THE HONG KONG POLYTECHNIC UNIVERSITY
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Department of Aeronautical and Aviation Engineering
航空及民航工程學系

Introduction to Aircraft Systems

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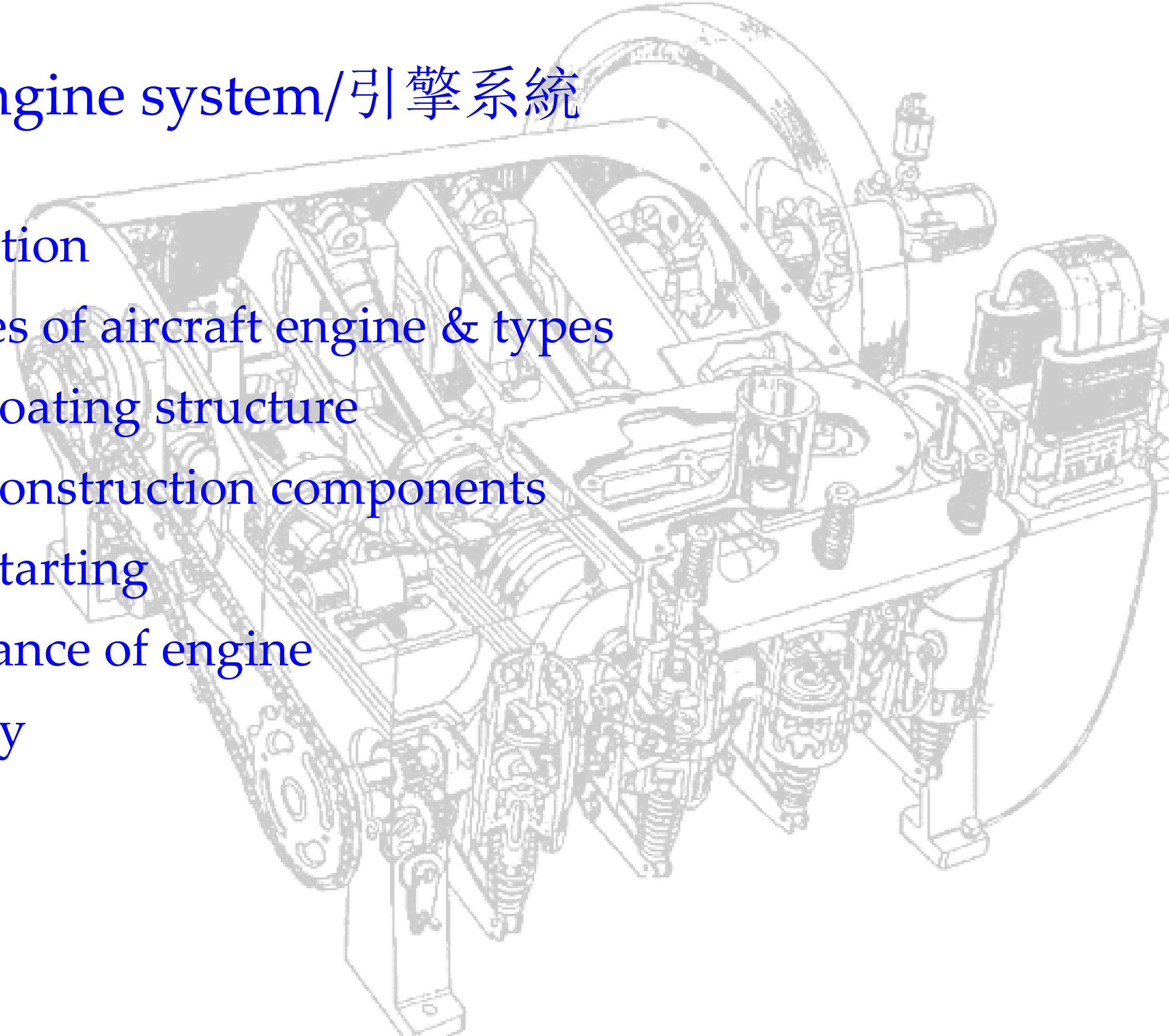
Aircraft engine system/引擎系統

- Introduction
- Principles of aircraft engine & types
- Engine coating structure
- Engine construction components
- Engine starting
- Performance of engine
- Summary

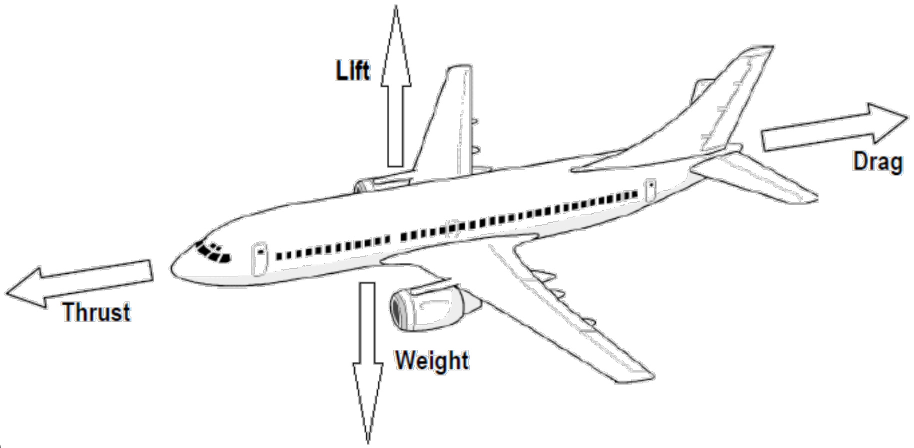


A cutaway drawing of the 1903 Wright Flyer Engine

Introduction

Introduction

- The aircraft experiences four forces:
  - Lift: normal to flight direction
  - Weight: vertical downward
  - Drag: opposite to flight direction
  - Thrust: align with flight direction
- Thrust is the force which moves an aircraft through the air. The thrust (T) is produced by the aircraft's propulsion system. The direction at which T points may be fixed or variable with respect to the airframe.



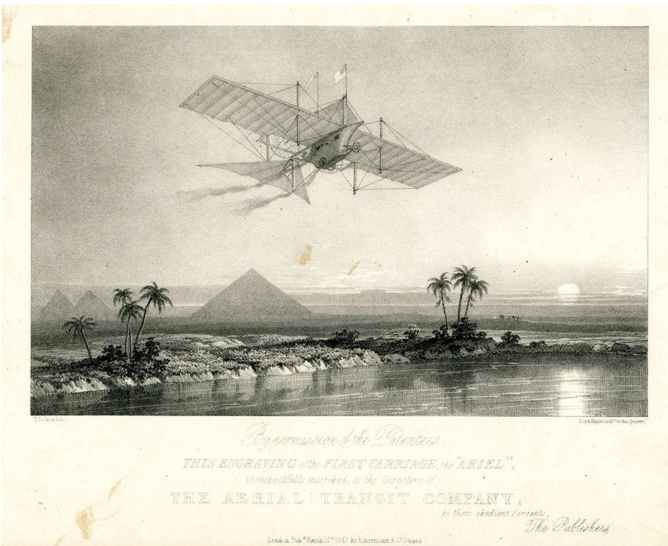
The thrust overcomes the drag and produce the moving speed, which is basis that the aerodynamic lifting surfaces can produce lift.

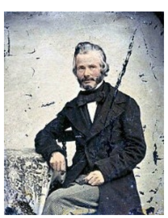
Introduction

- An aircraft engine is also referred to as aero engine. It is used to produce propulsion force of the aircraft.
- Most aircraft engines are either piston engines or gas turbines.
- In many unmanned aerial vehicles (UAV), the propulsion is realized by electric motors

Historical development: use of aircraft engine

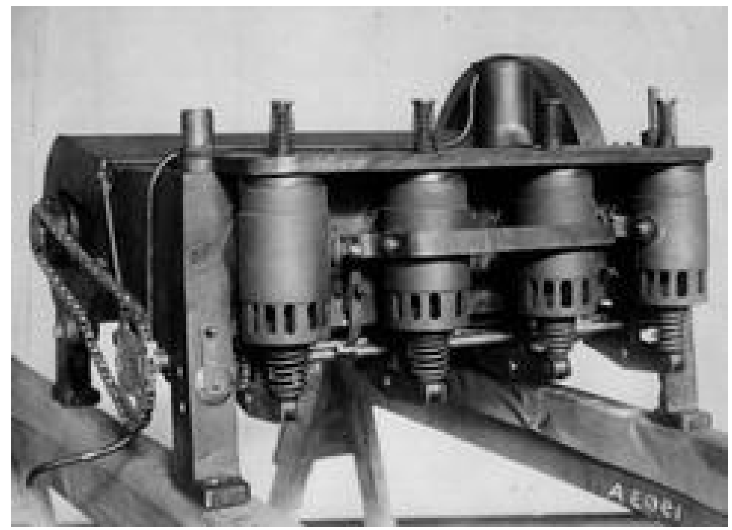
- 1848: John Stringfellow (UK) made a stream engine for a model aircraft





