(1 - \tau_c^{-1}) + \tau_c(\tau_c^{-1} - 1)\right] = c_p T_1 \left[\left(\frac{T_3}{T_1} - \tau_c\right)(1 - \tau_c^{-1})\right]$$

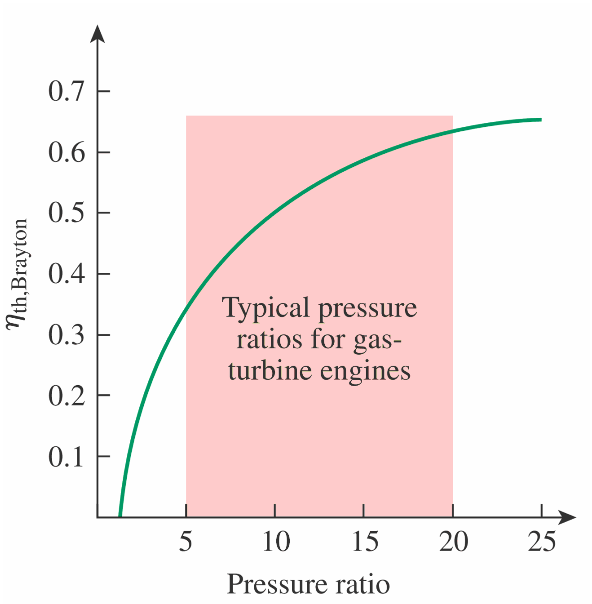
Derivando ed uguagliando a zero si ottiene:

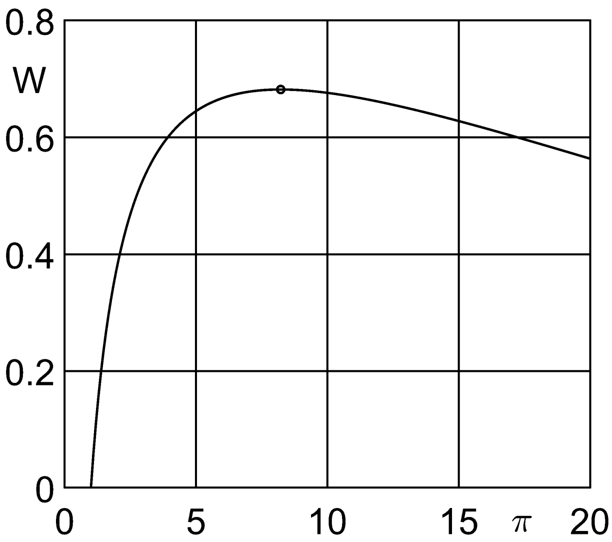
$$\frac{T_3}{T_1}\tau_{c_{max}}^{-2} = 1 \quad \rightarrow \quad \tau_{c_{max}} = \sqrt{\frac{T_3}{T_1}} \quad \rightarrow \quad \pi_{c_{max}} = \left(\frac{T_3}{T_1}\right)^{\frac{\gamma}{2(\gamma-1)}}$$

Rendimento del Ciclo Brayton

$$W_{net} = c_p T_1 \left[\left(\frac{T_3}{T_1} - \tau_c \right) (1 - \tau_c^{-1}) \right] \qquad \pi_{c_{max}} = \left(\frac{T_3}{T_1} \right)^{\frac{\gamma}{2(\gamma-1)}}$$

$$\eta_{th} = 1 - \frac{1}{\tau_c} = 1 - \frac{1}{\pi_c^{\frac{\gamma-1}{\gamma}}}$$

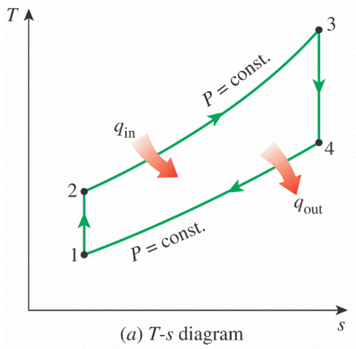




Prese d'aria

I **requisiti primari** delle prese d'aria (Fig A380) sono:

- **convogliare** l'aria al motore in quantità sufficiente ed al giusto numero di Mach in tutte le condizioni di volo;
- **minimizzare** le **perdite** di pressione di ristagno;
- produrre un flusso "**pulito**" (spazialmente uniforme e stazionario) all'ingresso del **compressore**.



(*a*) *T-s* diagram

Prese d'aria

I **requisiti primari** delle prese d'aria sono:

- **convogliare** l'aria al motore in quantità sufficiente ed al giusto numero di Mach in tutte le condizioni di volo;
- **minimizzare** le **perdite** di pressione di ristagno;
- produrre un flusso "**pulito**" (spazialmente uniforme e stazionario) all'ingresso del **compressore**.

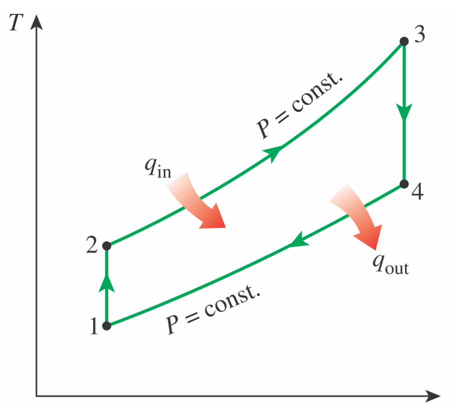
A questi si aggiungono altri requisiti come:

- basso costo e peso;
- buona integrazione aerodinamica per ridurre la **resistenza** di **installazione**;
- **riduzione del rumore**.

In regime **supersonico** le cose si complicano.

In figura quella dell' Eurofighter Typhoon

Compressori



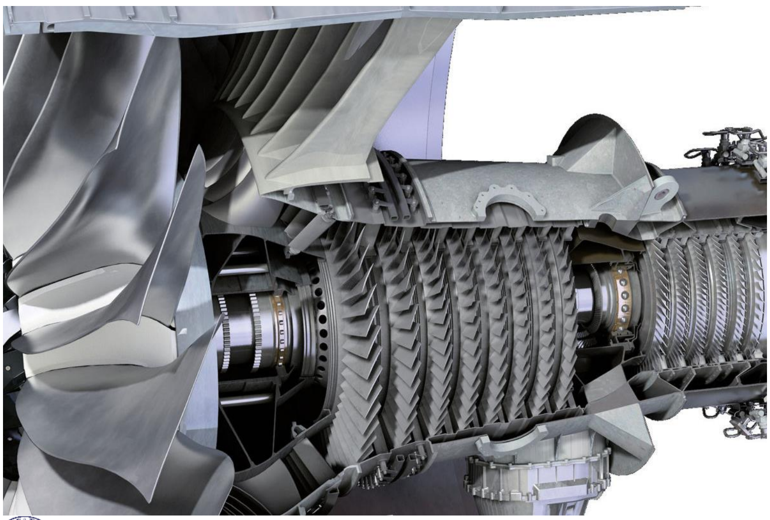
(*a*) *T-s* diagram

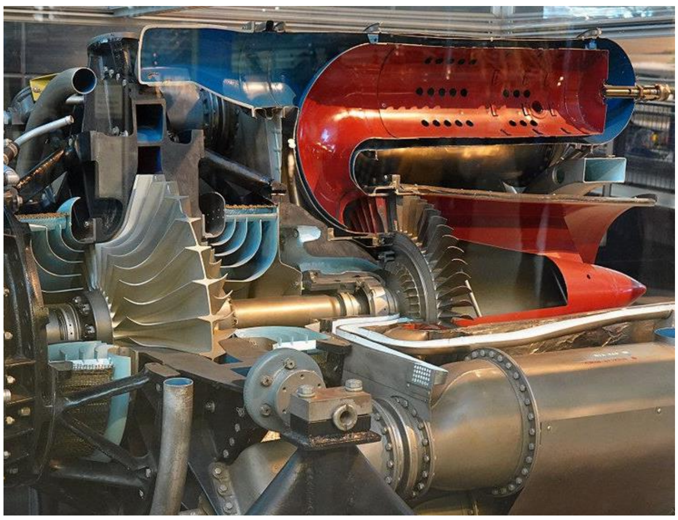
I **requisiti primari** dei compressori sono:

- comprimere l'aria a monte della CC;
- **minimizzare** le **perdite** di pressione di ristagno;

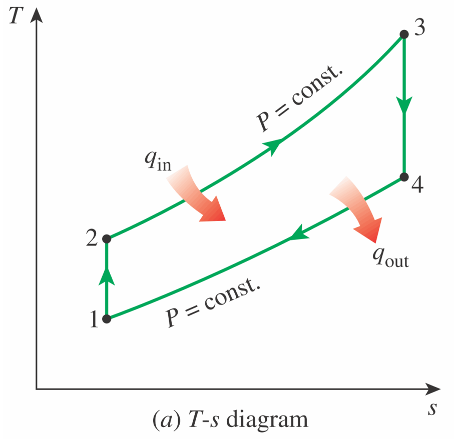
I compressori possono essere:

- **assiali** se il moto è in direzione assiale;
- **centrifughi** se il moto ruota e diventa ortogonale all'asse.



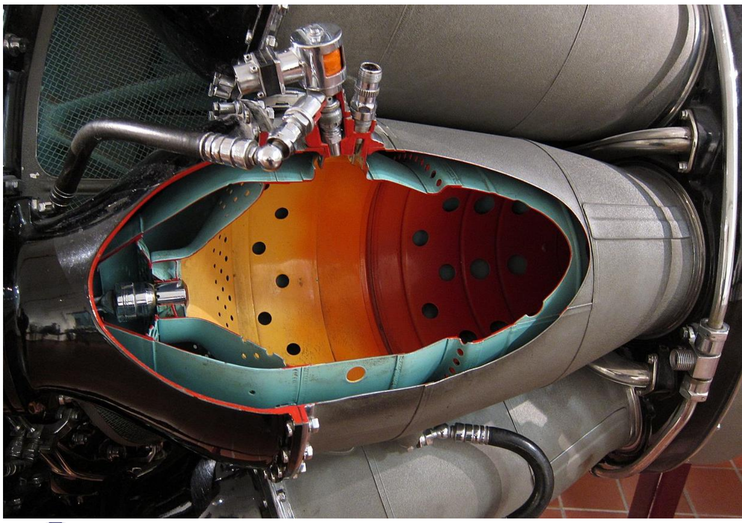


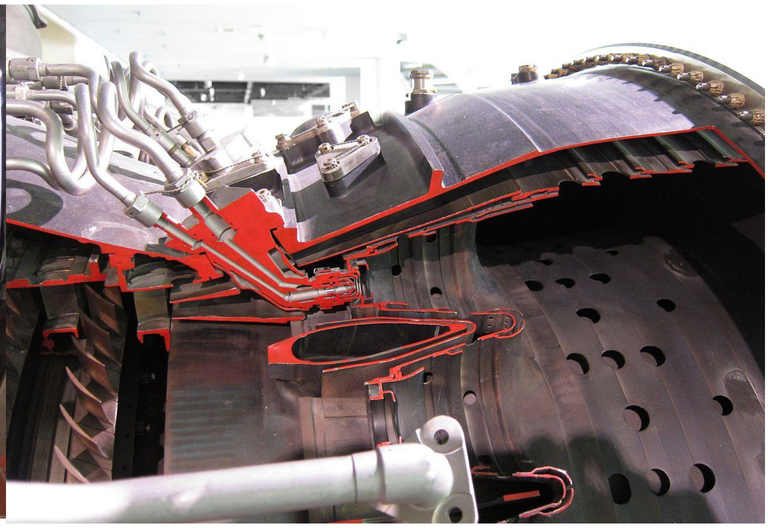
Camere di combustione



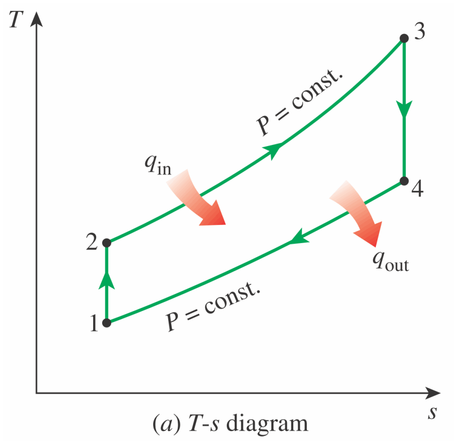
I **requisiti primari** delle camere di combustione sono:

- avere una **combustione** completa e **stabile**;
- **minimizzare** le **perdite** di pressione di ristagno;
- assenza di "punti caldi";
- alta **affidabilità**.





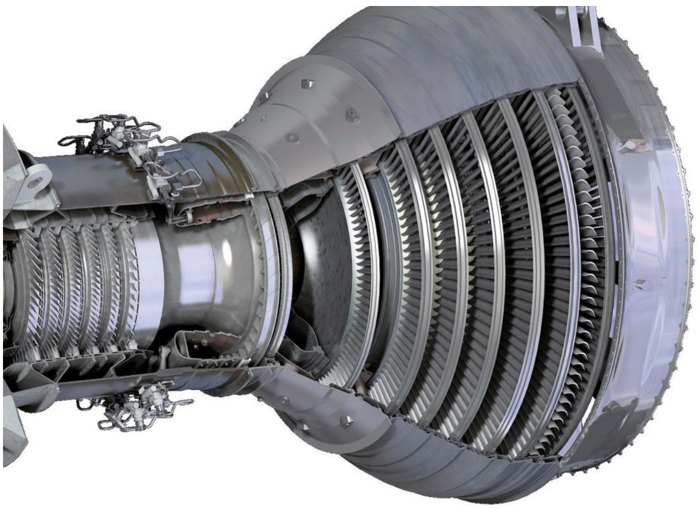
Turbine

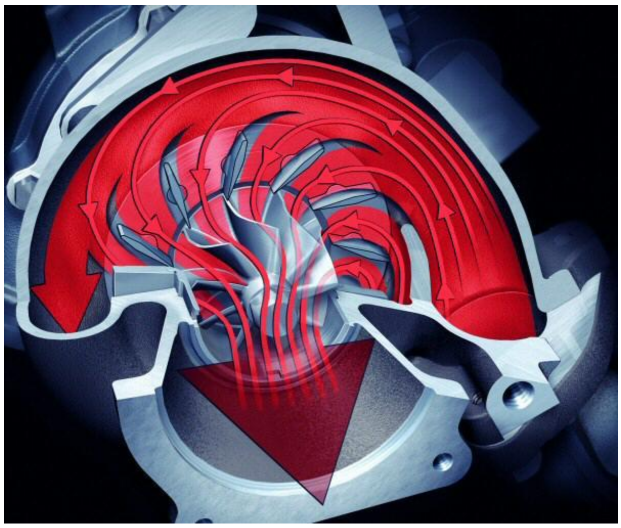


I **requisiti primari** delle turbine sono:

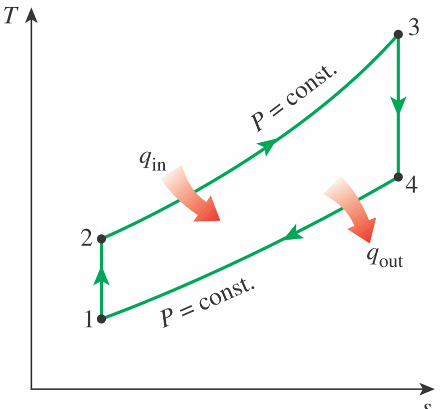
- estrarre energia dal flusso per alimentare il compressore;
- **minimizzare** le **perdite** di pressione di ristagno;

I primi stadi delle turbine sono soggetti ad alte temperature e pressioni e necessitano di un raffreddamento attivo.





Ugelli



(a) T-s diagram

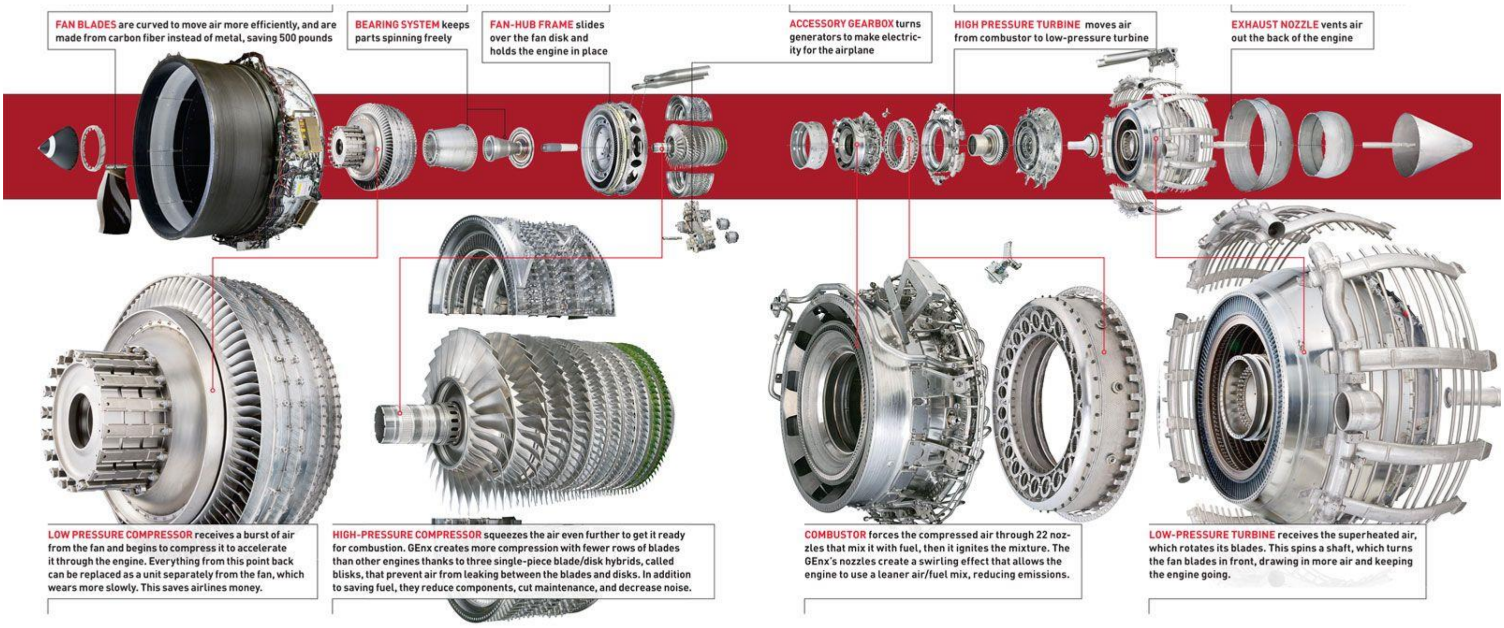
I **requisiti** primari degli ugelli sono:

- **espandere** i gas minimizzando le perdite;
- basso costo e peso;
- ridurre la **resistenza** di **installazione**;
- riduzione del **rumore** (Fig. B787);
- efficiente Inversione della spinta (Fokker 100).