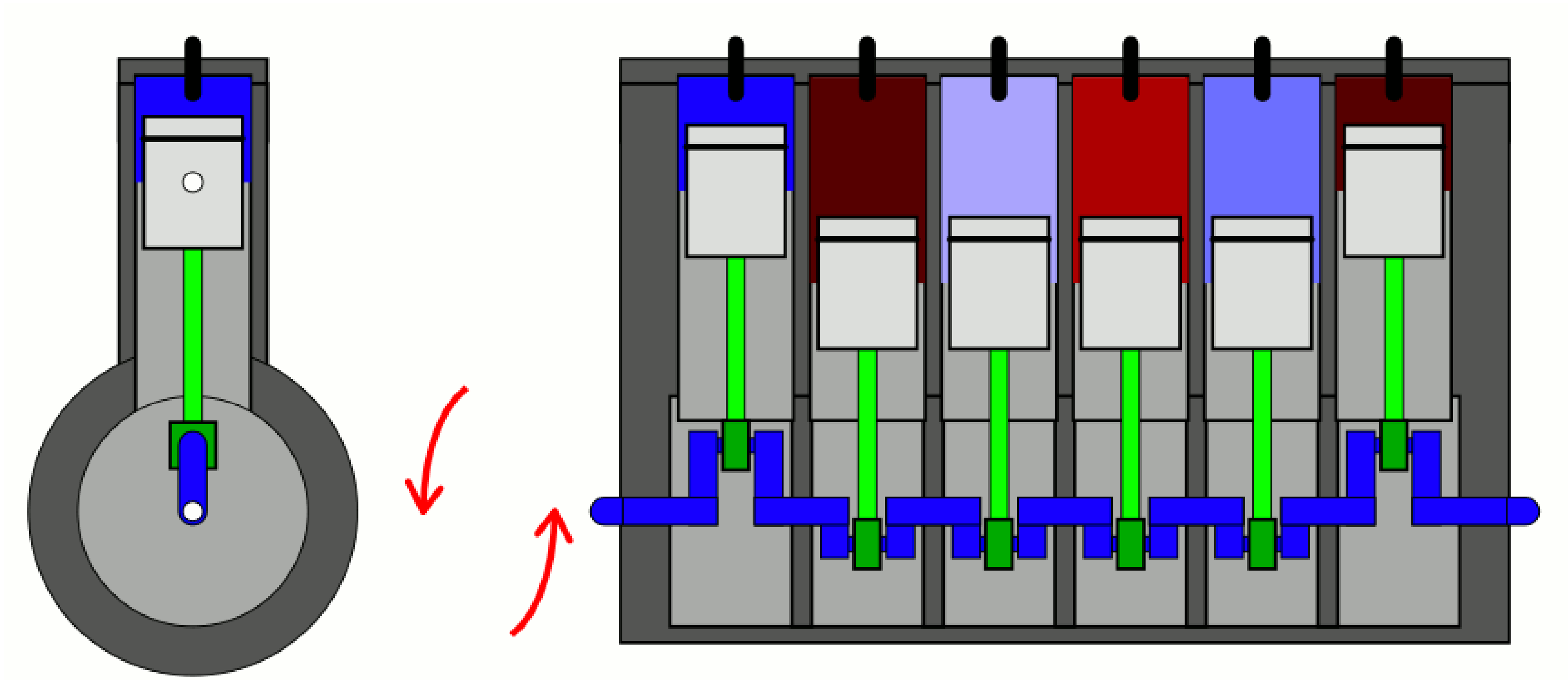
John Stringfellow (1799 – 1883) was a British early aeronautical inventor, known for his work on the aerial steam carriage

- 1903: Charles Taylor (US) built the inline engine for Wright Flyer I



Charles Taylor (1868 –1956): American inventor, mechanic and machinist. He built the first aircraft engine for Wright Flyer, and was a vital contributor in the building and maintaining of early Wright engines and airplanes

Inline engine/straight engine



Historical development: Langley aerodrome

- 1903: Manly-Balzer engine was the first purpose-designed engine for aircraft. It set standards for later radial engines.

Charles Manly & Samuel Langley

It is the first internal combustion engine for Langley's unsuccessful aerodrome. The original form was designed and built by Stephen Blazer in New York. Later, Manly redesigned it to the water-cooled and achieved the best power-to-weight ratio till 1906. It can run up to 10 hours duration.

Historical development: design powerful engine

- 1908: The Antoinette engine built by Leon Levavasseur. It was water-cooled with eight cylinders arranged in a V shape. It was safe, strong, and powerful with the leading power-to-weight ratio performance for 25 years.

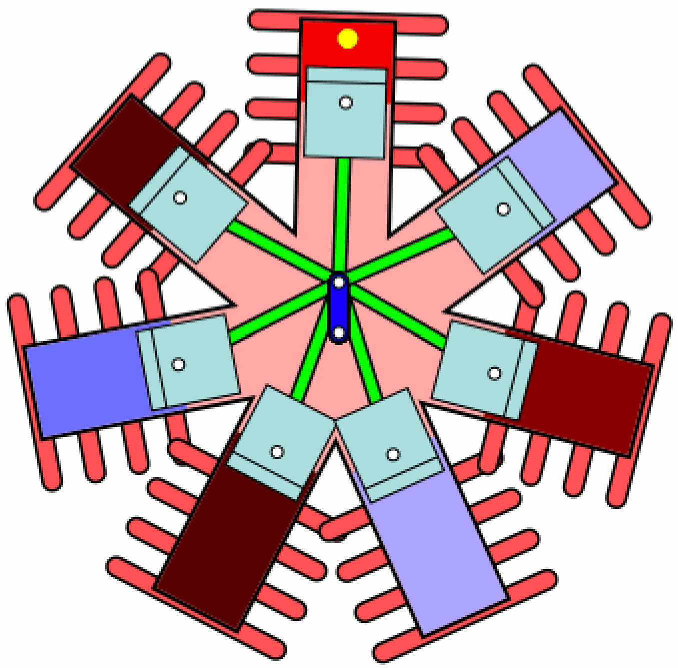
Antoinette V8 aircraft engine exhibited

Léon Levavasseur (1863 –1922): French powerplant engineer, aircraft designer and inventor. His innovations included the V8 engine, direct fuel injection, and liquid engine cooling.

Historical development: during WWI

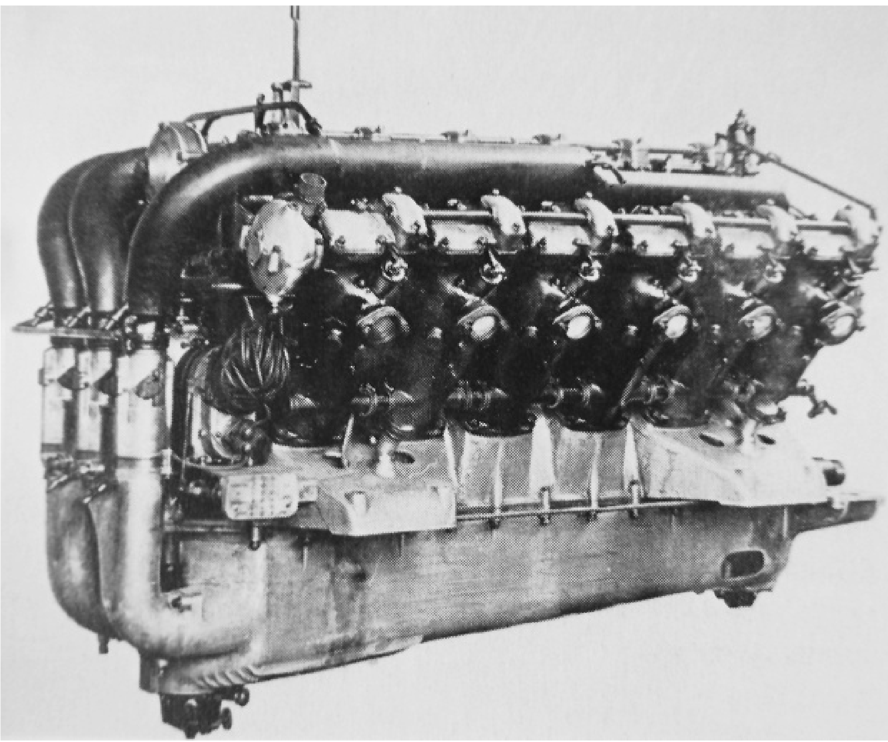
- 1908: The Gnome Omega (or Gnome 50 horsepower) rotary engine was designed by the Seguin Brothers in France. It revolutionized aviation and was used extensively in WWI. It has fixed crankshaft and rotating cylinders that carried propeller.

Rotary engine



Historical development: during WWI

- 1915: Mercedes D VI engine with 18 cylinders. It was the most powerful engine during WWI.



During WWI, the Germans begun to test very large aircraft with heavy bombloads. To promote the development of these aircraft, larger and more powerful engines were needed. The Mercedes D VI engines realized the power of 380 kW at that time.

Historical development: during WWI

- 1915: Rolls-Royce started the aviation engine. The liquid-cooled V-12 was developed with a performance of 375-horsepower in 1917.
- The efforts leads to the later Merlin and Griffons in WW-II.

RR Merlin: One of the most successful engine during WW-II. IT equipped many famous fighters such as Spitfire, Hawker, Supermarmine, etc.

RR Griffons entered service since 1938 and remain in RAF service today.

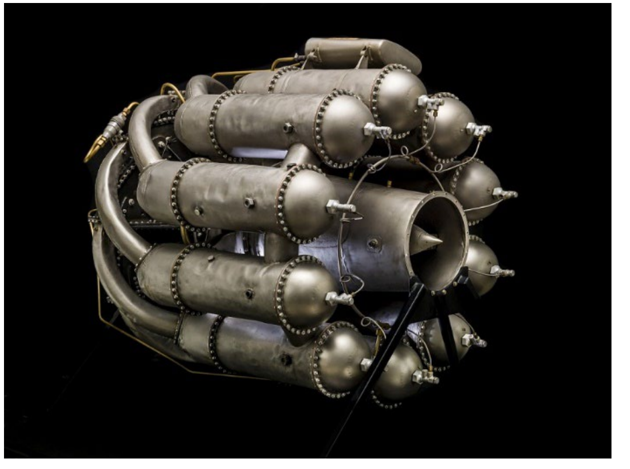
Merlin

Griffons

RR’s convention of naming the 4-stroke engines by bird of prey

Historical development: turbojet/渦輪噴射發動機

- 1930: Fank Whittle submitted the patent for a turbojet engine.