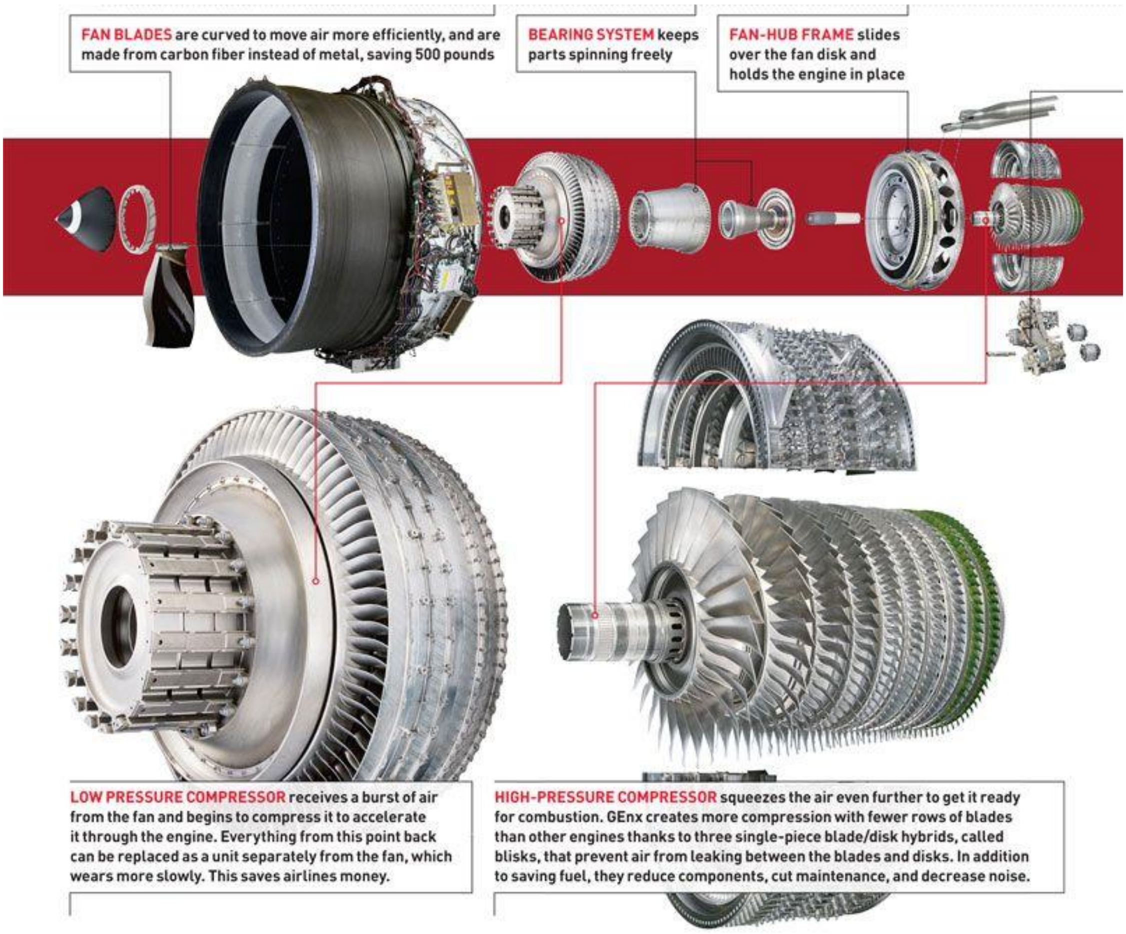
Componenti

Componenti

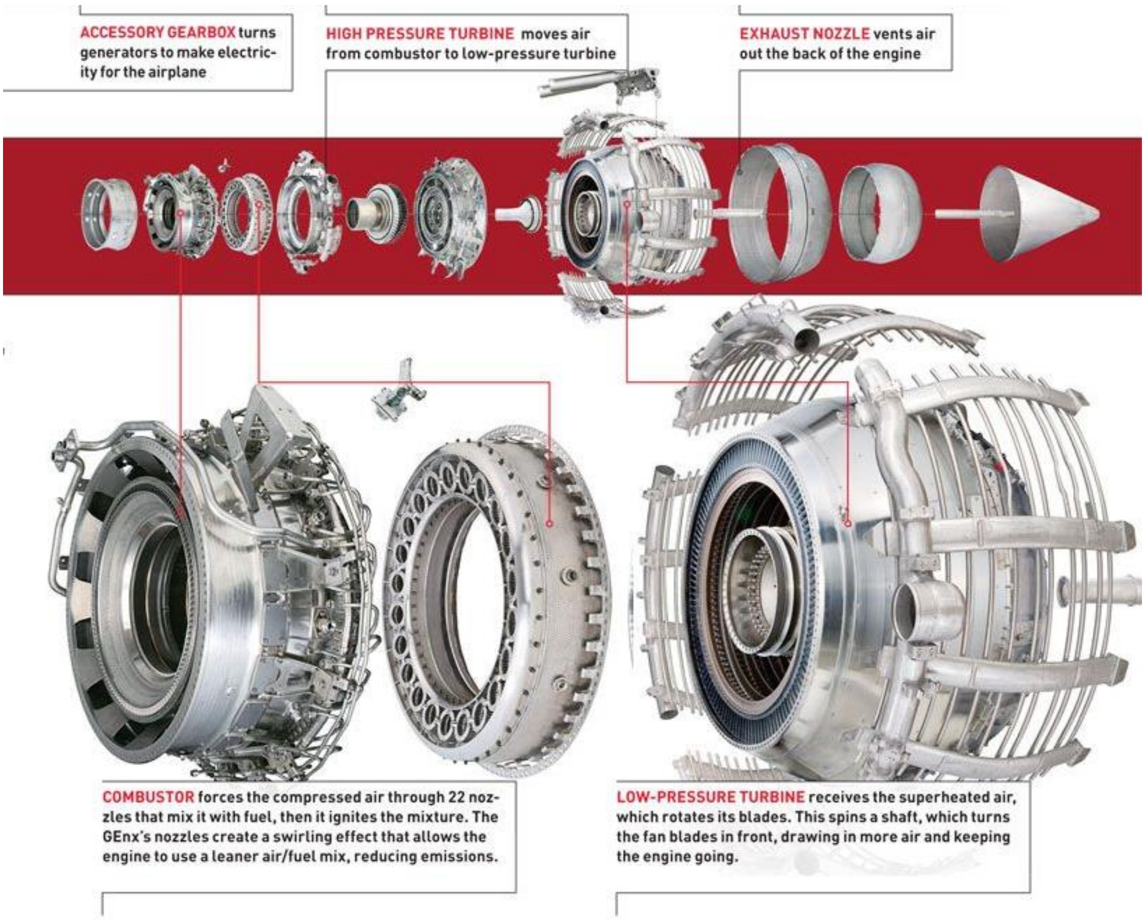
Vista esplosa del GEnX B787



Componenti

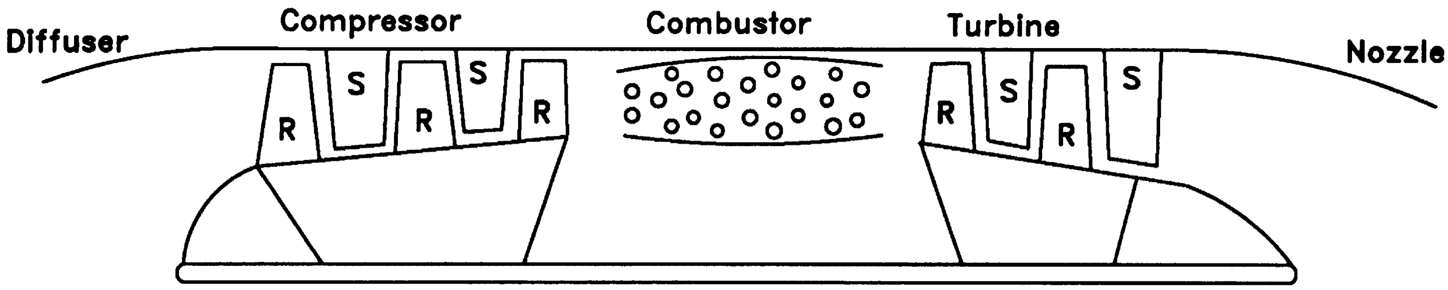


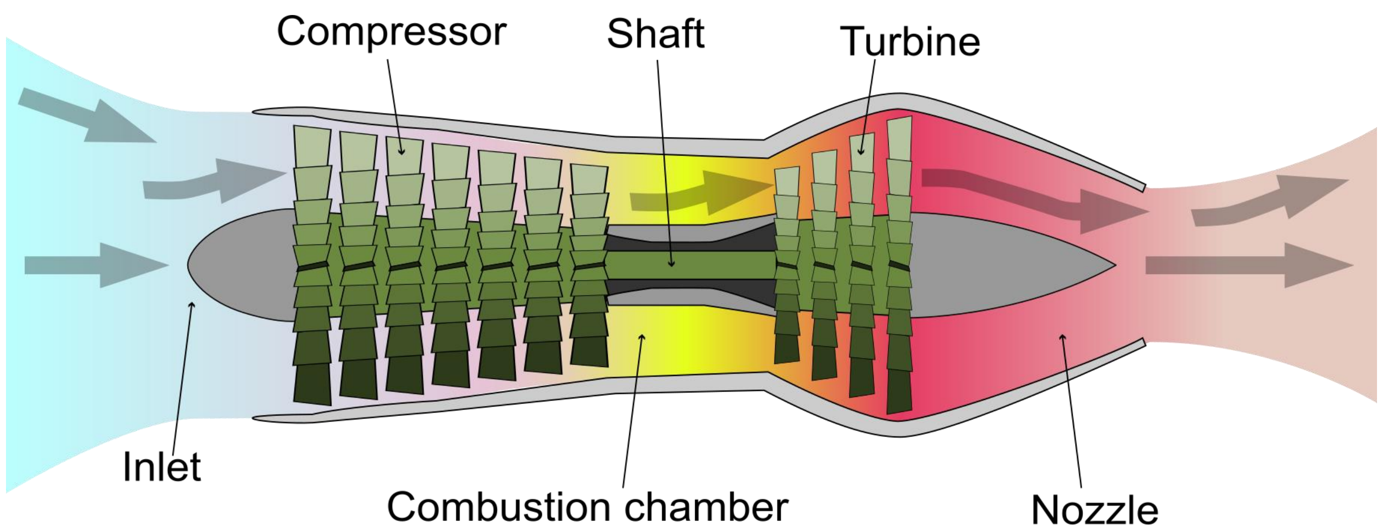
Componenti



Turbogetto mono albero

TurboJet

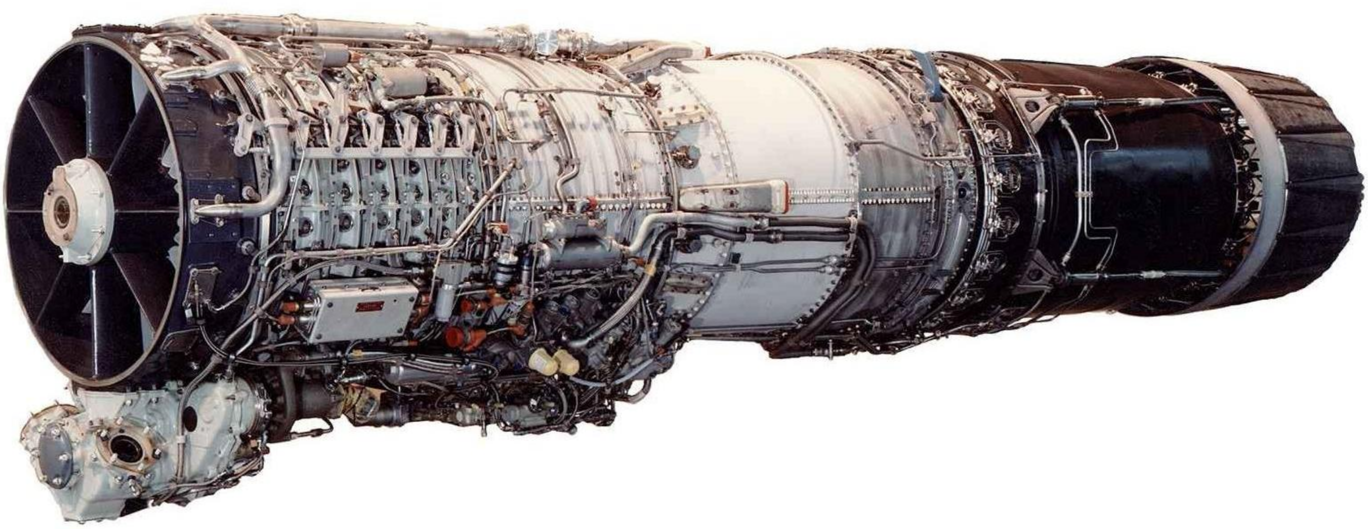




Configurazione con compressore assiale ed **albero singolo** (single-shaft o single-spool).

Turbogetto

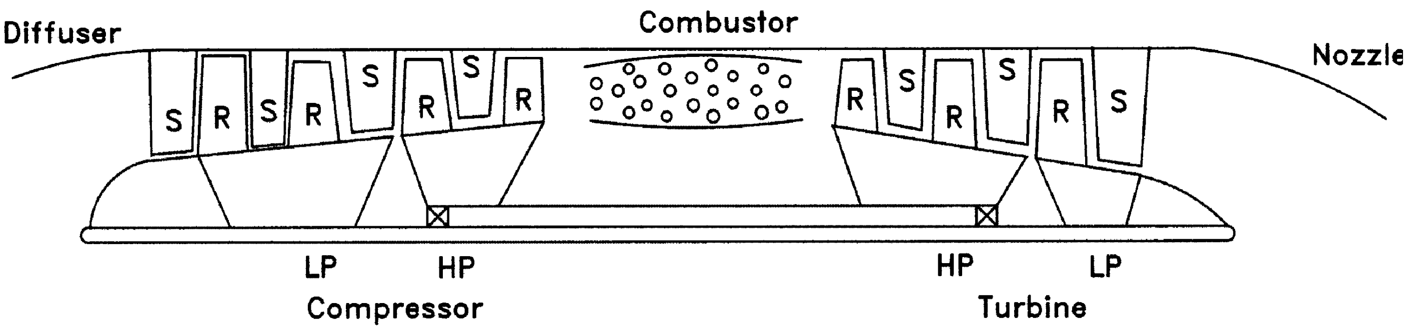
TurboJet

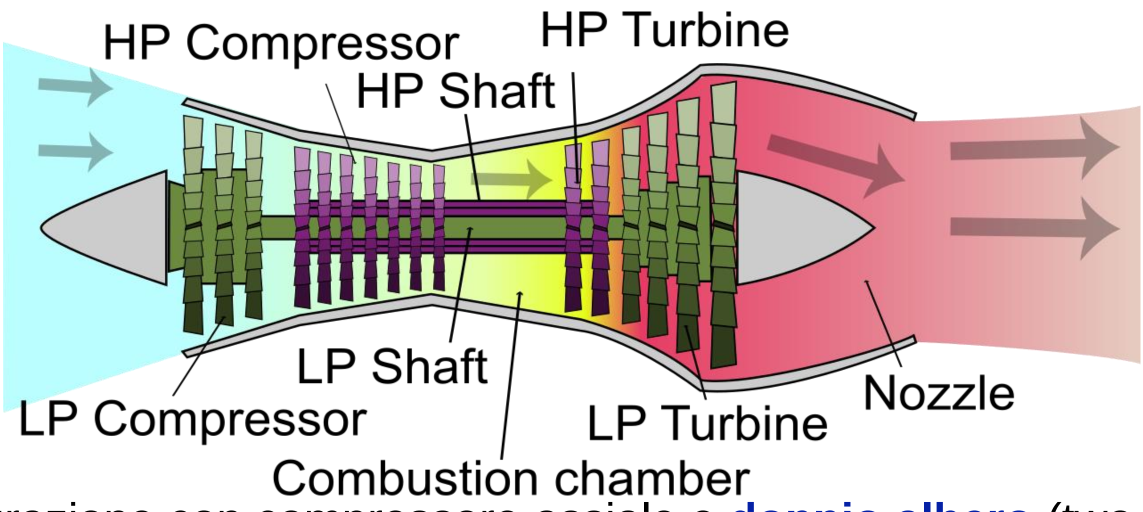


Ge J79-17 (F104). Peso 1750*kg*, *L*=5.30*m*, *D*=0.98*m*, *Fmax*=52.96 (79.33)*kN*, $\dot{m}_a$=77*kg/s*, π_c=15.5, TSFC=87 (200)*kg/kNh*. In parentesi i dati relativi al post bruciatore acceso.

Turbogetto doppio albero

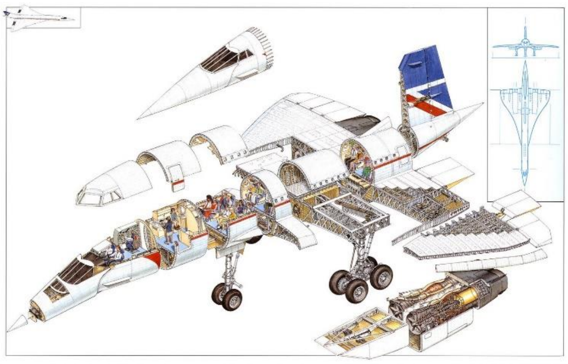
TurboJet

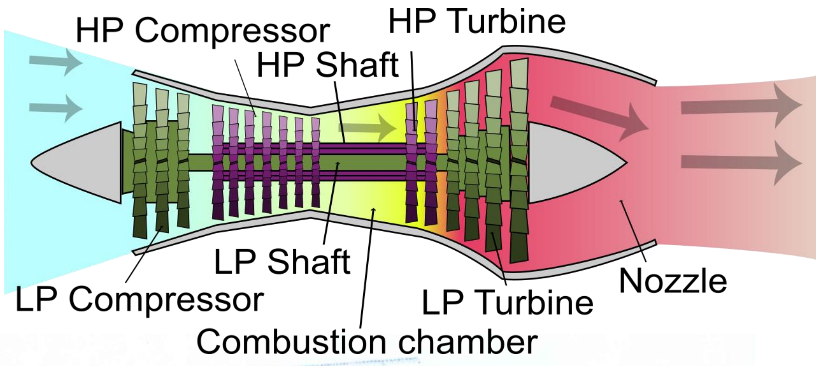


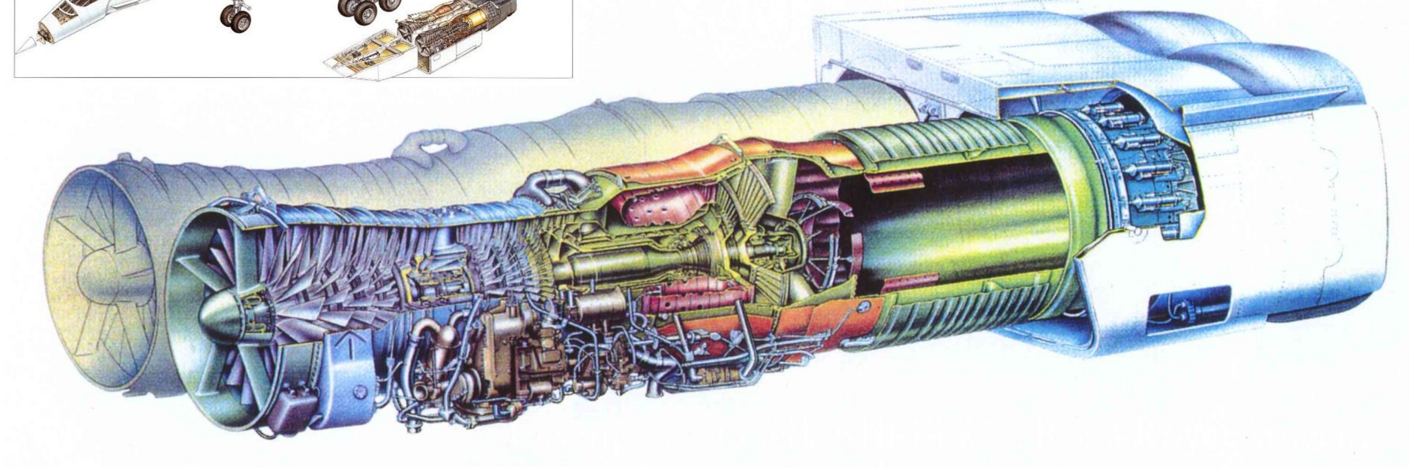


Configurazione con compressore assiale e **doppio albero** (two-spool o twin-spool).

Turbogetto doppio albero

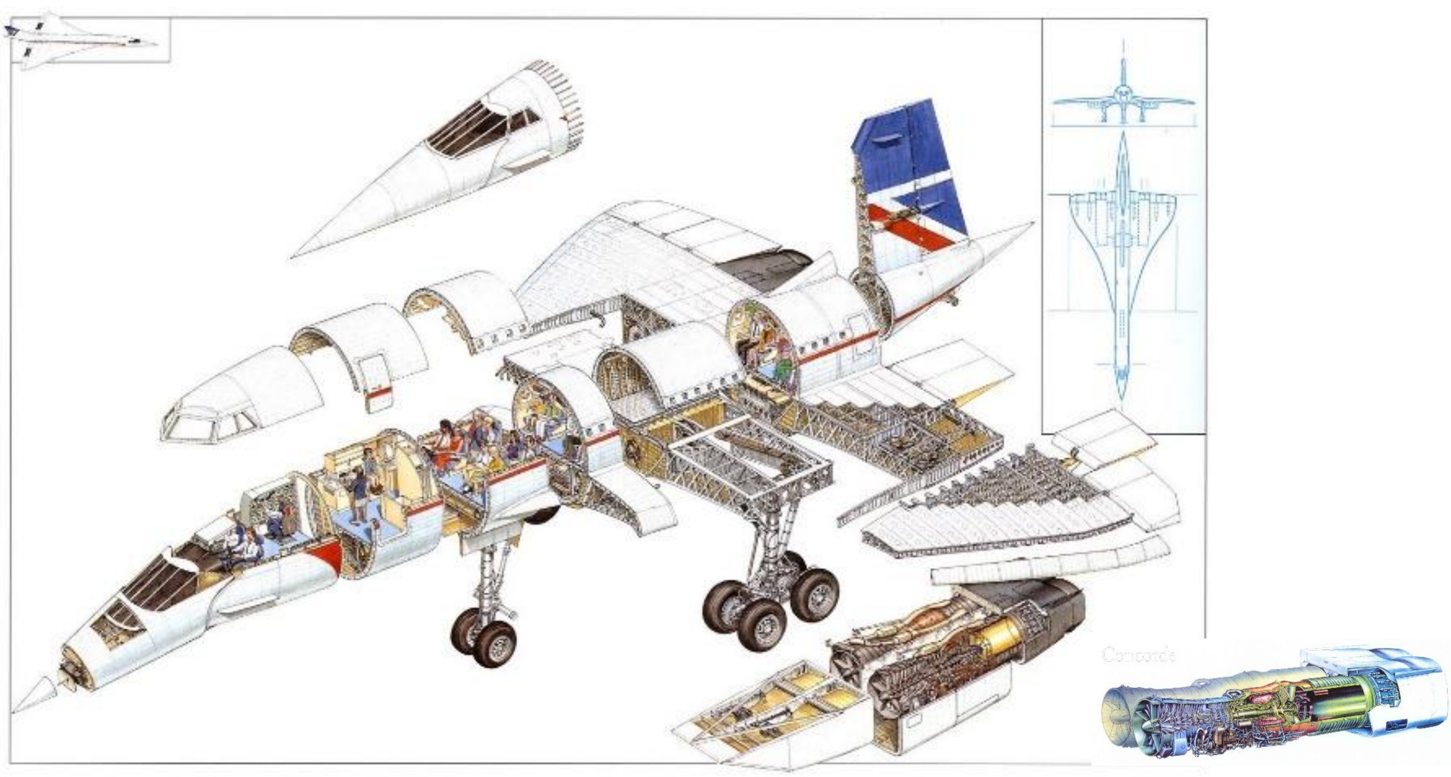






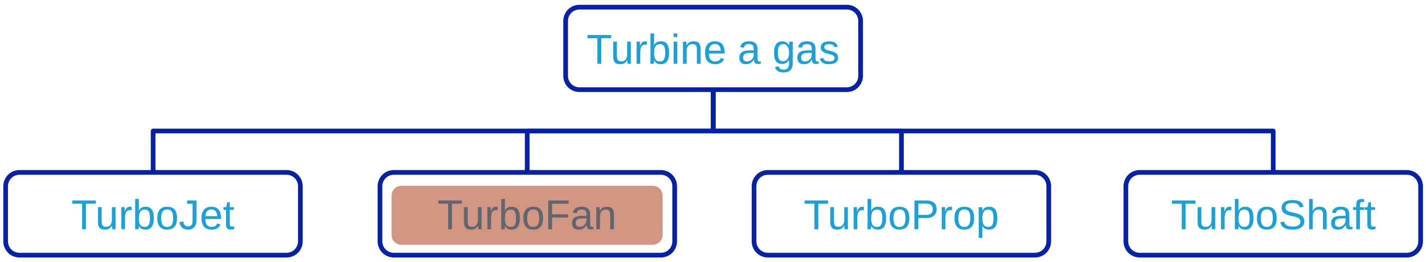
Olympus 593 (concorde). Peso 3175*kg*, *L*=4.04*m*, *D*=1.21, *Fmax*=139 (169)*kN*, $\dot{m}_a$=186*kg/s*, π_c=15.5, *TSFC*=121 (140)*kg/kNh*. In parentesi i dati relativi al post bruciatore acceso.

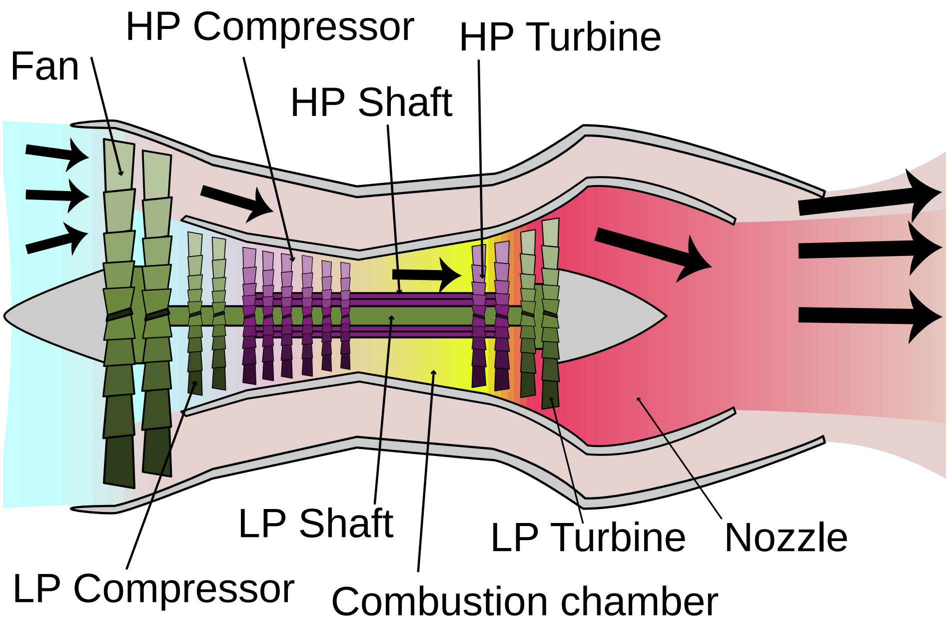
Turbogetto doppio albero



Olympus 593 (concorde). Peso 3175*kg*, *L*=4.04*m*, *D*=1.21, *Fmax*=139 (169)*kN*, $\dot{m}_a$=186*kg/s*, π_c=15.5, *TSFC*=121 (140)*kg/kNh*. In parentesi i dati relativi al post bruciatore acceso.