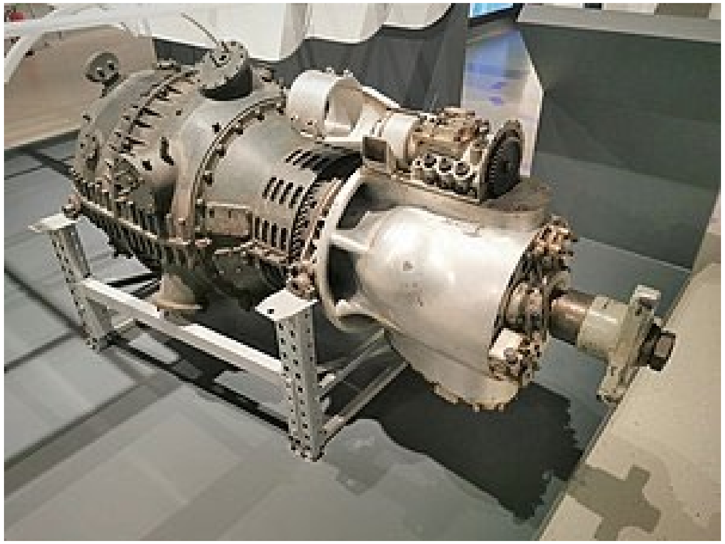


Whittle W.1X engine. This engine and the W.2B drawings were sent to GE in 1941, which was improved and uprated and used to power the first US jet aircraft.

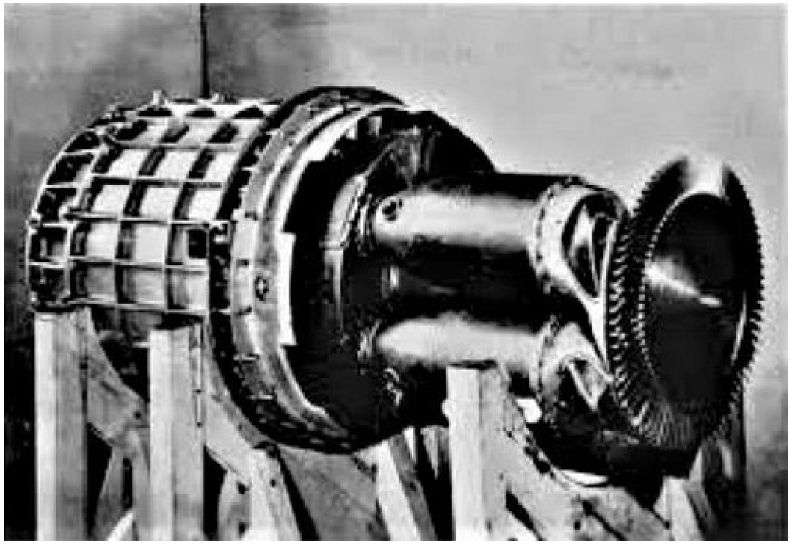
Air Commodore Frank Whittle (1907-1996): English engineer, inventor and RAF air officer. He is credited with co-creating the turbojet engine. His turbojet engine was developed several years earlier than Hans von Ohain in German and Anselm Franz in Austria.

Historical development: turbofan/渦輪風扇發動機

- In 1940: the first working turbofan engine Jendrassik CS-1.
- In 1943: the first run turbofan engine Daimler-Benz DB 760



It was designed by Hungarian engineer Gyorgy Jendrassik in 1937. But it was not in service.



The Daimler-Benz DB 007 was an early German jet engine design from 1939. This was a complex design featuring contra-rotating stages and a bypass fan, making it one of the earliest turbofan designs to be produced

Historical development: turbofan

- 1950: Rolls-Royce's Conway entered service. It was the world's first production turbofan

It was used in many successful aircraft including Boeing 707, Douglas DC-8, etc.

Conway is named after River Conwy. It was RR's convention of using river names for gas turbine engines.

Historical development: turboprop/渦輪螺旋槳發動機

- 1945: The first turboprop-powered aircraft Gloster Meter aircraft equipped with two Rolls-Royce Trent engines.

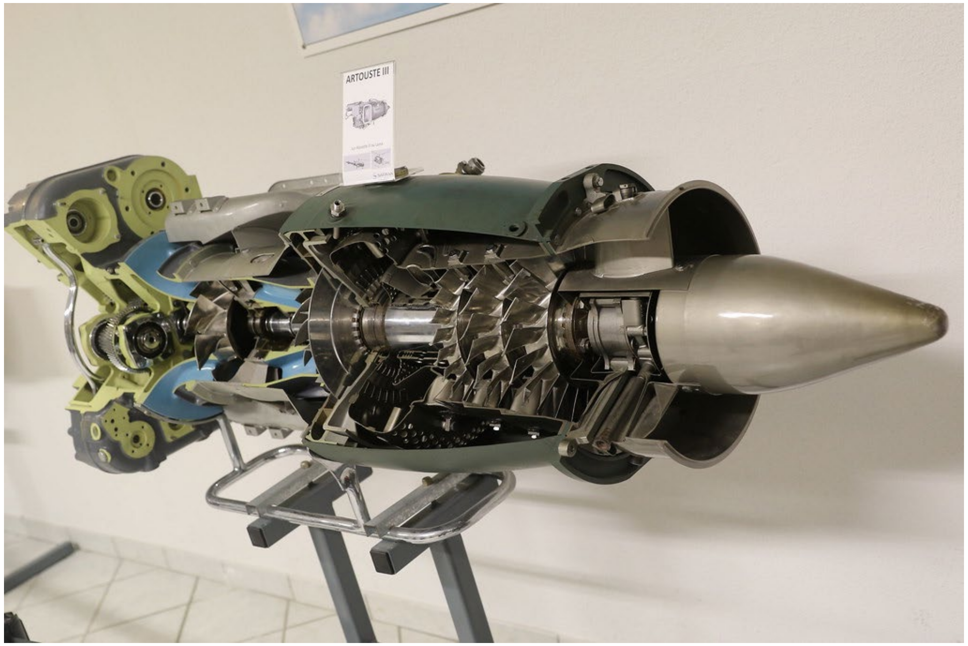
Gloster Meter was the UK jet fighter and the Allies' only jet aircraft in combat in WWII.

The Trent Meter was the First turboprop-powered aircraft. It was found separating controls for thrust and speed requires a lot of skills and a development was completed by 1948.

The Trent is the 3rd longest river in the UK.

Historical development: turboshaft/渦輪軸發動機

- 1948: the first turboshaft engine was applied. In 1950, turboshaft engine was used in the larger Turbomeca Artouste.



The Turbomeca Artouste is an early French turboshaft engine, first run in 1947. Originally conceived as an auxiliary power unit (APU), it was soon adapted to aircraft propulsion in the 1950s. Artoustes were licence-built by Bristol Siddeley in the UK, Hindustan Aeronautics Limited in India, and developed by Continental CAE in the US as the Continental T51.

Aérospatiale Alouette II above De Panne beach, outfitted with a Turbomeca Artouste.
Source: Tom Houquet, Airliners

Historical development: ramjet/衝壓發動機

- 1949: The Leduc 010 engine used for the first ramjet-powered aircraft.

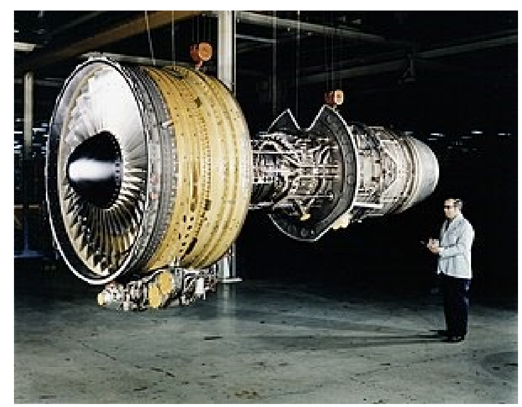
The Leduc 0.10 is a research aircraft built in France, one of the world's first aircraft to fly powered solely by a ramjet

Ramjet engine works efficiently at supersonic speeds around Mach 3 and can operate up to Mach 6.

Historical development: High bypass ratio engine

- 1968: GE's high bypass ratio TF39 enters service with much better efficiency and thrust

TF39 was developed to power the Lockheed C-5 Galaxy. It was the first high bypass ratio engine. It was further developed to the CF6 engines.

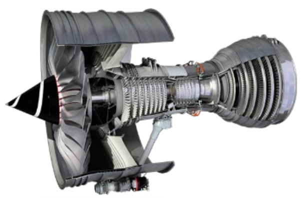


Manufacturing industry

- In commercial aviation, the major engine manufacturers include:
  - Pratt & Whitney (US)
  - General Electric (US)
  - Rolls-Royce (UK)
  - CFM International (Joint venture of Safran Aircraft Engines and General Electric)
  - United Engine Corporation (Russia)
  - Aviadvigatel (Russia)
  - Aeroengine Corporation of China