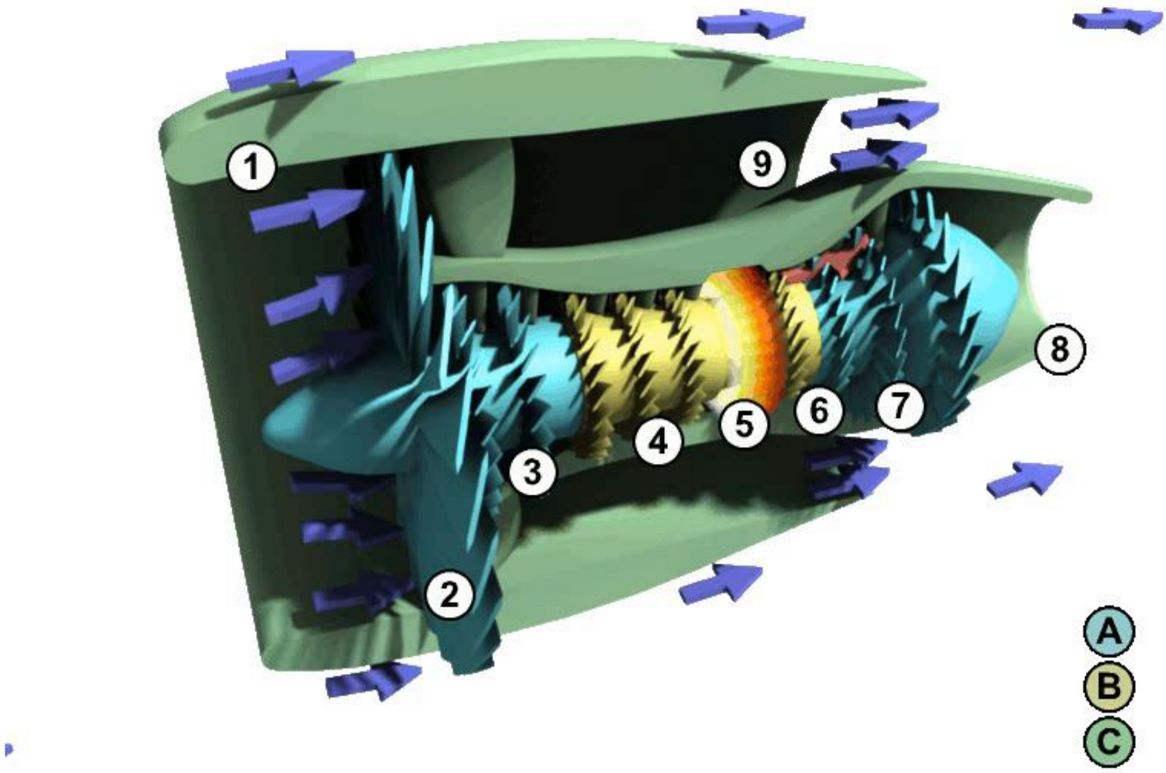
TurboFan





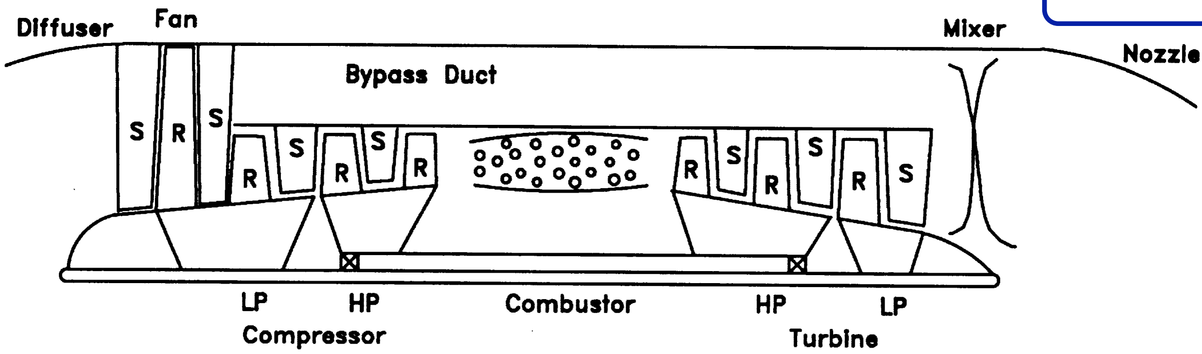
TurboFan

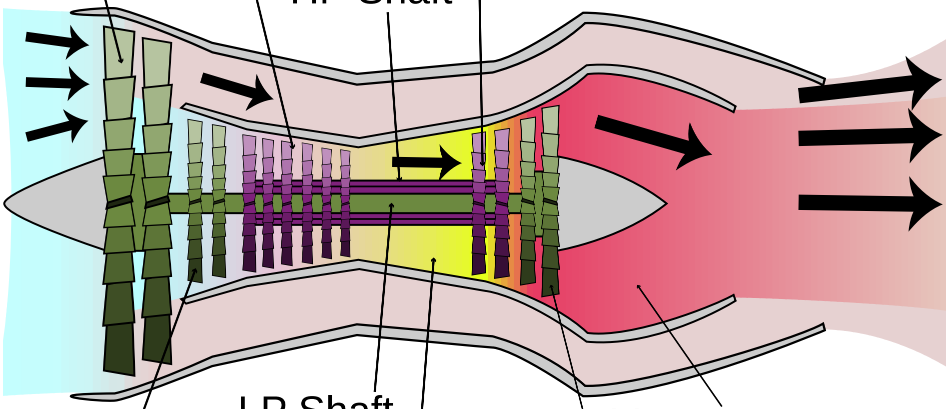
TurboFan



TurboFan a flussi miscelati

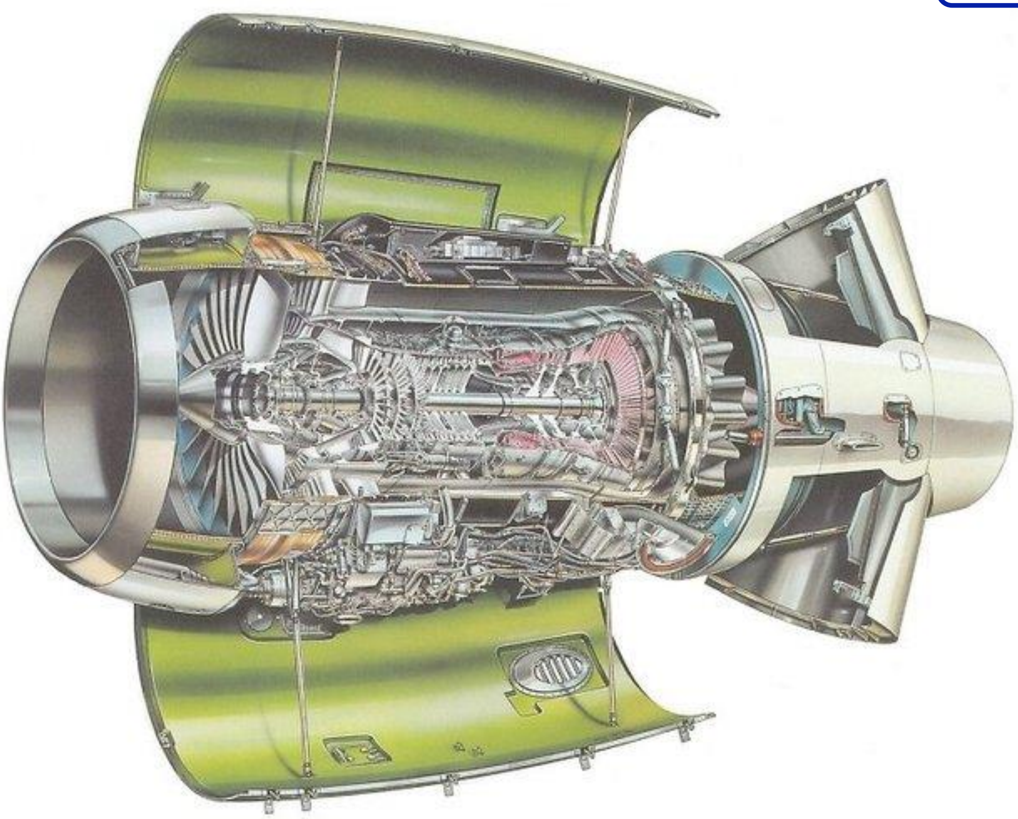
TurboFan





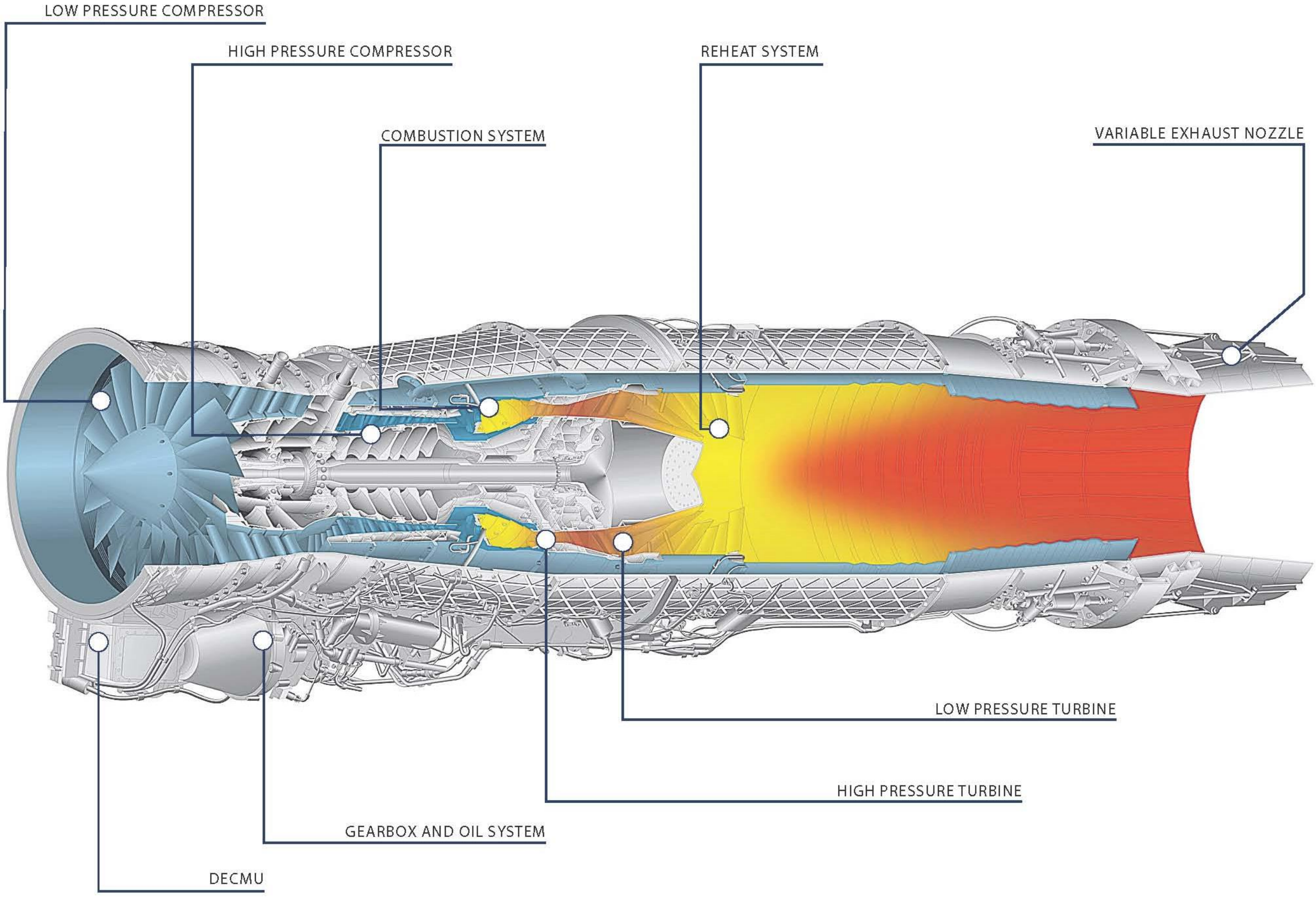
TurboFan a flussi miscelati

TurboFan



Pratt & Whitney JT8D (B737, MD80). Peso 2150*kg*, *L*=3.9*m*, *D*=1.25*m*, *Fmax*=93*kN*, $\dot{m}_a$=213*kg*/*s*, α=1.77, π_c=19, *Comp* 1/6/7, Turb 1/3.

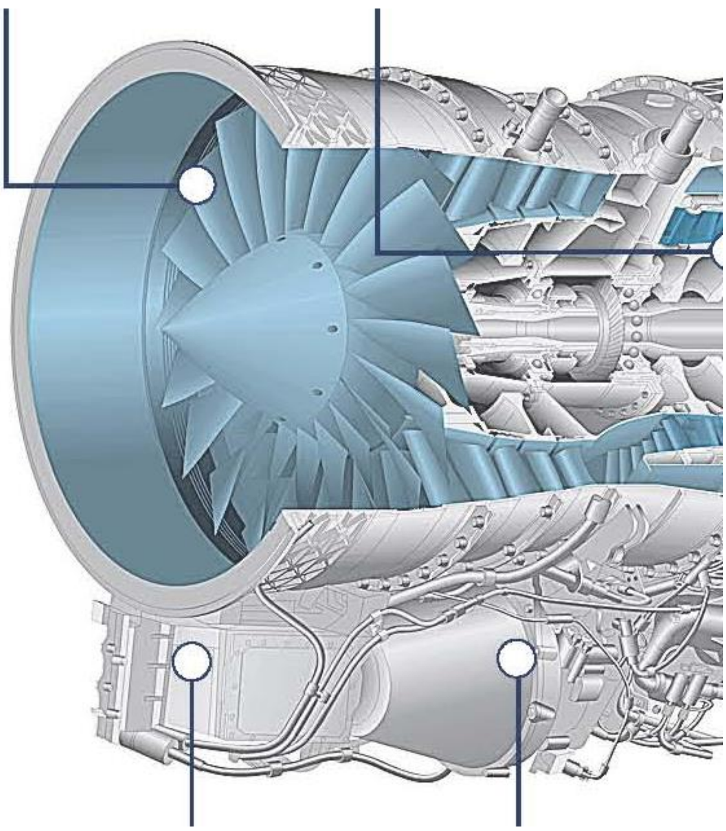
EuroJet EJ200



EuroJet EJ200

LOW PRESSURE COMPRESSOR

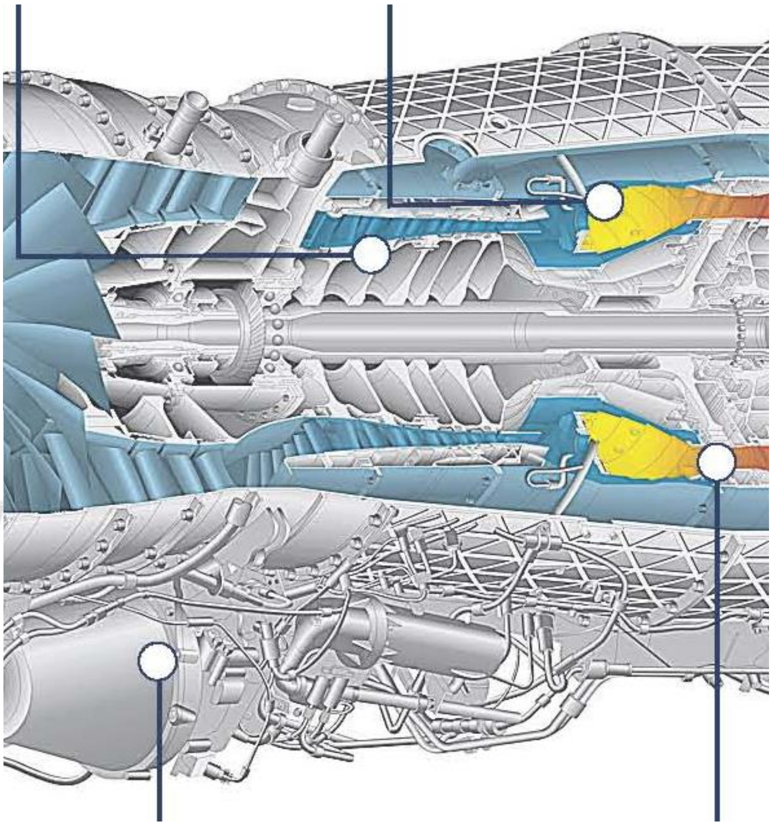
The LP compressor is a 3-stage, FOD-tolerant axial flow unit with a very high pressure ratio (4.2:1). It is an all-blisk (integrally bladed disc) design featuring wide chord aerofoils attached by advanced linear friction welding techniques and operates without the need for inlet guide vanes.



EuroJet EJ200

HIGH PRESSURE COMPRESSOR

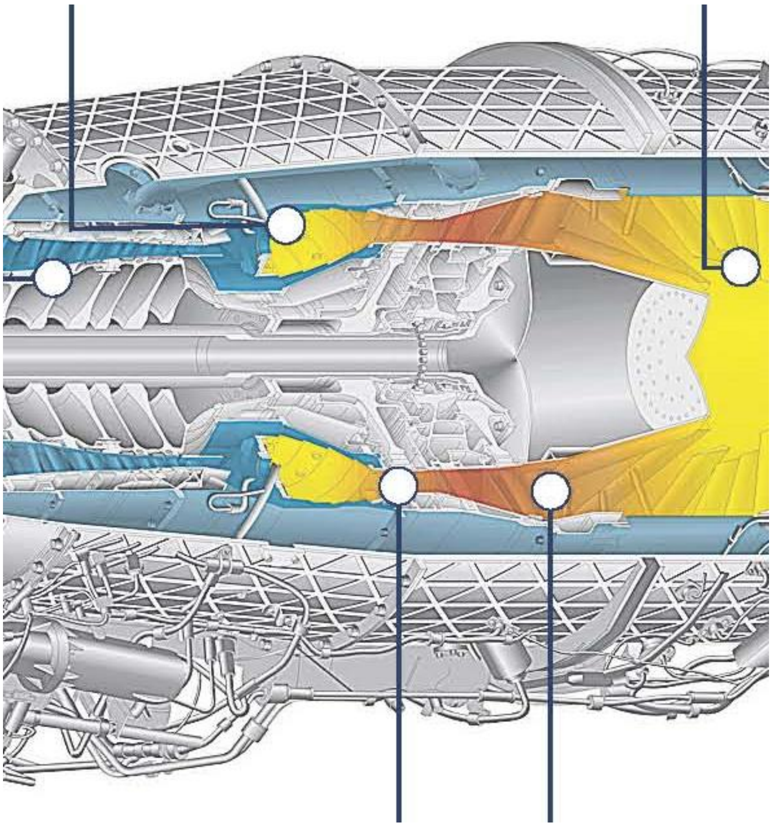
The axial flow HP compressor consists of 5 stages, delivering a pressure increase of 6.2:1 [overall the EJ200 compression system delivers 26:1 in only 8 stages] with a high surge margin and only 1 set of variable inlet guide vanes.



EuroJet EJ200

COMBUSTION SYSTEM

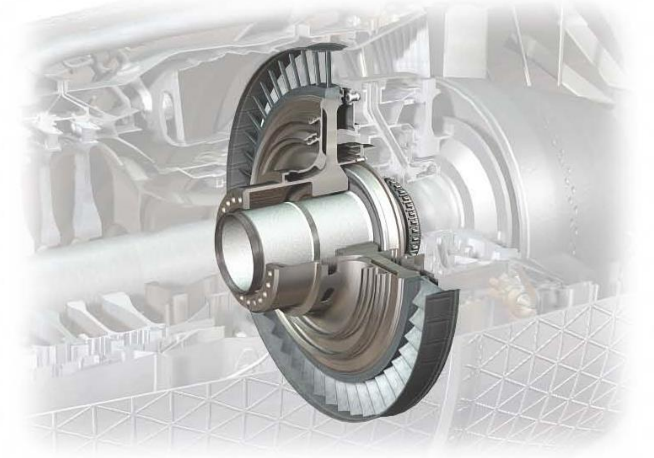
The annular combustor is a very compact design employing latest technology features to achieve extremely demanding requirements in terms of emissions (zero visible smoke), combustion stability / handling, efficiency and life. Features include advanced air spray fuel injectors with preferential fuelling, film cooling & thermal barrier coating and fuel boroscope access.

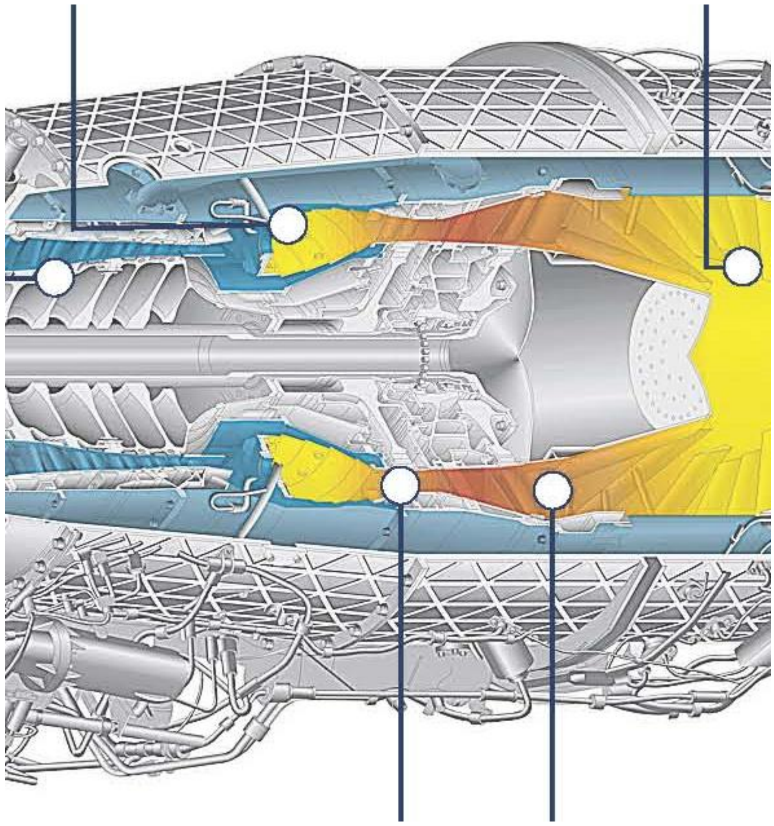


EuroJet EJ200

HIGH PRESSURE TURBINE

The HP turbine is a single-stage, shroudless design using 3-D, single-crystal, nickel alloy aerofoils with advanced internal and film cooling, ensuring long life, low blade numbers and high levels of performance. Tip clearance control is also employed to maintain efficiency. Turbine blade temperature is measured using an optical pyrometer, which is linked to the digital engine control and monitoring unit (DECMU). Plasma-sprayed thermal barrier coatings are used on liners and vanes.

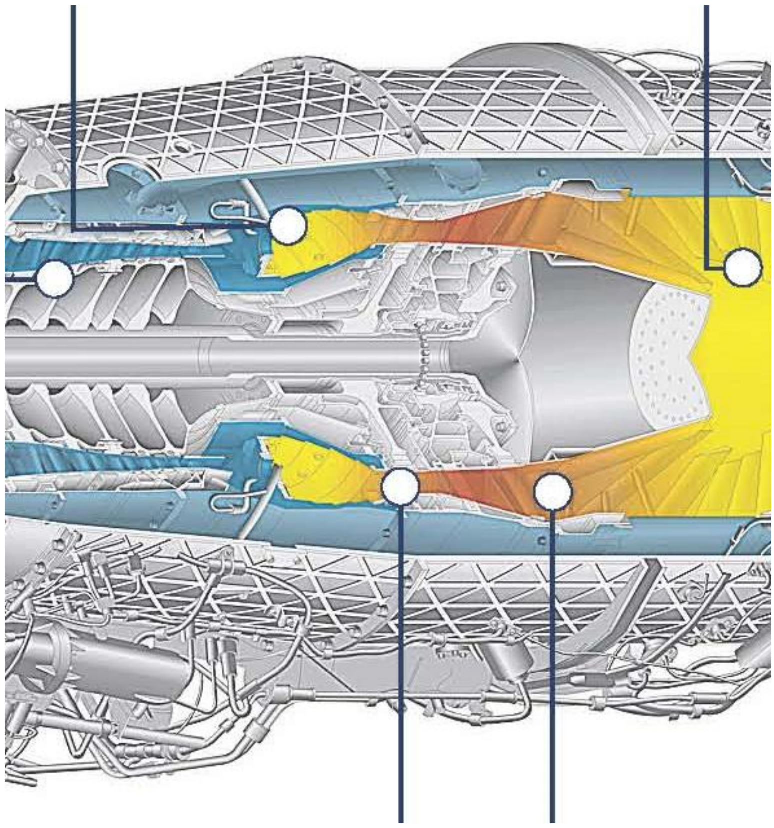




EuroJet EJ200

LOW PRESSURE TURBINE

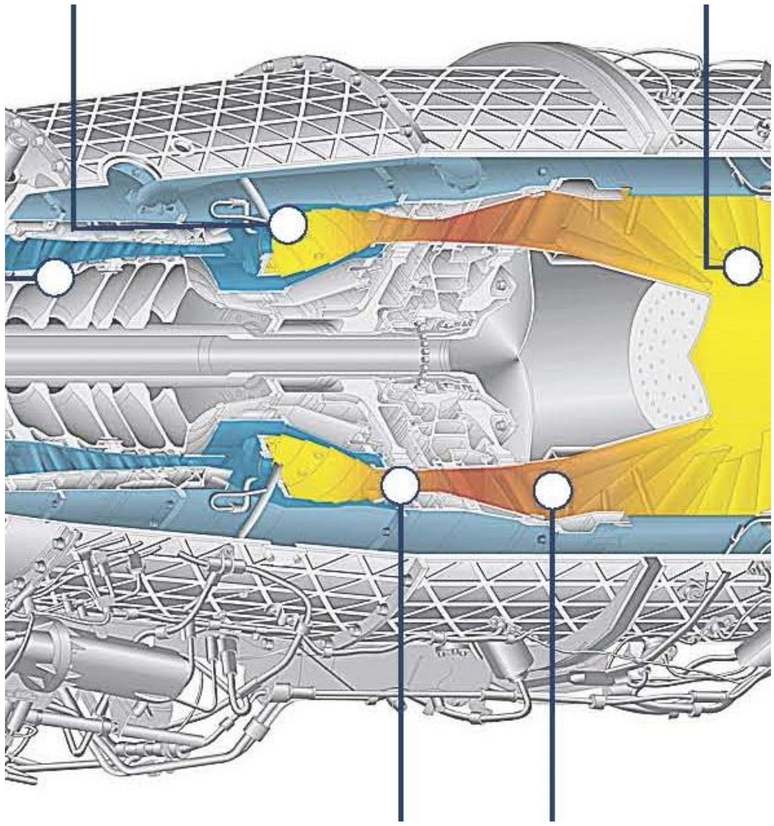
The LP turbine is a single-stage shrouded design chosen for its high efficiency and performance retention characteristics. Single-crystal, cooled turbine blades are used in the turbine rotor and thermal barrier coatings are used on static components (vanes). As with the HP turbine, this unit represents a step change from previous designs.



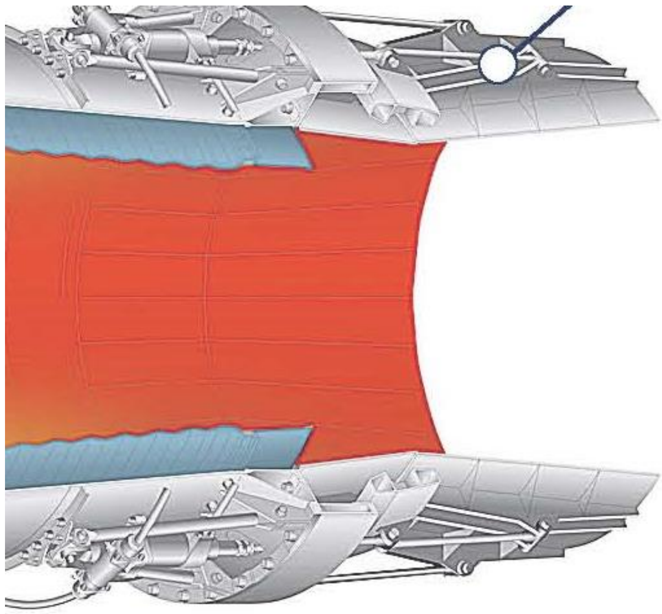
EuroJet EJ200

REHEAT SYSTEM

The advanced-staged afterburner system uses radial burners and primary vaporisers in the hot stream and fuel injection in the cold stream to give very high combustion efficiency over the operational range. The three burners are independently supplied with fuel, giving continuous and smooth modulation between minimum and maximum reheat. The design achieves smooth selection, low smoke and maximum thrust boost whilst minimizing instabilities.

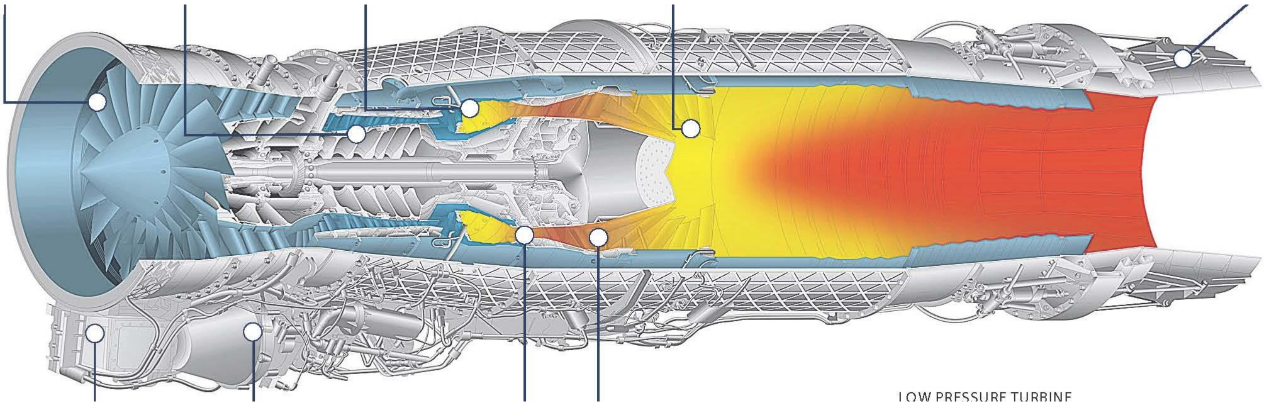


EuroJet EJ200



RESSURE TURBINE

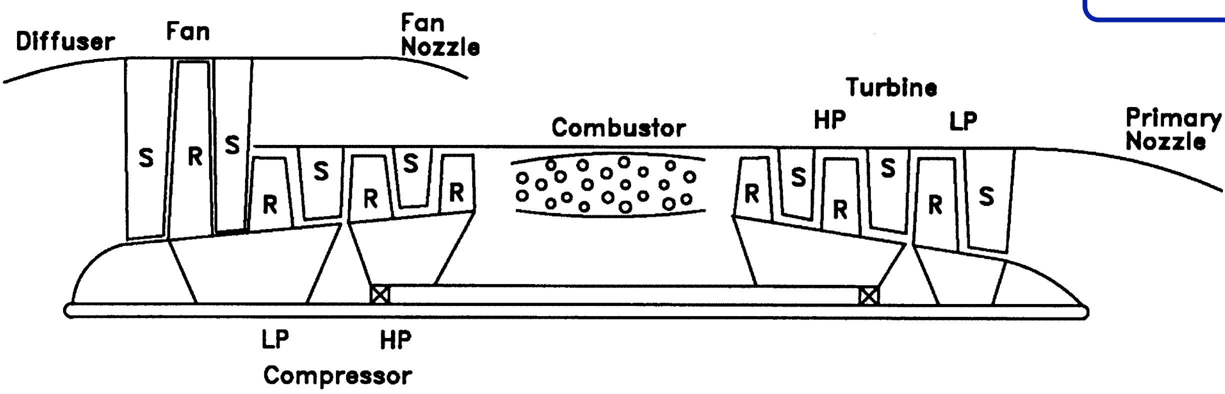
EuroJet EJ200

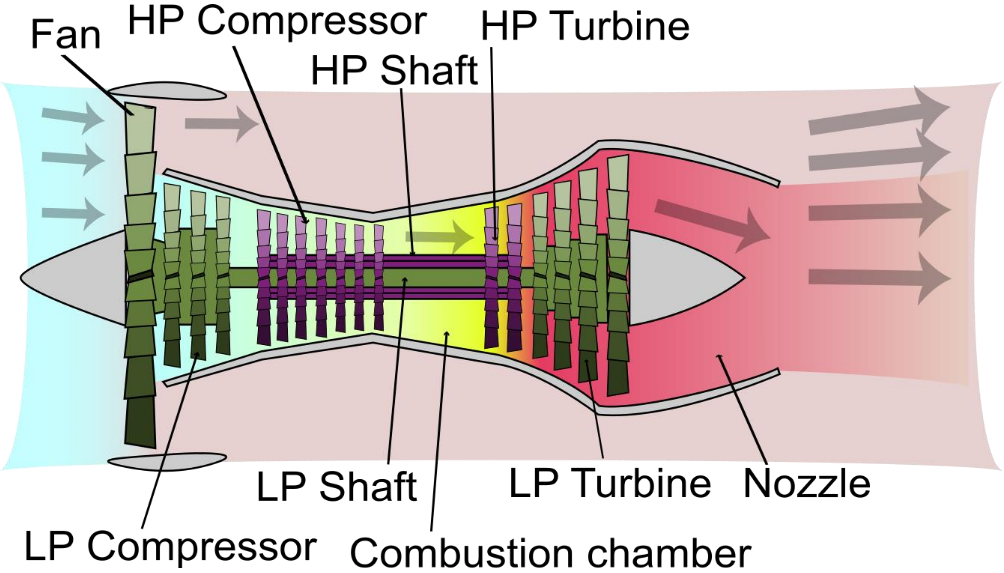


EJ200 engine specifications (uninstalled, ISA, SLS)		
Max. thrust, reheated	90 kN	20,000 lbf
Max. thrust, dry	60 kN	13,500 lbf
Pressure ratio	26:1	26:1
Fan pressure ratio	4.2:1	4.2:1
Bypass ratio	0.4:1	0.4:1
Overall pressure ratio	26:1	26:1
Specific fuel consumption		
Reheated	47–49 g/kNs	1.66–1.73 lb/lbf hr
Dry	21–23 g/kNs	0.74–0.81 lb/lbf hr
Air flow rate	75–77 kg/s	165–170 lb/s
Length (incl. afterburner)	approx. 4,000 mm	approx. 157 in
Inlet Diameter	740 mm	29 in
Weight (incl. afterburner)	appr. 1000 kg	appr. 2.200 lbs

TurboFan a flussi separati

TurboFan





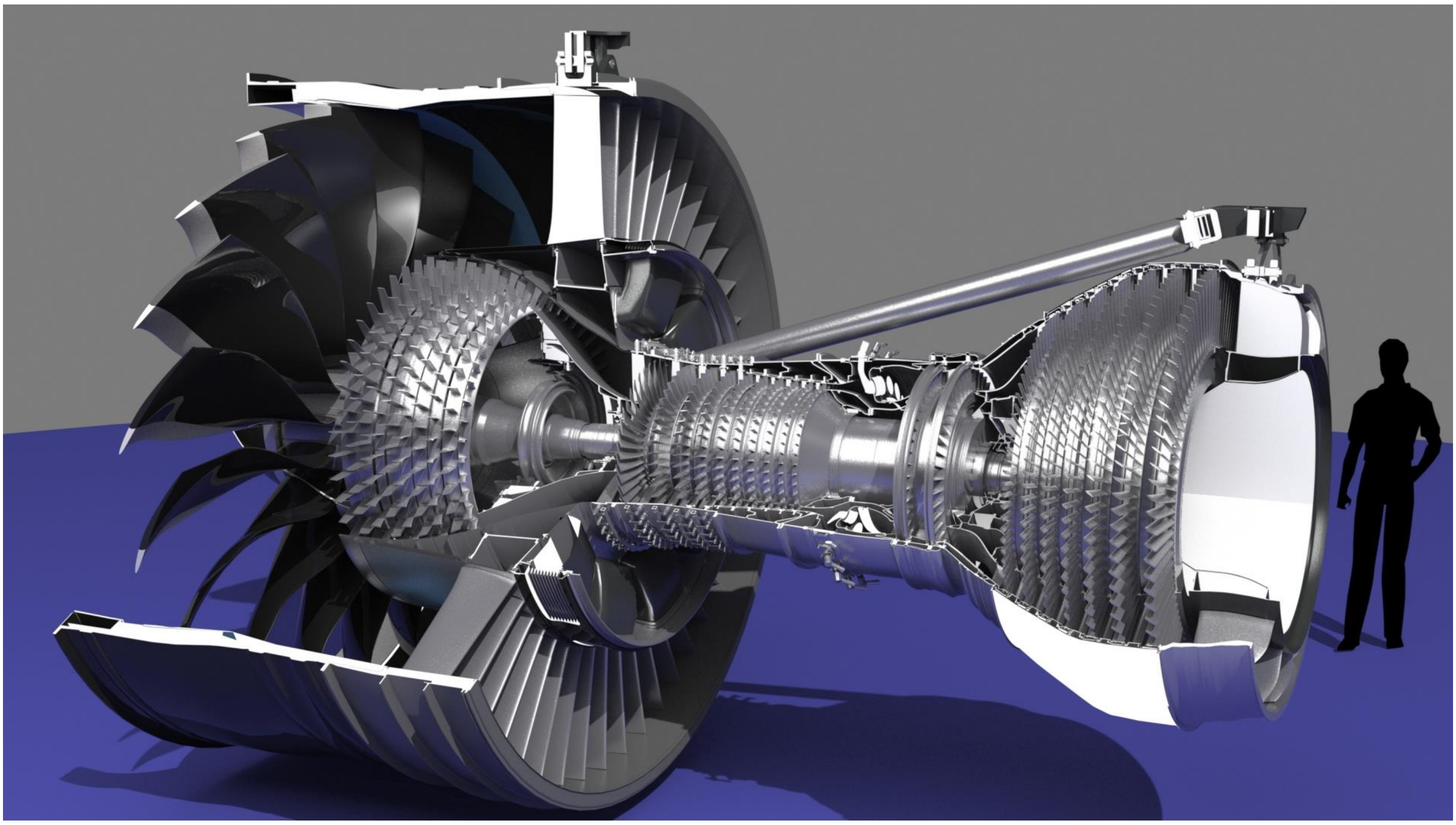
TurboFan a flussi separati

GEnX(787, 747). Peso 6150*kg*, *L*=4.7*m*, *D*=2.82*m*, *Fmax*=330*kN*, $\dot{m}_a$=1200*kg/s*, α=9.1, π_c=46, Comp 1/4/10, Turb 2/7.

TurboFan a flussi separati

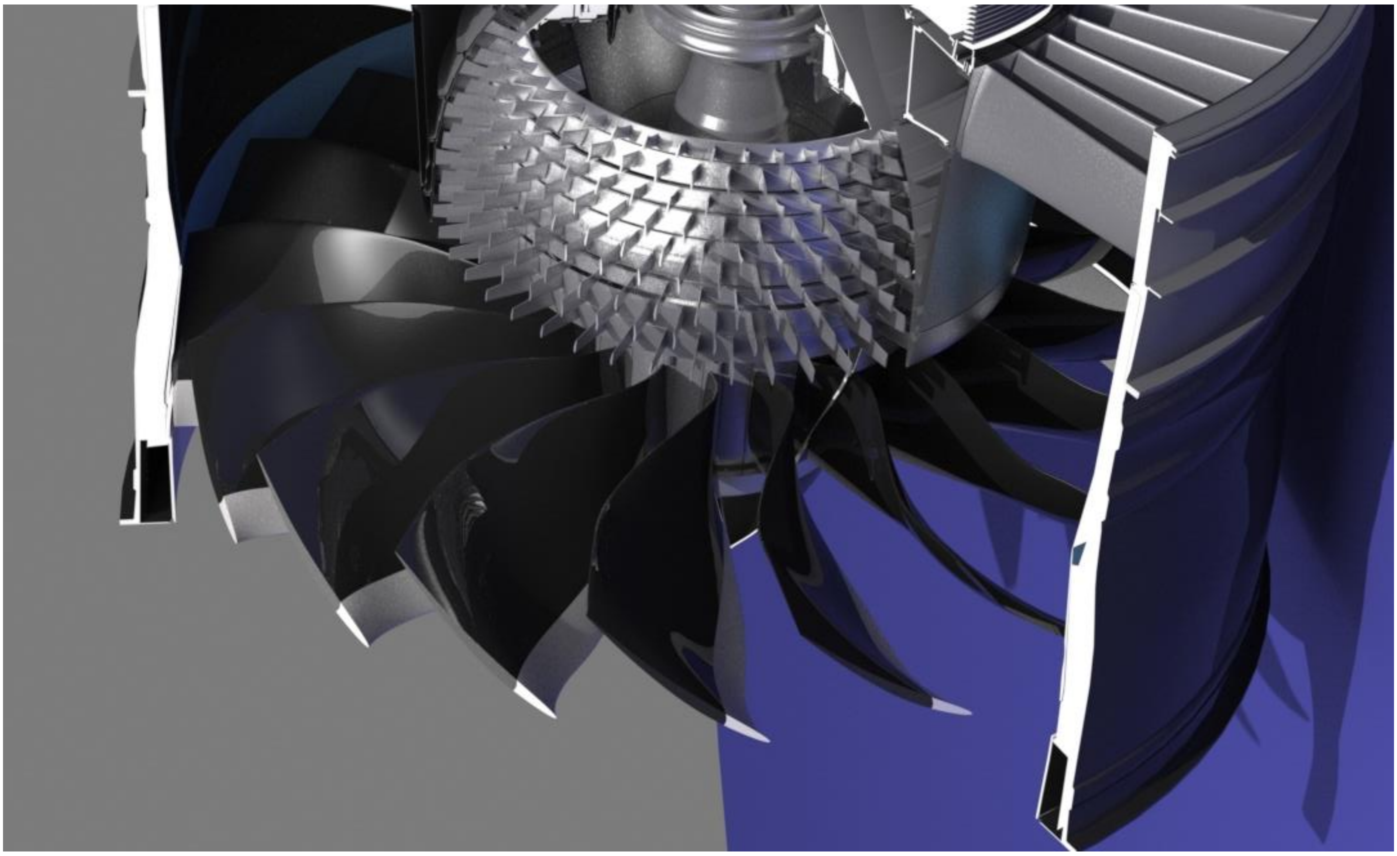
GEnX(787, 747). Peso 6150*kg*, *L*=4.7*m*, *D*=2.82*m*, *Fmax*=330*kN*, $\dot{m}_a$=1200*kg/s*, α=9.1, π_c=46, Comp 1/4/10, Turb 2/7.