PW 4000

GE 90



Trent 900

LEAP 1-C

United engine corporation

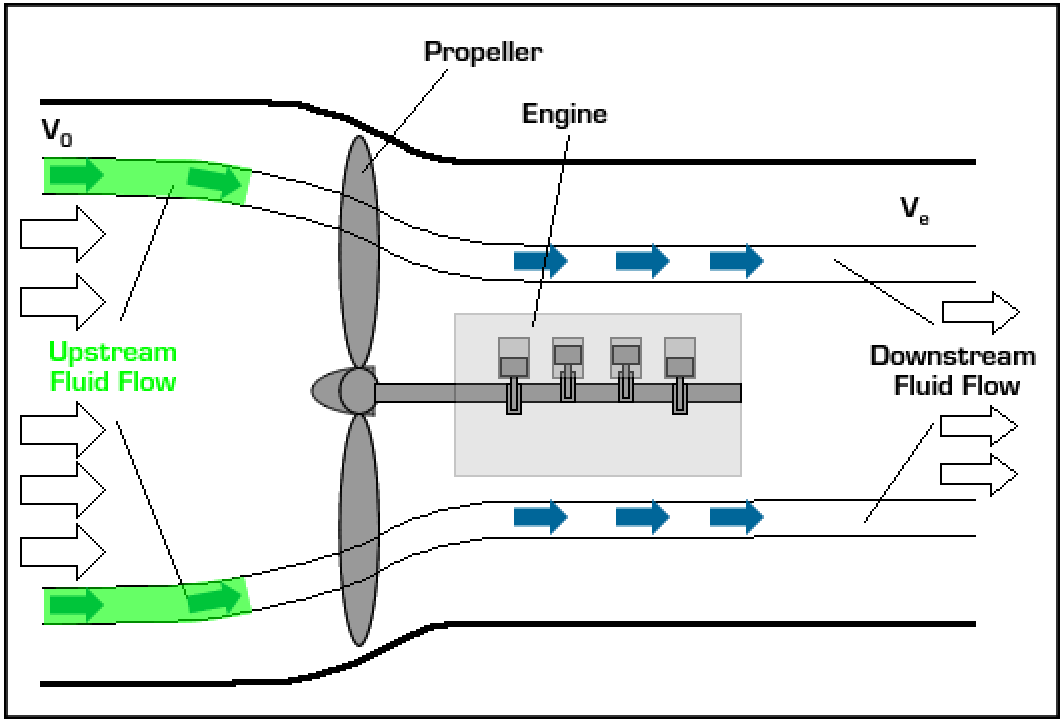
中国航空发动机集团
AERO ENGINE CORPORATION OF CHINA

CJ1000

Principles of aircraft engine & types

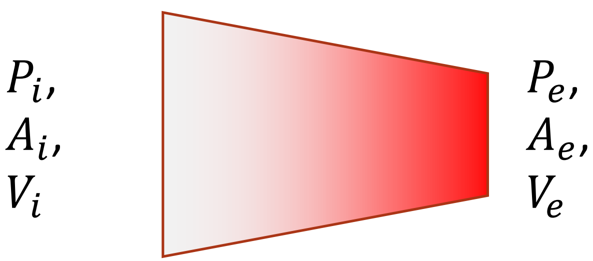
How engines generate thrust for aircraft?

- For turboprop and turboshaft engines, the forces due to the expansion of combusted gases move the shaft, driving the propeller that provide thrust to the aircraft.



How engines generate thrust for aircraft?

- For turbojet, turbofan and ramjet engines, forces are generated due to the moment change of the air jet.
  - The forces act as thrust to the aircraft directly.

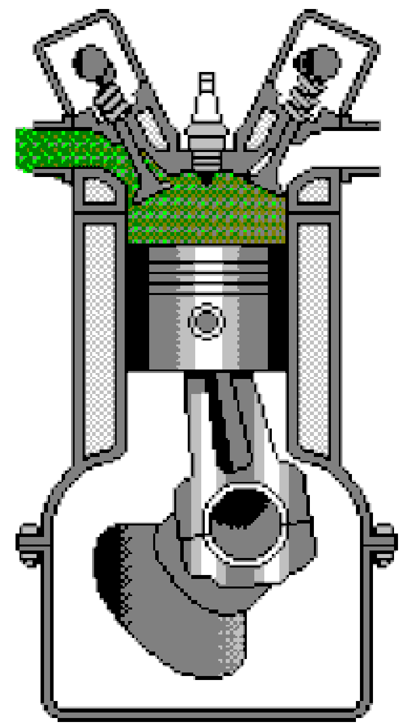


The mass flow rate is $\dot{m}_e > \dot{m}_i$

By using Newton's second law,

$$F = \dot{m}_e V_e - \dot{m}_i V_i + (P_e - P_i) A_e$$

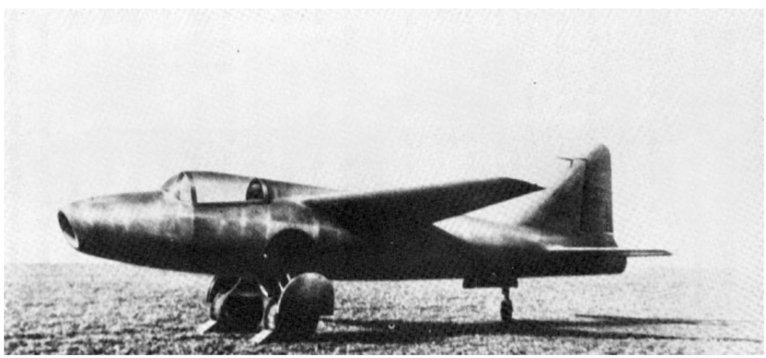
Types of aircraft engine: piston engine



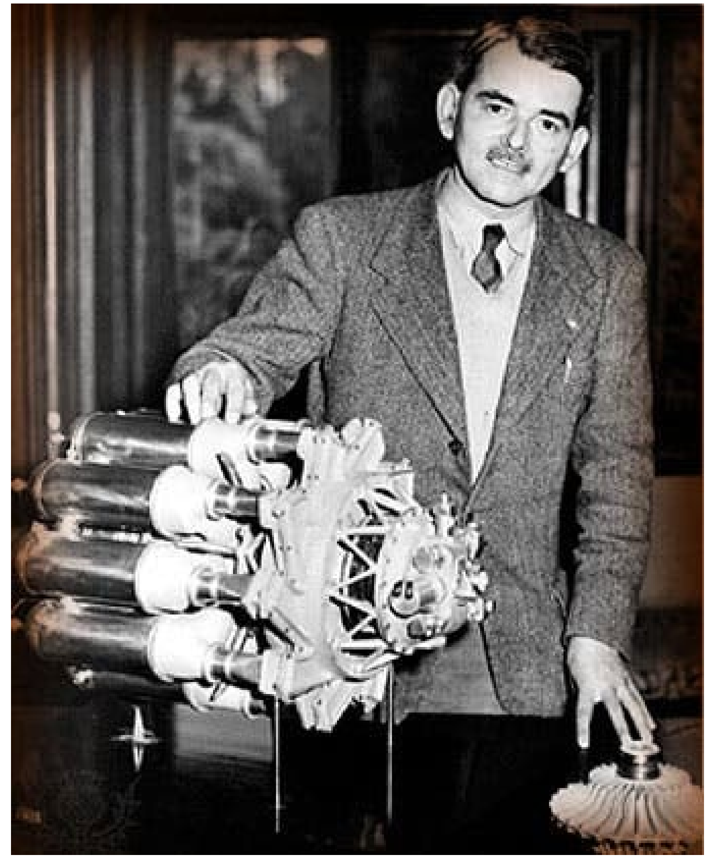
- Aircraft piston engine (i.e., reciprocating engine) involves four-stroke cycle
  - Intake: air & fuel intake
  - Compression: compress the mixture for ignition
  - Power: gas expansion to move the shaft rotation
  - Exhaust: the gas is evacuated to prepare for the next cycle

Types of aircraft engine: jet engine (since 1930s)

- Sir Frank Whittle design of jet engines:
  - Based on the centrifugal compressors:
  - Fuel pump, relief valve and throttle valve to control fuel to the combustion chamber



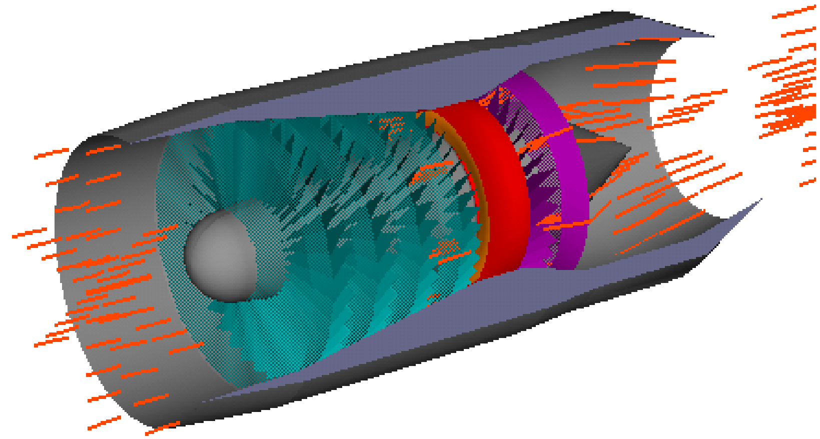
Heinkel He 178, the world's first aircraft to fly purely on turbojet power.



Sir Frank Whittle

Types of aircraft engine: turbojet engine

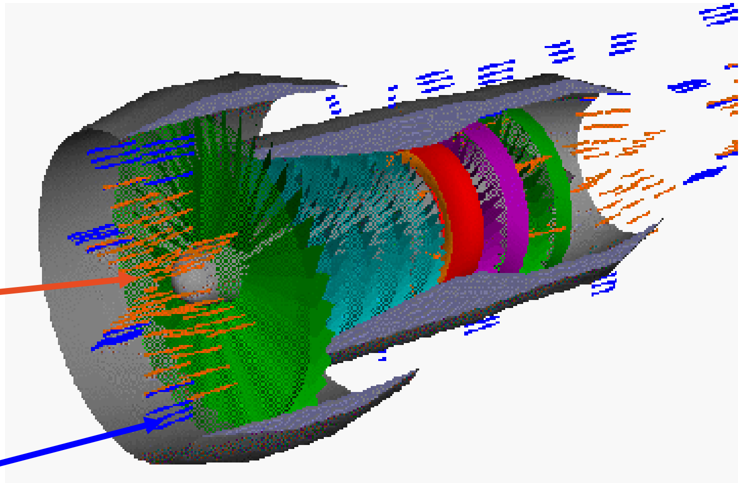
- The fans in the front do work to the **compressor**
- The compressed air passed into the **combustion chamber**
- The high-pressure and high-temperature air interacts with the injected fuel: combustion!
- The hot expansion air passes through the exit nozzle: generating thrust
  - The air also helps turning the shaft of the compressor