TurboFan a flussi separati



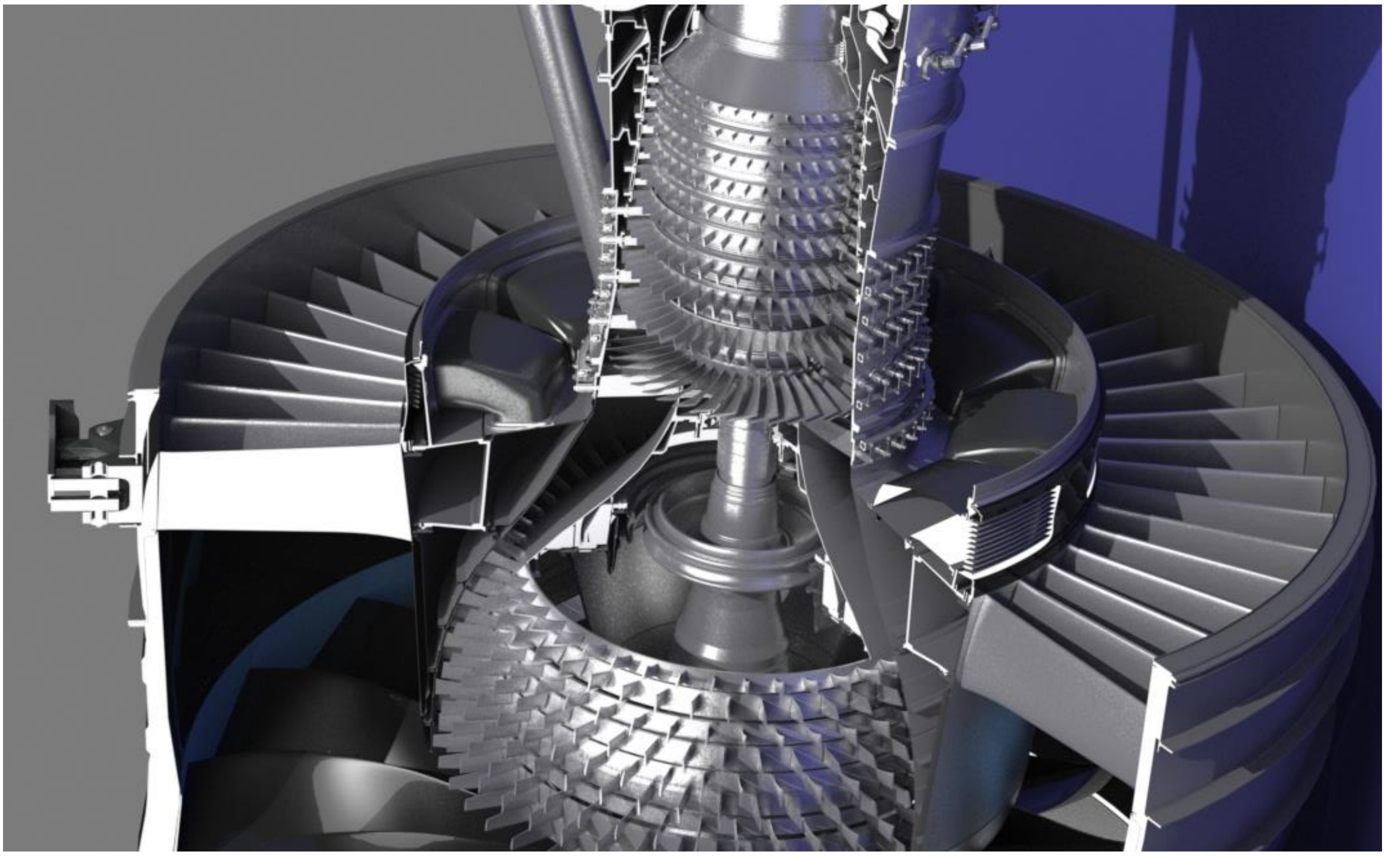
GEnX(787, 747). Peso 6150*kg*, *L*=4.7*m*, *D*=2.82*m*, *Fmax*=330*kN*, $\dot{m}_a$=1200*kg*/*s*, α=9.1, π_c=46, Comp 1/4/10, Turb 2/7.

TurboFan a flussi separati



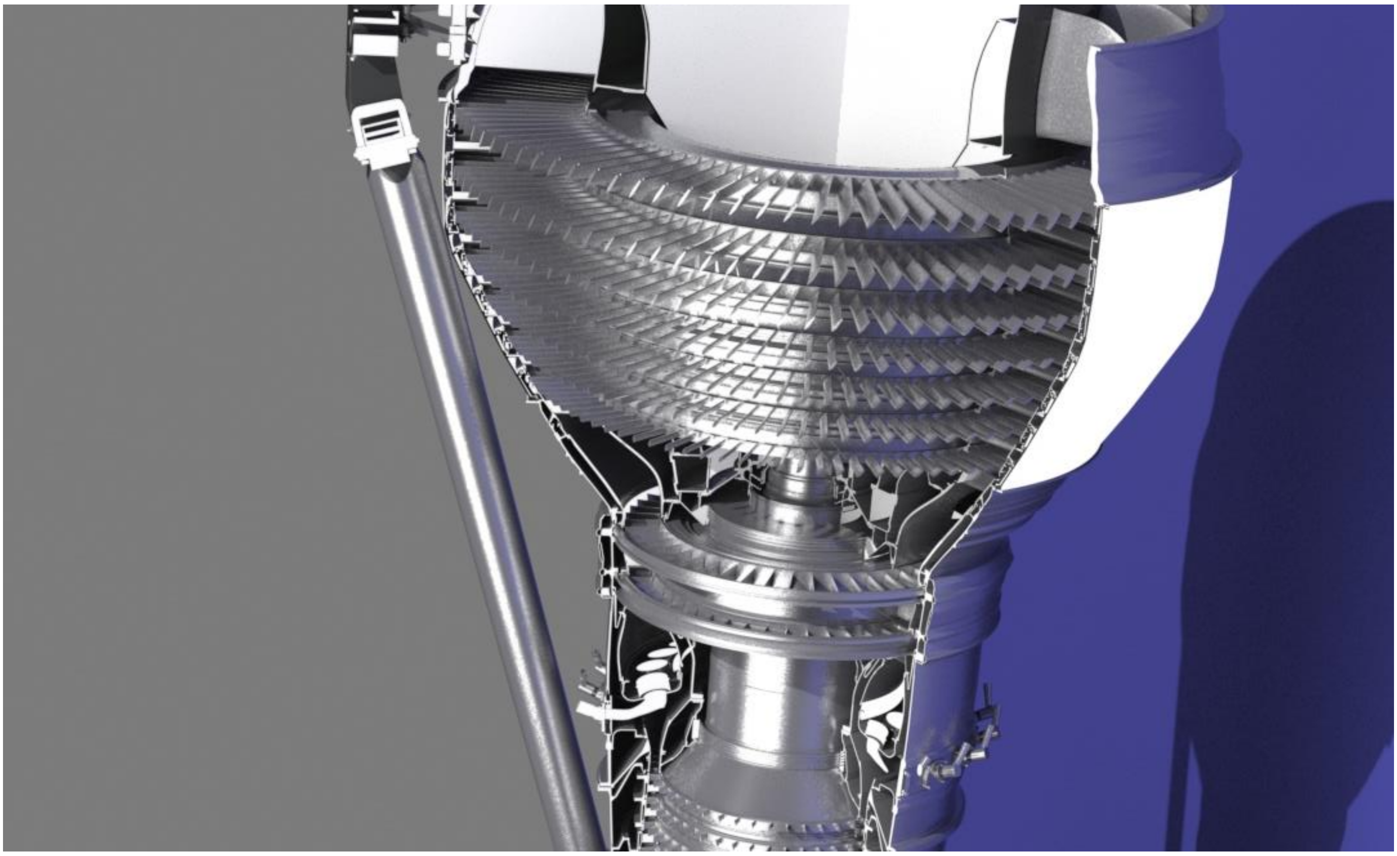
GEnX(787, 747). Peso 6150*kg*, *L*=4.7*m*, *D*=2.82*m*, *Fmax*=330*kN*, $\dot{m}_a$=1200*kg*/*s*, α=9.1, π_c=46, Comp 1/4/10, Turb 2/7.

TurboFan a flussi separati



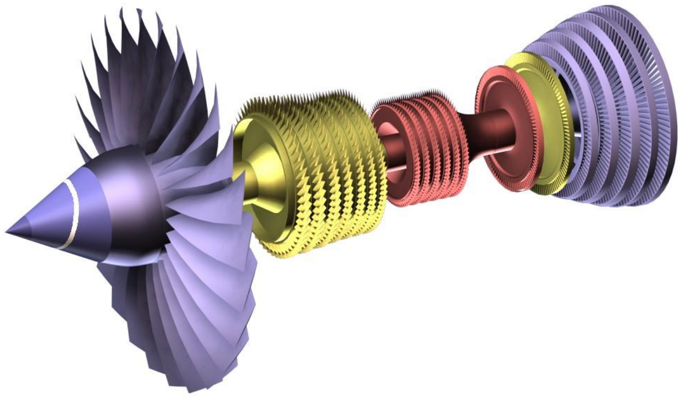
GEnX(787, 747). Peso 6150kg, L=4.7m, D=2.82m, $Fmax$=330kN, $\dot{m}_a$=1200kg/s, α=9.1, π_c=46, Comp 1/4/10, Turb 2/7.

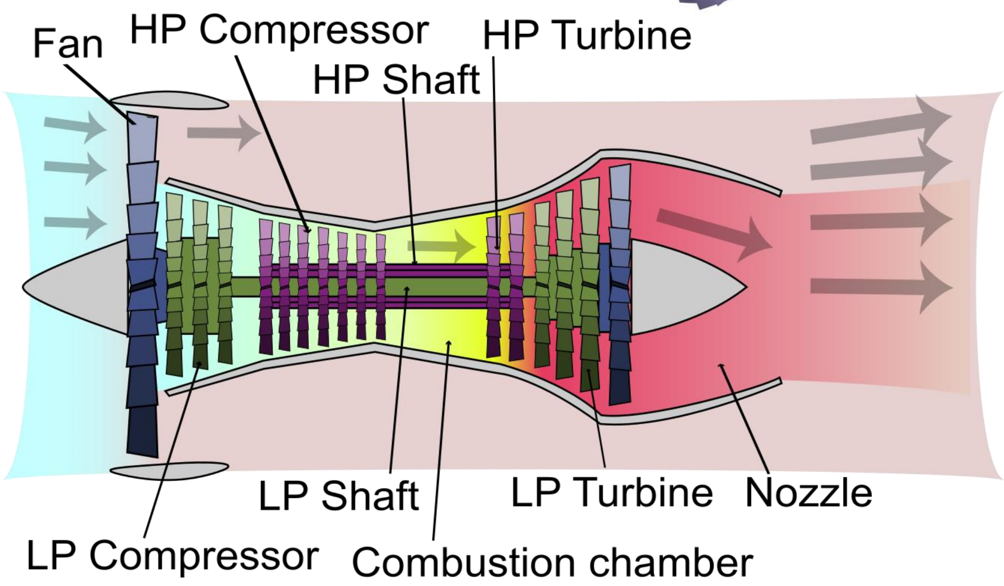
TurboFan a flussi separati



GEnX(787, 747). Peso 6150kg, L=4.7m, D=2.82m, $Fmax$=330kN, $\dot{m}_a$=1200kg/s, α=9.1, π_c=46, Comp 1/4/10, Turb 2/7.

TurboFan a flussi separati trialbero

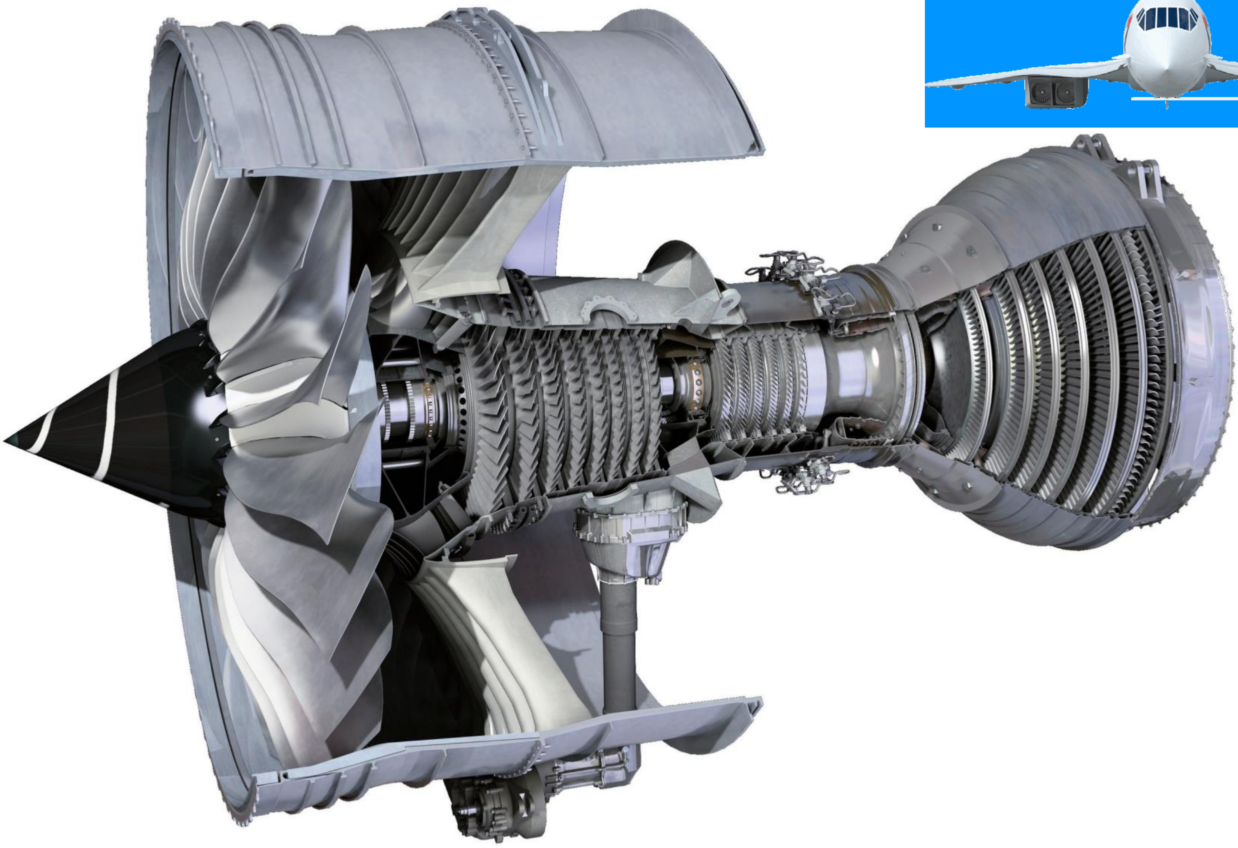




TurboFan a flussi separati

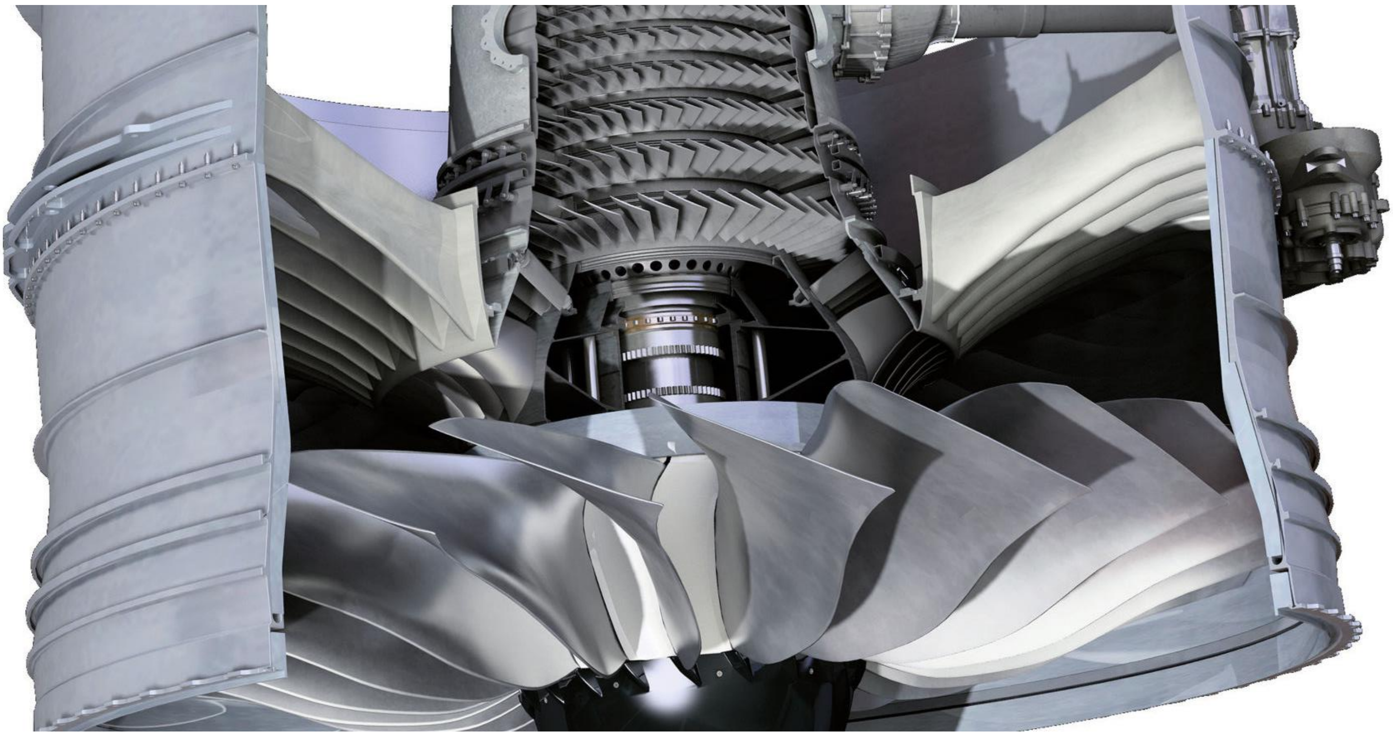
Trent 1000 (787). Peso 6000*kg*, *L*=4.7*m*, *D*=2.85*m*, *Fmax*=300*kN*, $\dot{m}_a$=1100*kg*/*s*, α=10, π_c =50, Comp 1/8/6, Turb 1/1/6.