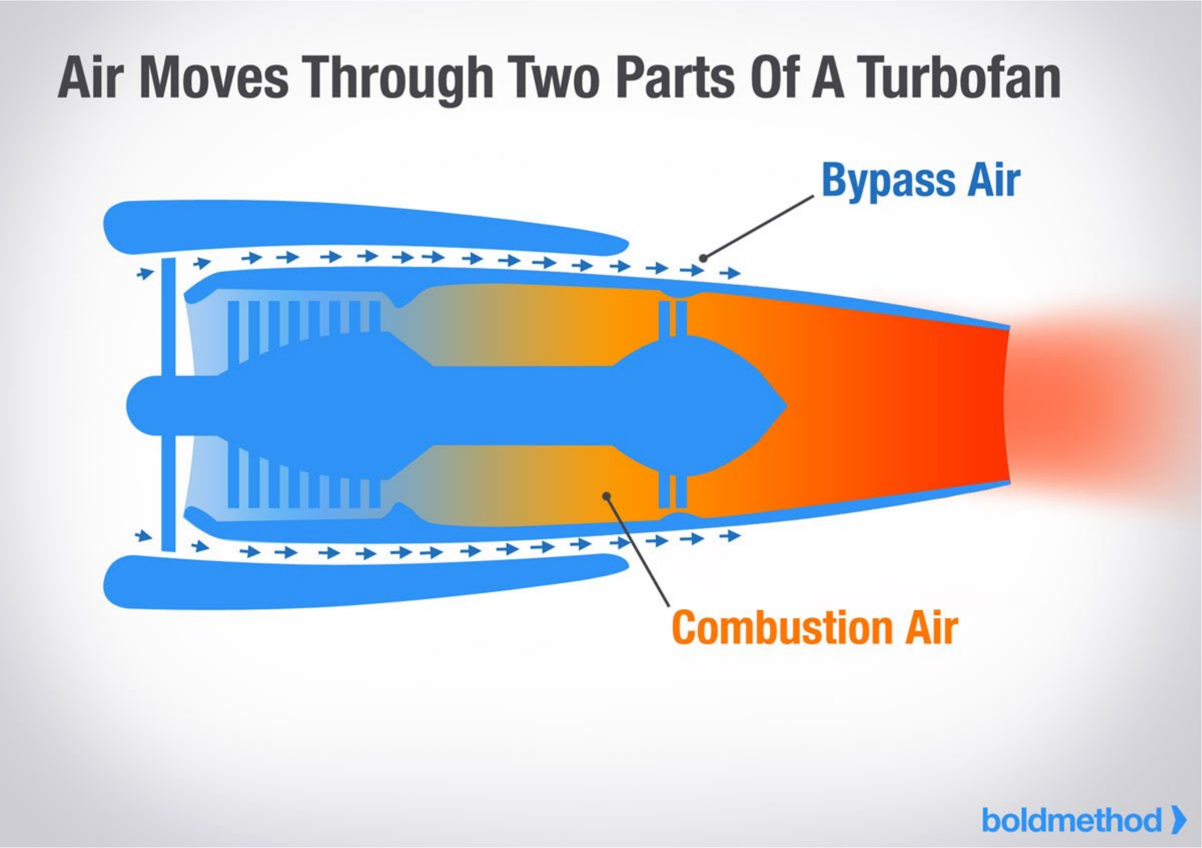
- The air flow is faster while at the exit nozzle than that at the inlet
- The moment change corresponds to the (thrust) force generation of the engine system

Types of aircraft engine: turbofan engine

- The principle is similar to the turbojet engine
- An additional fan is added to sucks the air
  - A part of the air is compressed and burned
  - A part of the air flow through the bypass, which also generates the thrust
- The fuel efficiency increases with the bypass ratio



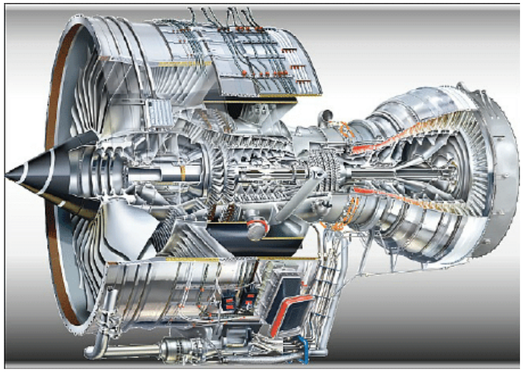
Bypass ratio/涵道比/旁通比



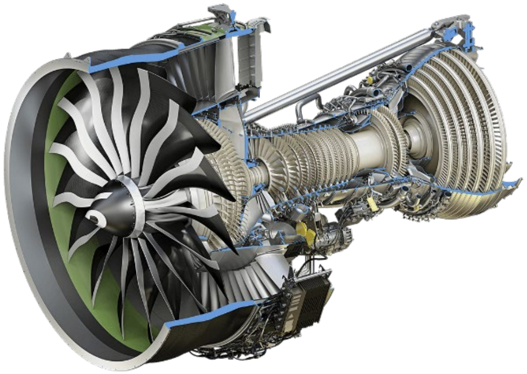
Bypass ratio (BPR):the ratio between the mass flow rate of the bypass stream to the mass flow rate entering the core

High BPR turbofan engines

- Many commercial turbofan engines have high bypass ratio
  - High fuel efficiency & Low noise emission



Rolls-Royce Trent



GE9X Turbofan

LEAP

Pratt & Whitney PW4000

Types of aircraft engine: turbofan engine

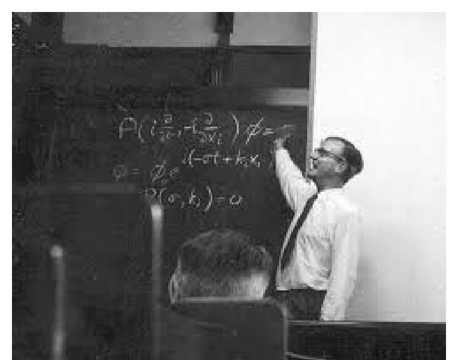
- A feature in turbofan engine is that speed of the jet flow is reduced.
  - Large BPR means the mass flow rate will be higher. So, to realize the same thrust, the needed change in speed can be low.
- The bypass air has relatively lower temperature, making the temperature of the mixed air (with the hot air from the exhaust) low.
  - The thermal efficiency will be higher, leading to a higher fuel efficiency.
  - Thermal efficiency of a heat engine

$$\eta = 1 - \frac{T_{Low}}{T_{high}}$$

Consequently, the noise due to the engine jet is significantly reduced.

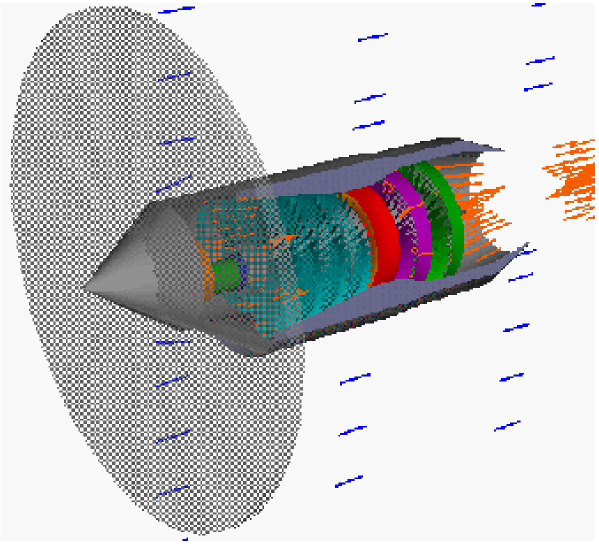
Sir James Lighthill

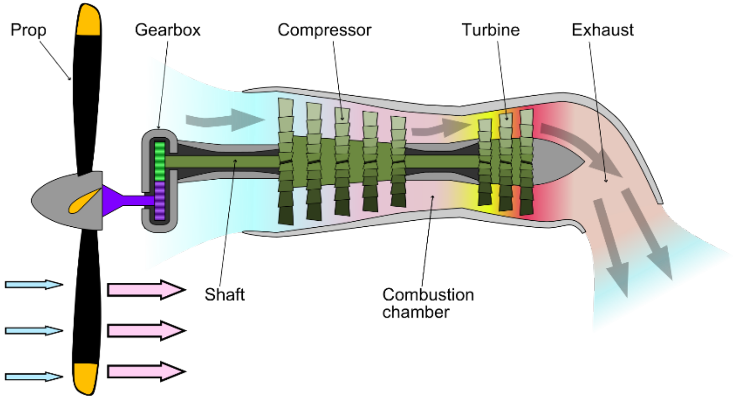
$\mathrm{PWL} \propto V^8$



Types of aircraft engine: turboprop engine

- Turboprop engines use a gas turbine core to turn the propeller
- Most of the exit gas is used to dive the turbine, which is connect to the shaft of the propeller.
  - The exit velocity is low
- The thrust of the aircraft is generated by the propeller