TurboFan a flussi separati



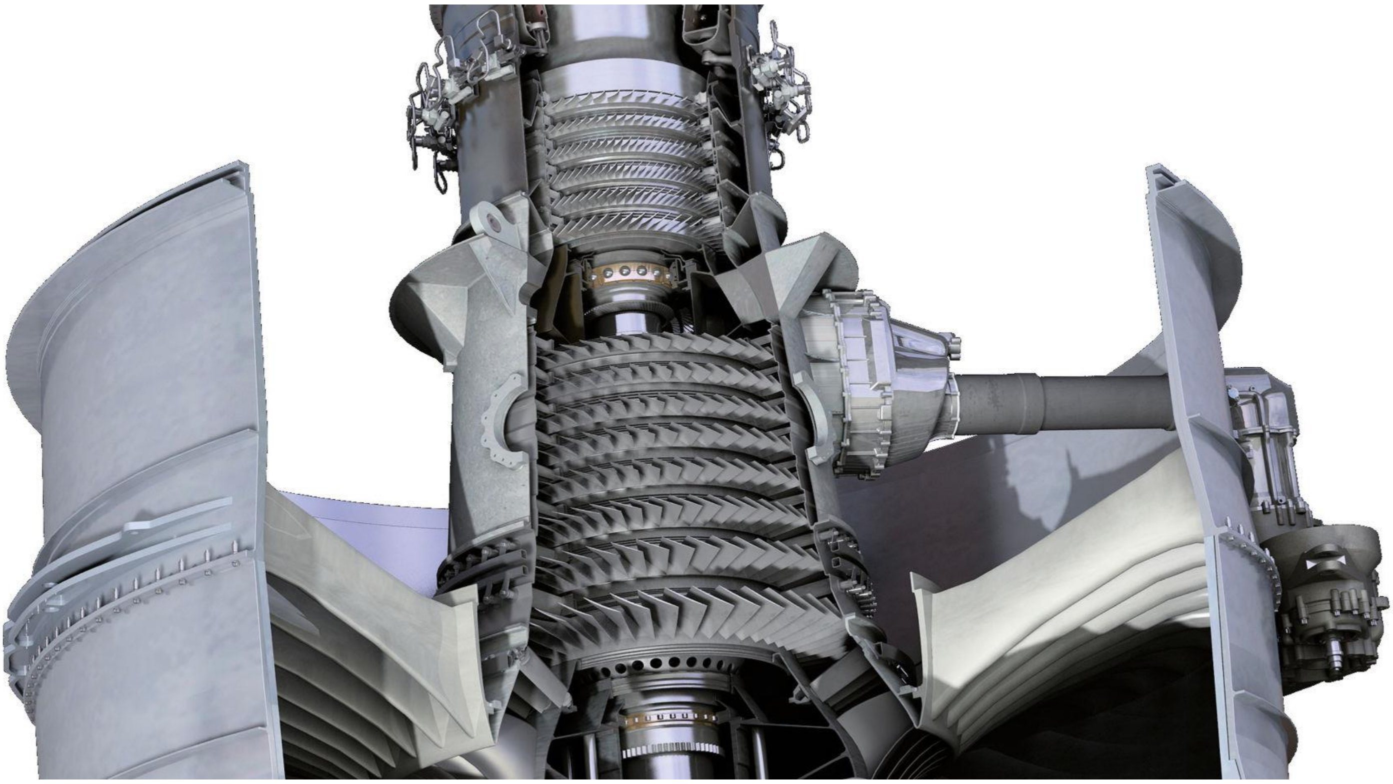
Confronto del Trent 1000 (787) con un Concorde.

TurboFan a flussi separati



Trent 1000 (787). Peso 6000*kg*, *L*=4.7*m*, *D*=2.85*m*, *Fmax*=300*kN*, $\dot{m}_a$=1100*kg*/*s*, α=10, π_c =50, Comp 1/8/6, Turb 1/1/6.

TurboFan a flussi separati

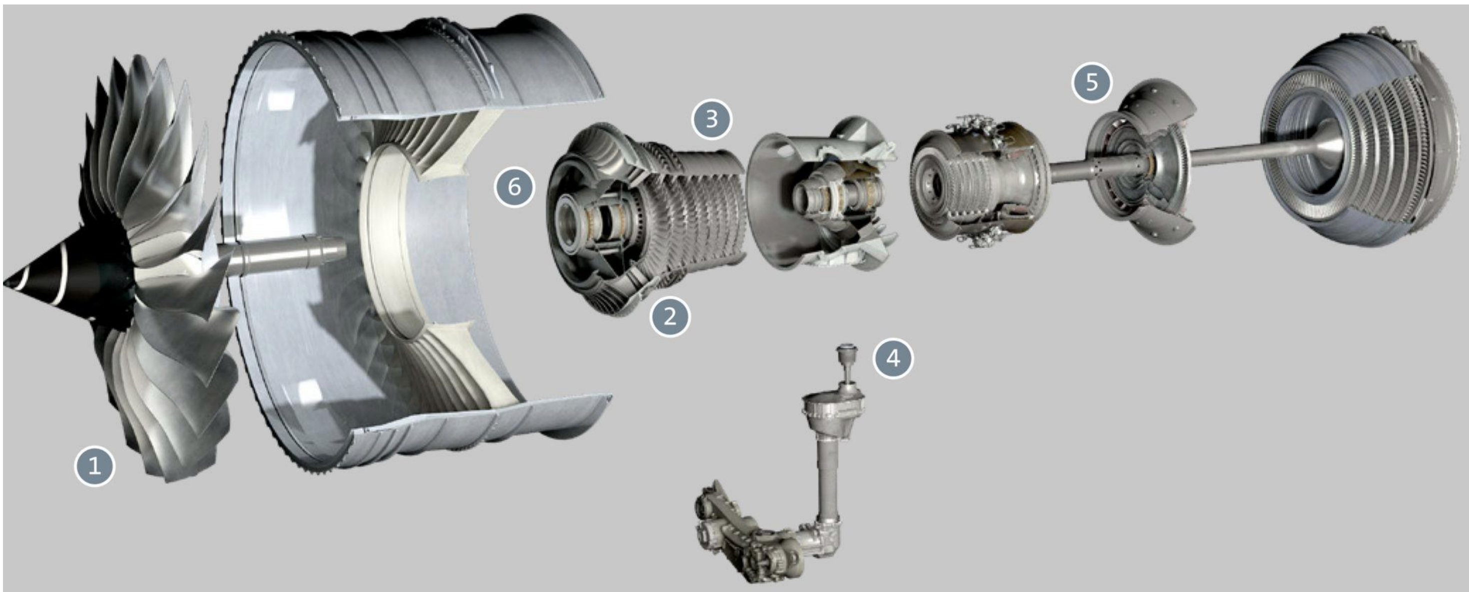


Trent 1000 (787). Peso 6000*kg*, *L*=4.7*m*, *D*=2.85*m*, *Fmax*=300*kN*, $\dot{m}_a$=1100*kg/s*, α=10, π_c =50, Comp 1/8/6, Turb 1/1/6.

TurboFan a flussi separati

Trent 1000 (787). Peso 6000*kg*, *L*=4.7*m*, *D*=2.85*m*, *Fmax*=300*kN*, $\dot{m}_a$=1100*kg/s*, α=10, π_c =50, Comp 1/8/6, Turb 1/1/6.

TurboFan a flussi separati



Trent 1000 (787). Peso 6000*kg*, *L*=4.7*m*, *D*=2.85*m*, *Fmax*=300*kN*, $\dot{m}_a$=1100*kg/s*, α=10, π_c =50, Comp 1/8/6, Turb 1/1/6.

TurboFan a flussi separati

PW 4000 (777). Peso 7000*kg*, *L*=4.8*m*, *D*=2.84*m*, *Fmax*=420*kN*, α=6, π_c =43, Comp 1/7/11, Turb 2/7.

TurboFan a flussi separati

PW 4000 (777). Peso 7000*kg*, *L*=4.8*m*, *D*=2.84*m*, *Fmax*=420*kN*, α=6, π_c =43, Comp 1/7/11, Turb 2/7. Incidente del 20.2.2021

TurboFan a flussi separati

PW 4000 (777). Peso 7000*kg*, *L*=4.8*m*, *D*=2.84*m*, *Fmax*=420*kN*, α=6, π_c =43, Comp 1/7/11, Turb 2/7. Incidente del 20.2.2021

TurboFan a flussi separati

PW 4000 (777). Peso 7000*kg*, *L*=4.8*m*, *D*=2.84*m*, *Fmax*=420*kN*, α=6, π_c =43, Comp 1/7/11, Turb 2/7. Incidente del 20.2.2021

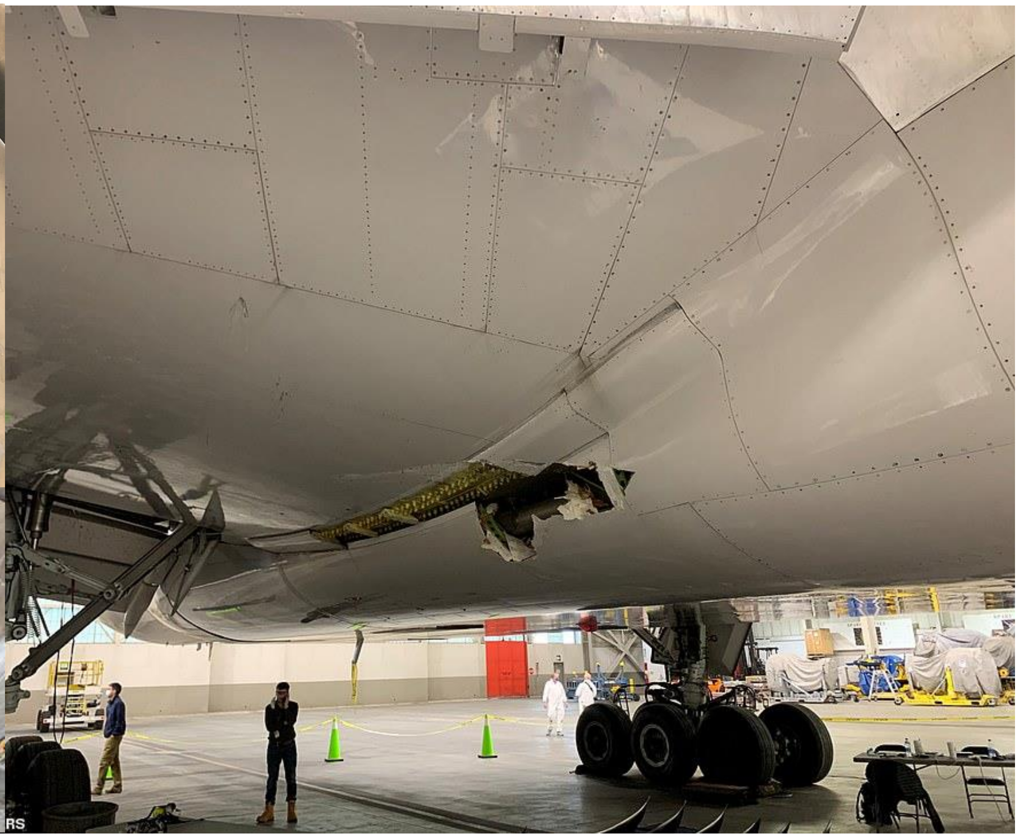
TurboFan a flussi separati

PW 4000 (777). Peso 7000*kg*, *L*=4.8*m*, *D*=2.84*m*, *Fmax*=420*kN*, α=6, π_c =43, Comp 1/7/11, Turb 2/7. Incidente del 20.2.2021

TurboFan a flussi separati

PW 4000 (777). Peso 7000*kg*, *L*=4.8*m*, *D*=2.84*m*, *Fmax*=420*kN*, α=6, π_c =43, Comp 1/7/11, Turb 2/7. Incidente del 20.2.2021

TurboFan a flussi separati

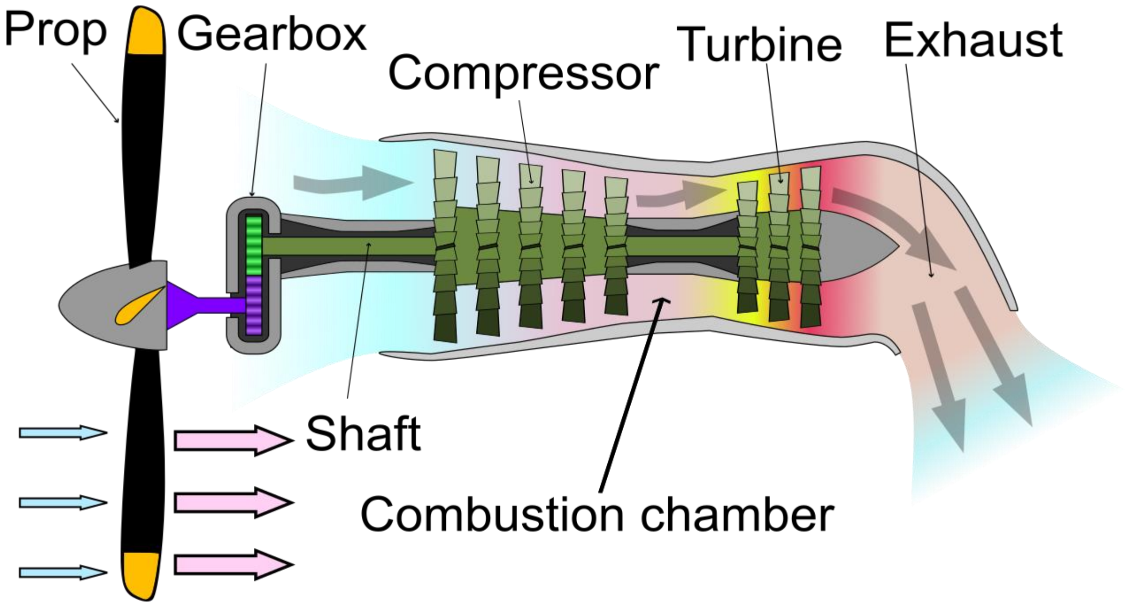


PW 4000 (777). Peso 7000*kg*, *L*=4.8*m*, *D*=2.84*m*, *Fmax*=420*kN*, α=6, π_c =43, Comp 1/7/11, Turb 2/7. Incidente del 20.2.2021

TurboProp

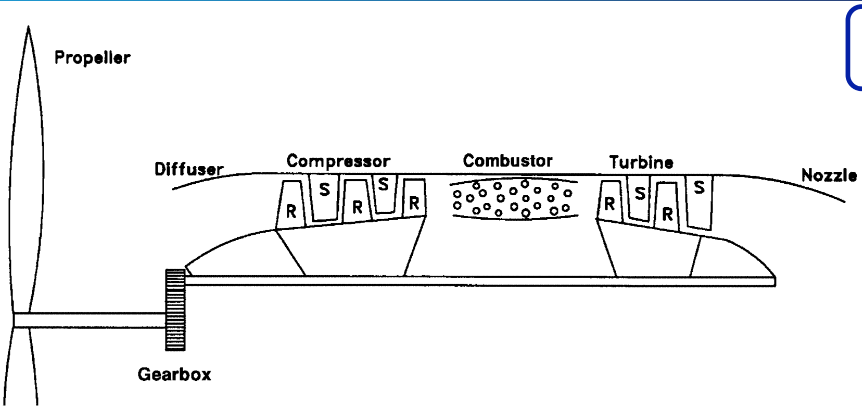
Turbine a gas

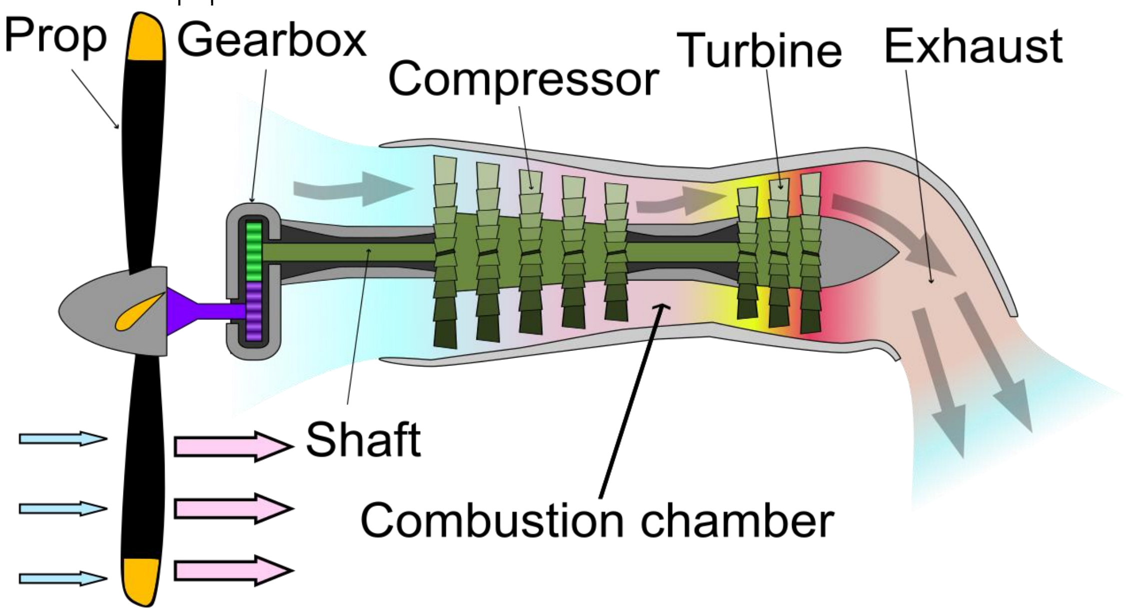
- TurboJet
- TurboFan
- **TurboProp**
- TurboShaft