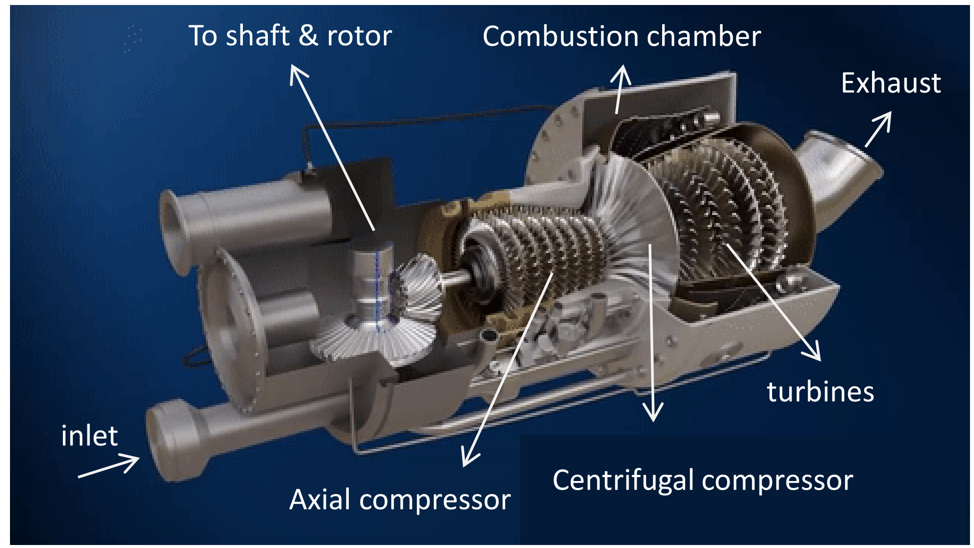


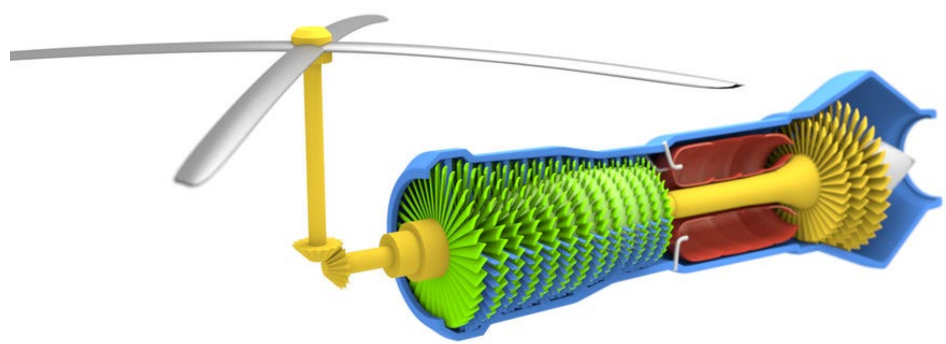


The Kuznetsov NK-12

Types of aircraft engine: turboshaft engine

- Turboshaft engine is a special type of jet engine used in helicopters
- The engine is used to drive the shaft of propellers, which will further generate thrust to the vehicle
- The ignition of the air-fuel mixture generates huge amount of exhaust gases to drive a number of turbines





Engine coating structures: nacelle/短舱

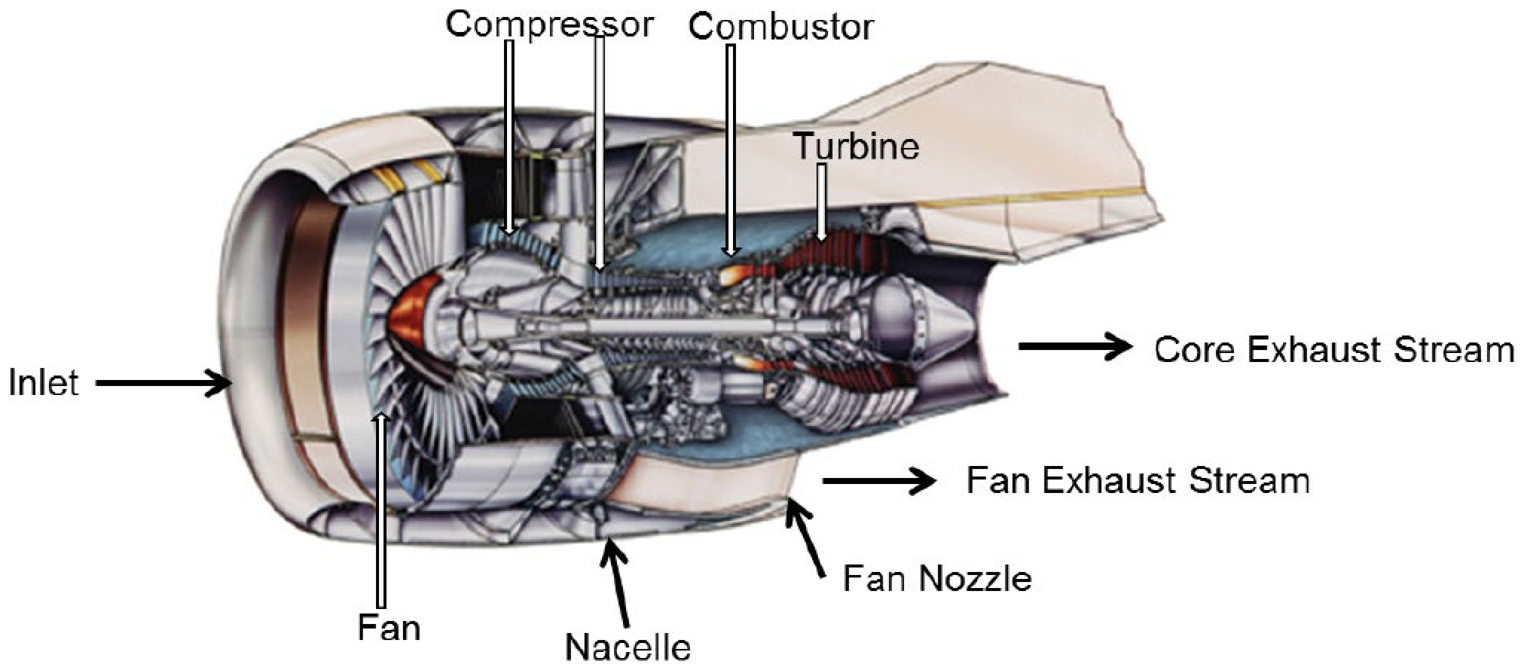
Aircraft power plant

- Aircraft engine, also referred to as the aircraft power plant, plays a key role in generating thrust.
  - It can be achieved by the thrust due to the jet flow in the turbojet & turbofans engines,
  - It could also be achieved by the combination of the reciprocating engines & turboshaft working with the propellers
- There should be set a set of components to make it work in the aircraft, and the performance of the engine can also be affected
- Despite of the significant difference in actual designs, aircraft engines can contain some common structures, which will be introduced in this section

Engine construction components

- In the standard numbering system published Air Transport Association (ATA), the engine related chapters are
  - ATA 71: Power plant
  - ATA 72: Engine construction
  - ATA 73: Fuel and control
  - ATA 74: Ignition
  - ATA 75: Air system
  - ATA 76: Controls
  - ATA 77: Indicating
  - ATA 78: Thrust reverser
  - ATA 79: Oil system
  - ATA 80: Starting

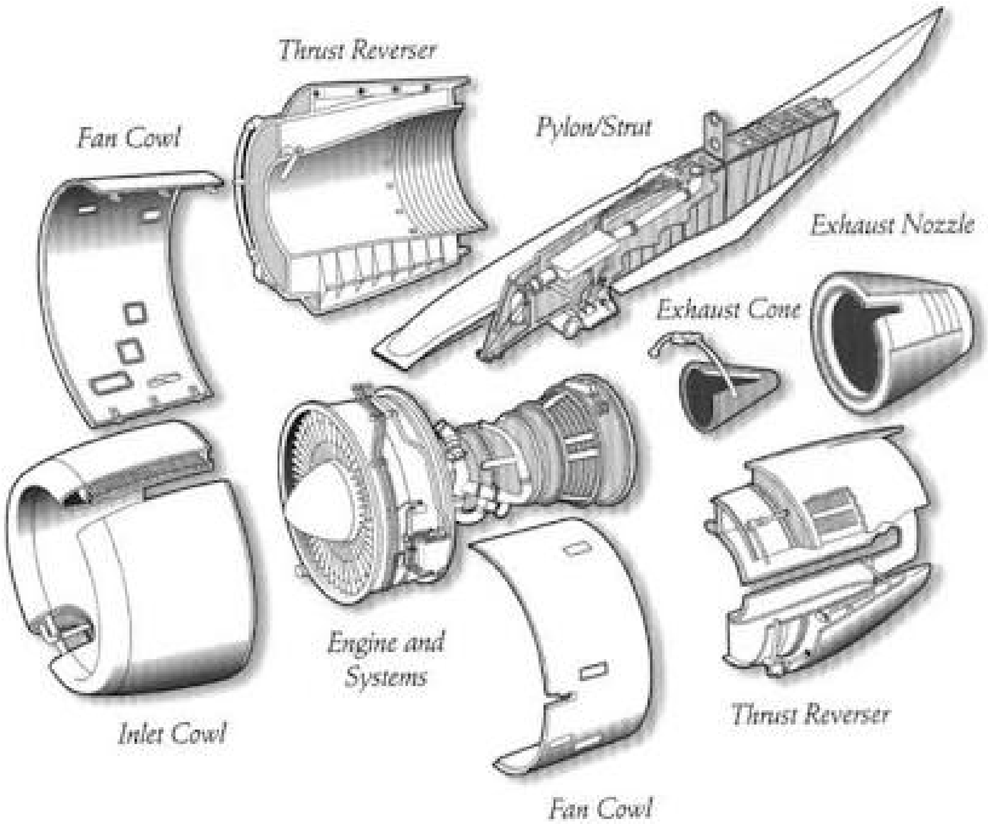
Power plant anatomy



The nacelle/短艙 is the aerodynamic structure around the basic engine to:

- Smooth the air around the engine to reduce drag
- Prevent damage to the external surface
- Given extra strength to the engine
- Make connections for air, fluids and electric systems

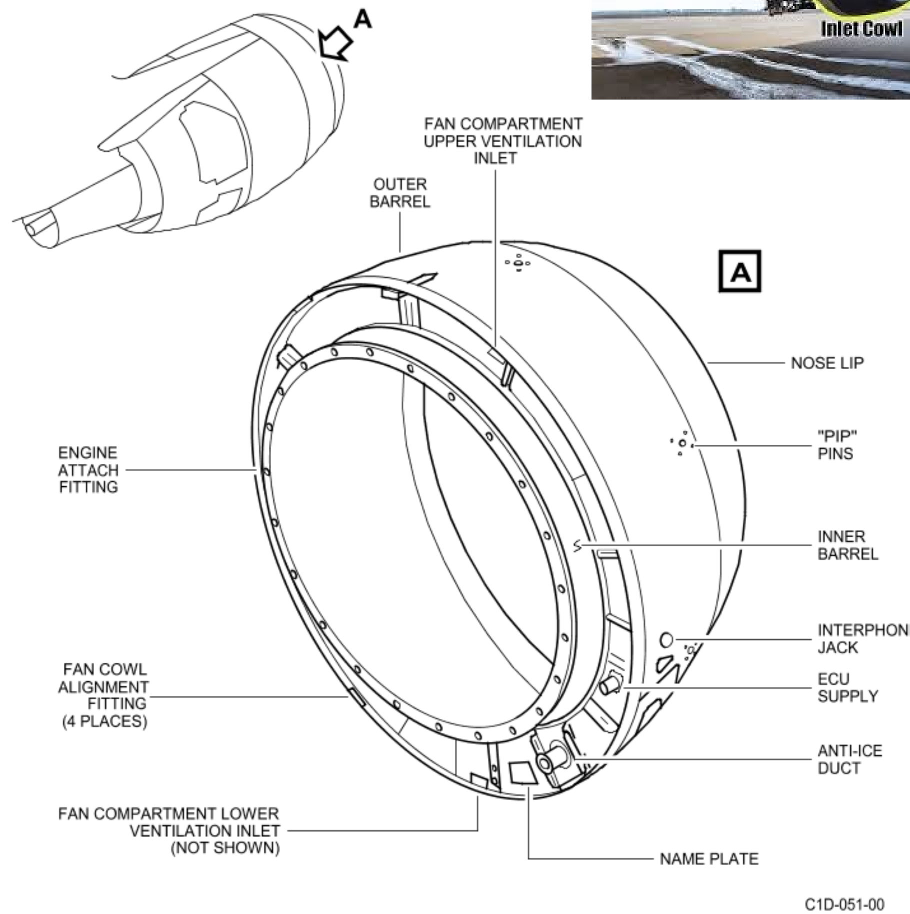
Power plant anatomy



- Cowls/整流罩 enclose the engine to form the engine nacelle

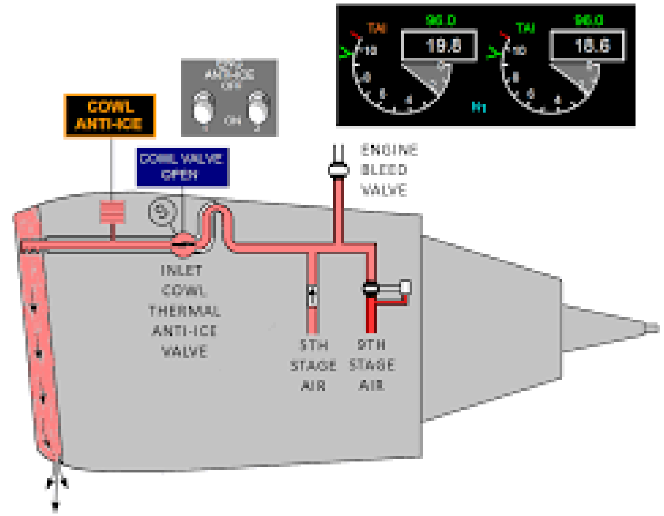
Air inlet cowl/進氣整流罩

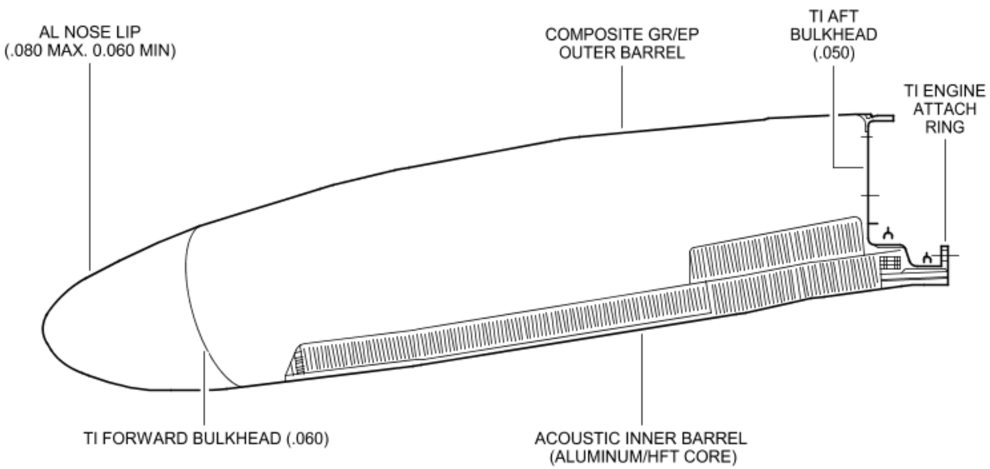
- The air inlet cowl is at the forward section of nacelle.
- It consists of
  - Inner and outer barrel
  - A nose lip, etc.
- It provides a smooth airflow into the engine
- Prevent ice formation at the front of the engine
- Attached on its rear flange to the engine fan case



Air inlet cowl/進氣整流罩

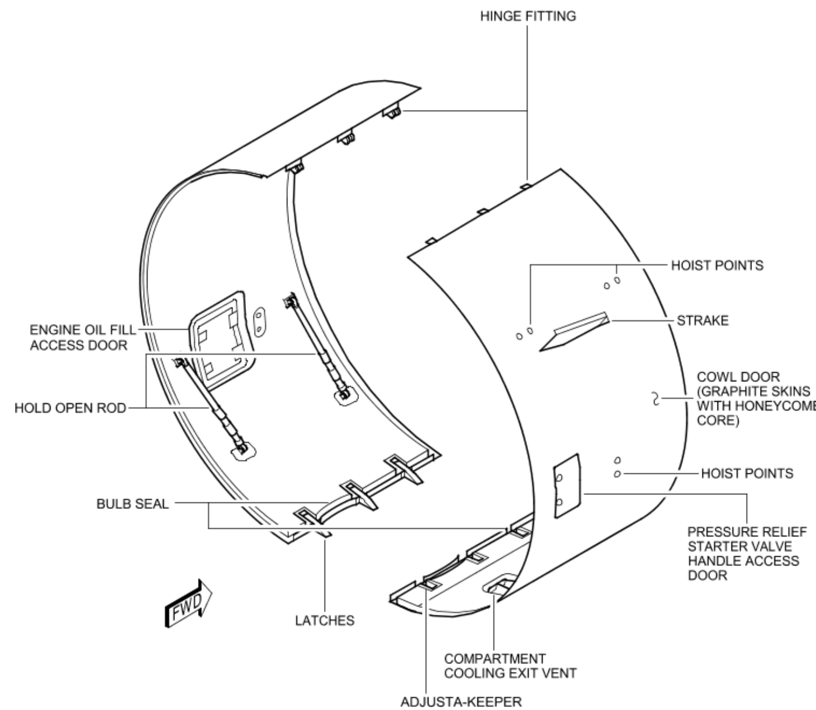
- The nose lip assembly consists of an outer lip skin, which comprise the anti-icing duct
- Acoustic liners are also installed on the air inlet cowl to reduce the noise

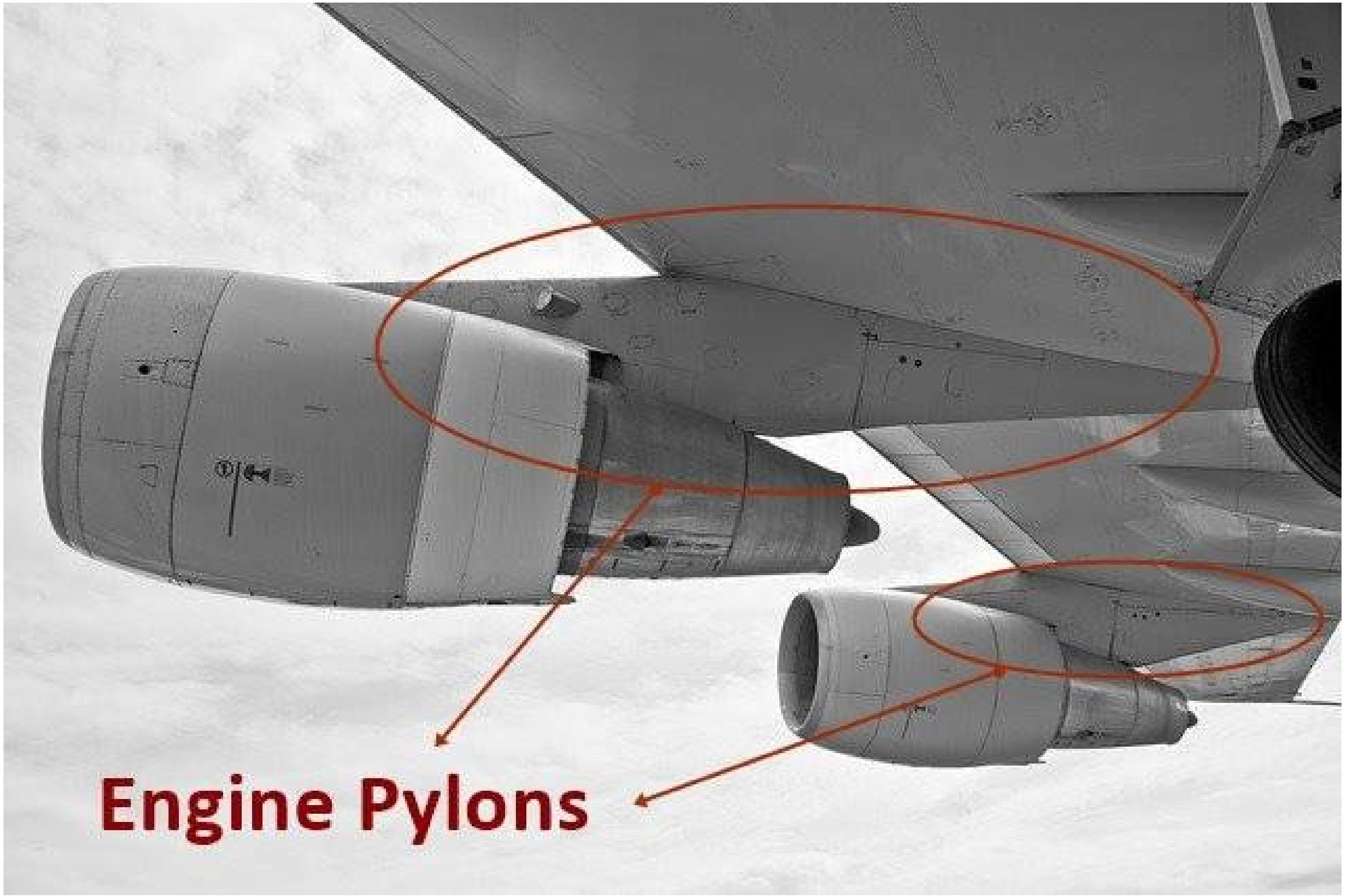




Fan cowl/風扇整流罩

- Main structure:
  - Fan cowl door assemblies enclose the engine fan
  - Each fan cowl door contains hoist points and rods to support
  - Each assembly is supported by hinges at pylon and centerline