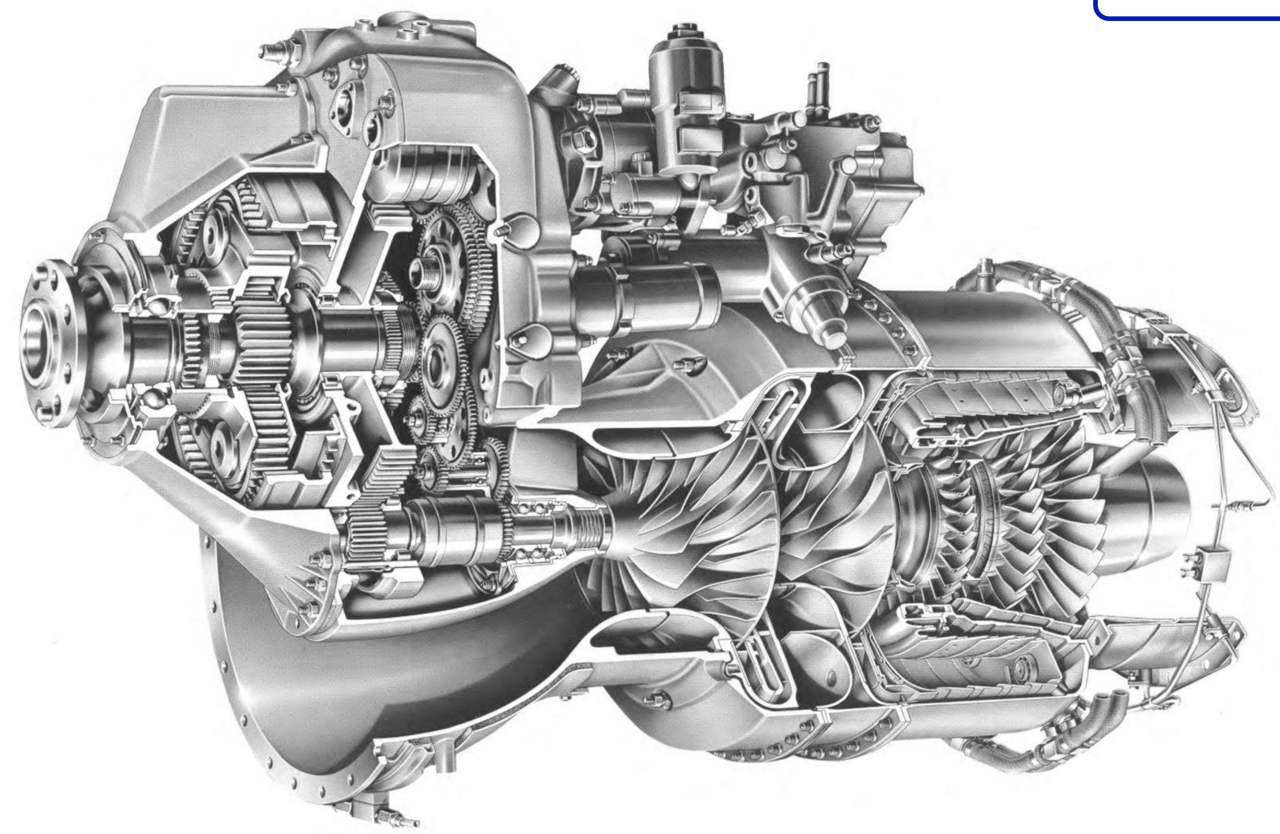
TurboProp

TurboProp



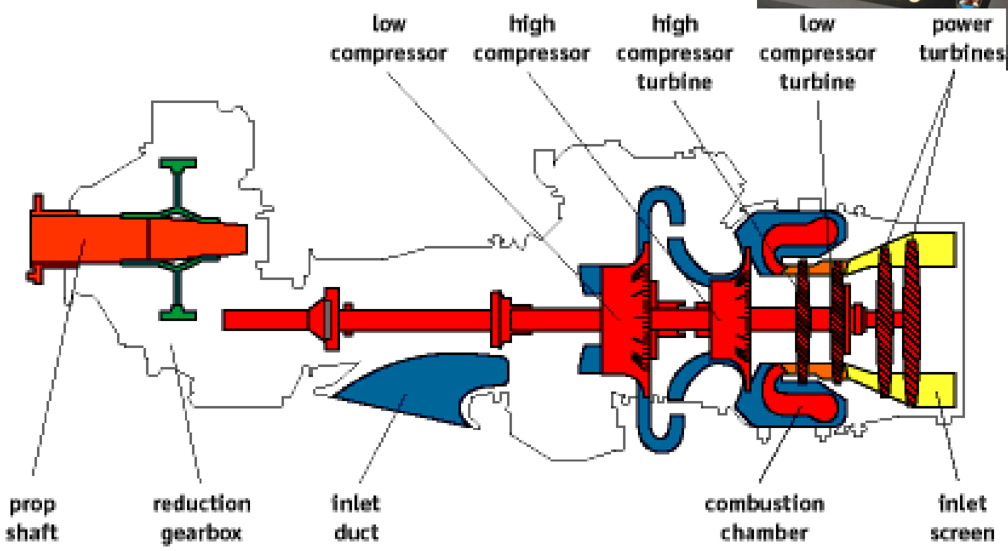


TurboProp mono albero



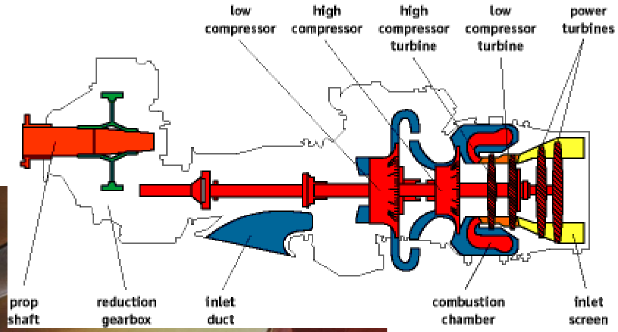
Garrett TPE331. Peso 175*kg*, *L*=1.1*m*, *D*=.53*m*, Equivalent Power 700*kW*, π_c =10.6, Comp 2, Turb 3.

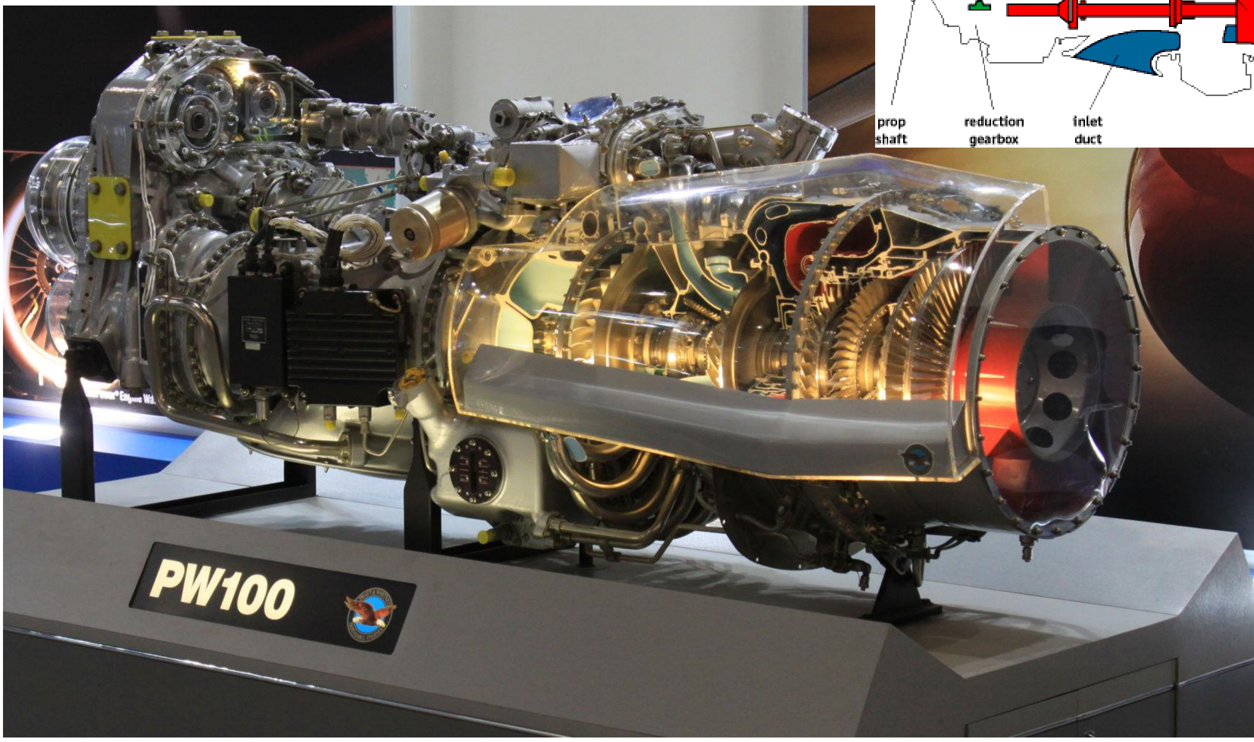
TurboProp triplo albero



PW127 (ATR). Peso 500*kg*, *L*=2.1*m*, *D*=.85*m*, Equivalent Power 2200*kW*, π_c =15.8, Comp 1/1, Turb 1/1/2.

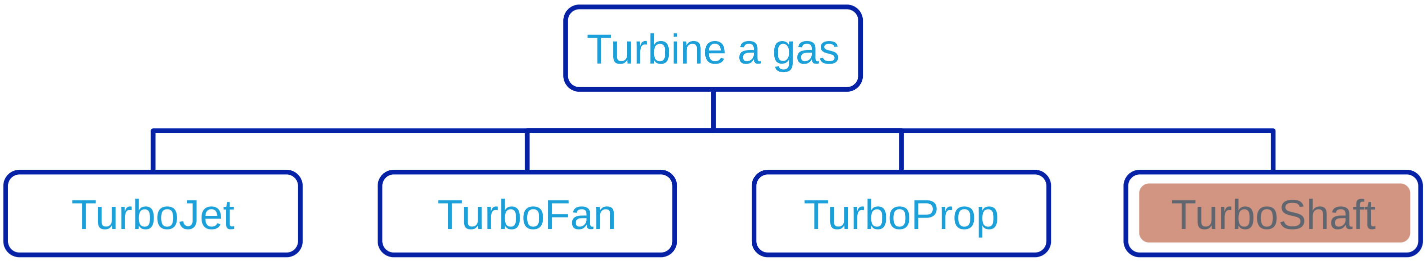
TurboProp triplo albero

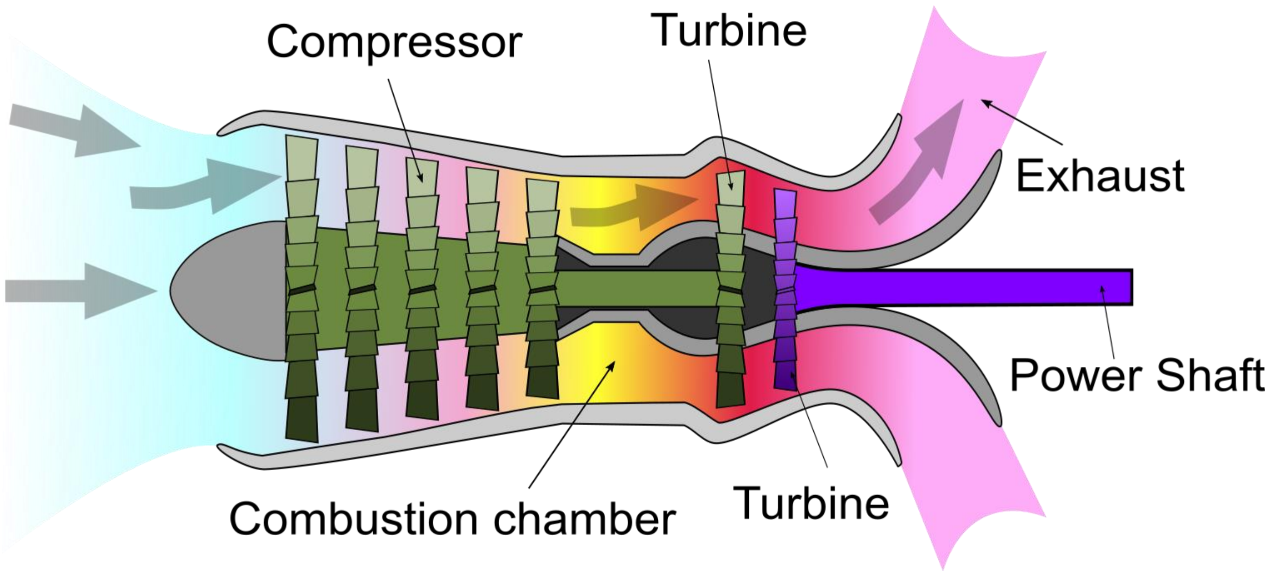




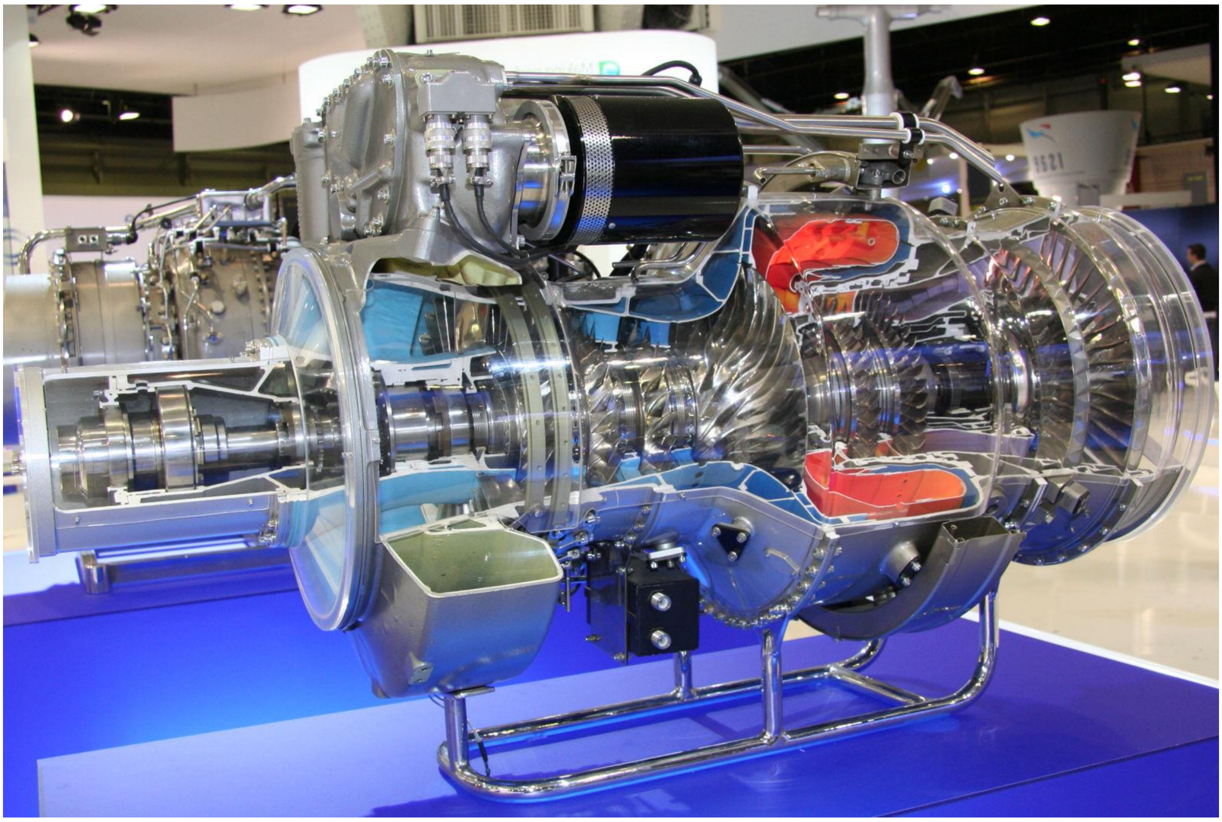
PW127 (ATR). Peso 500*kg*. *L*=2.1*m*, *D*=.85*m*. Equivalent Power 2200*kW*, π_c =15.8, Comp 1/1, Turb 1/1/2.

TurboShaft



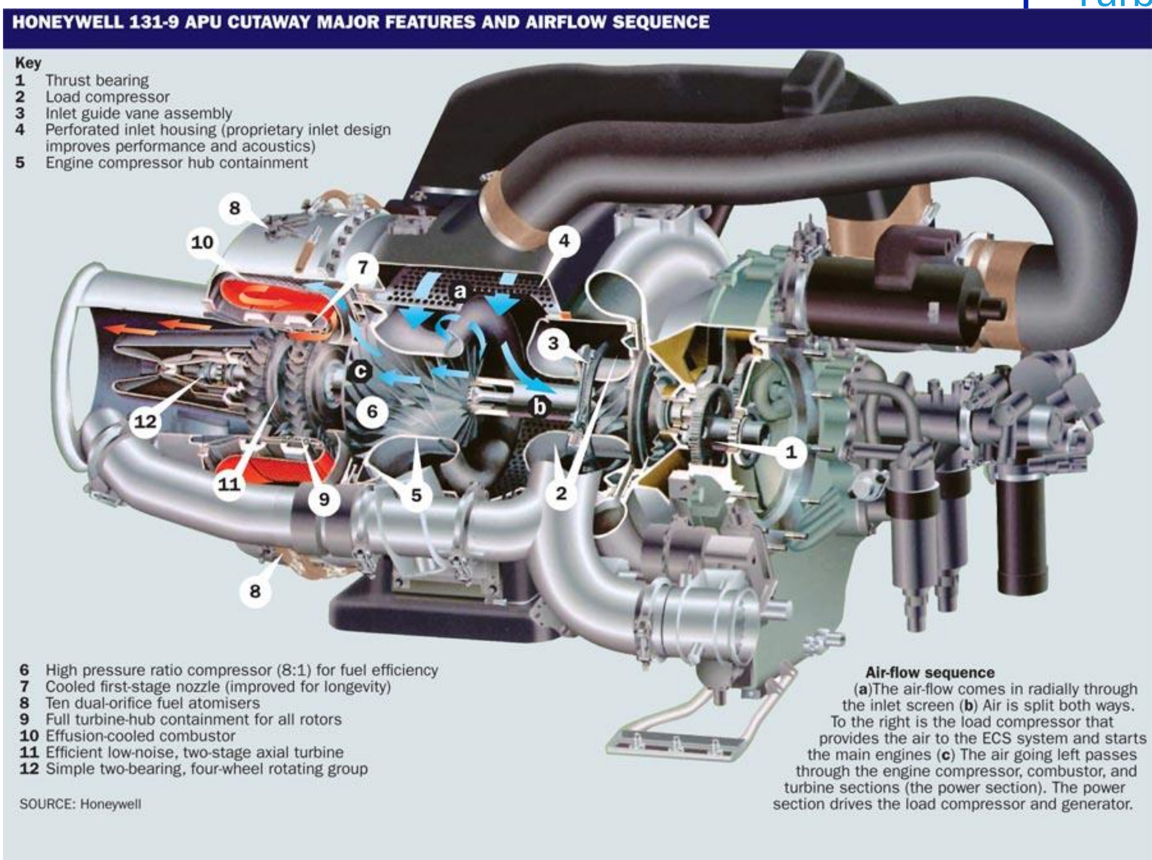


Turbo Shaft



Rolls Royce turbomeca RTM322- Peso 225*kg*, *L*=1.2*m*, *D*=.65*m*, Equivalent Power 1700*kW*, π_c =14.2, Comp 3+1, Turb 2+2.

Turbo Shaft



Honeywell 131.9 - Peso ?, *L*=?*m*, *D*=?*m*, Equivalent Power 440*kW*, π_c =?, Comp 1, Turb 1.