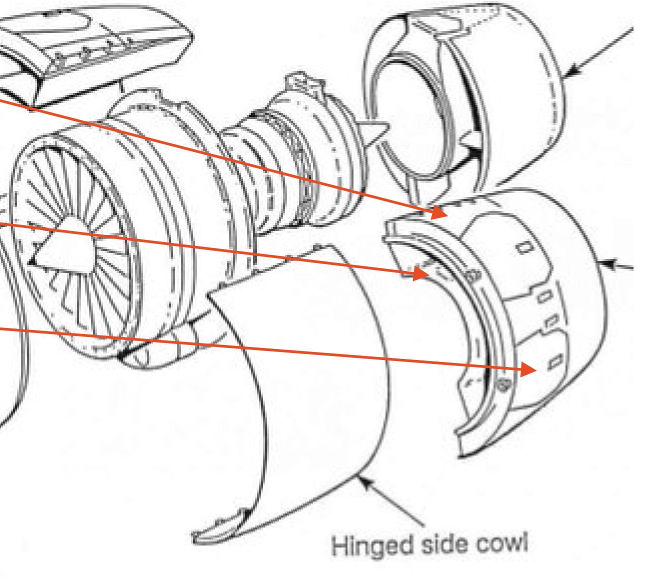




An engine pylon/引擎挂架 is a structural component that connects an aircraft engine to the wing or fuselage

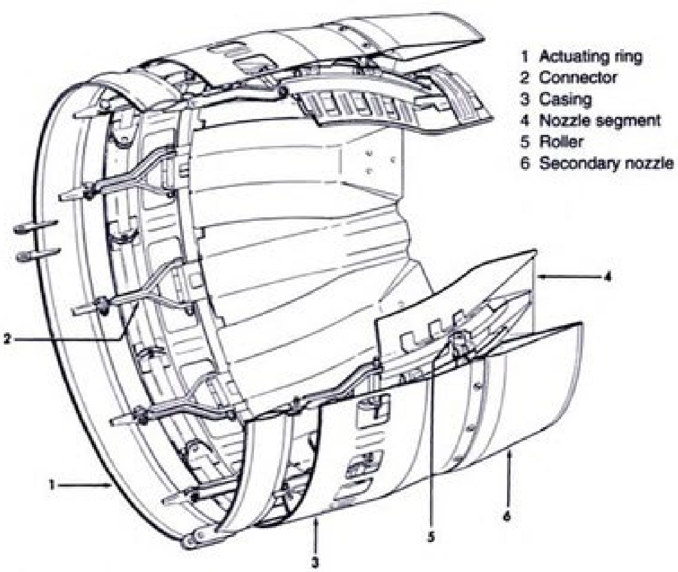
Thrust reverser cowl/反推裝置整流罩

- The thrust reverser is located between the fan cowl and exhaust nozzle, each is equipped with a cowl
  - When operating, four pivoting doors redirect the airflow to realize the braking effect.
- The cowl is hinged at the top to the pylon
  - Outer cowl controls the external flow pattern of the air from the fan
  - Inner cowl controls the inner flow passing the fan
  - Pivoting doors



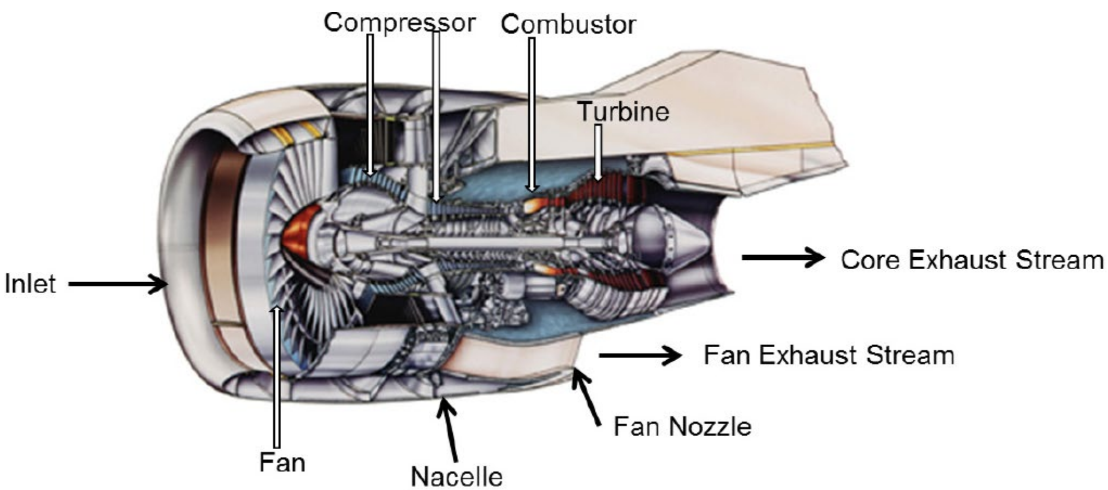
Common nozzle assembly (CNA)/共用噴嘴組件

- The cold bypass flow and hot gases exhausted from the engine core are collected and mixed at the nozzle
- Interchangeable assembly has acoustic liner
- It is supported metal struct to the inner duct assembly



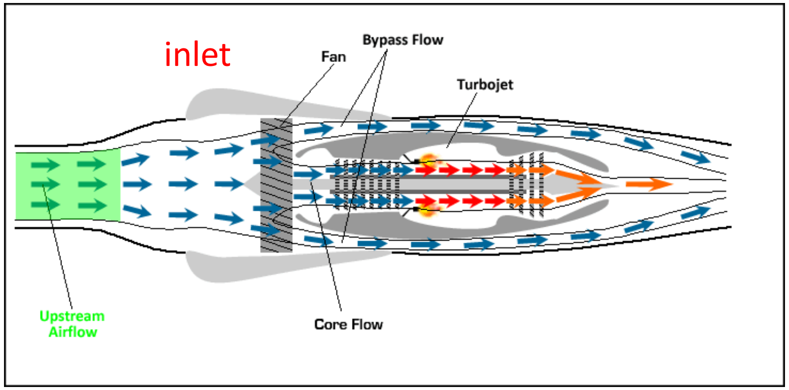
Every gas turbine engine has a combustion section, a compressor and a turbine. The compressor, burner, and turbine are called the core of the engine(核心機).

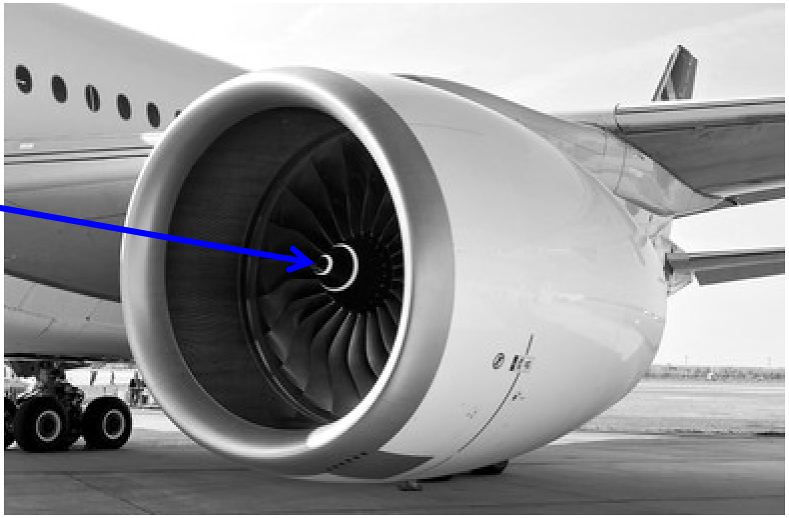
Engine construction components



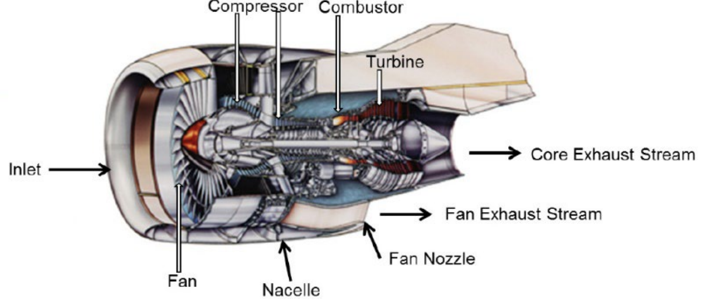
Air intake/進氣口

- Intake should be:
  - Able to admit/ingest the **maximum** amount of air
  - Deliver the air to **compressor** at high speed
  - Low drag and low noise levels
- The **inlet core** is used to:
  - Streamline the air
  - Anti-ide
  - Eager eye: scare birds

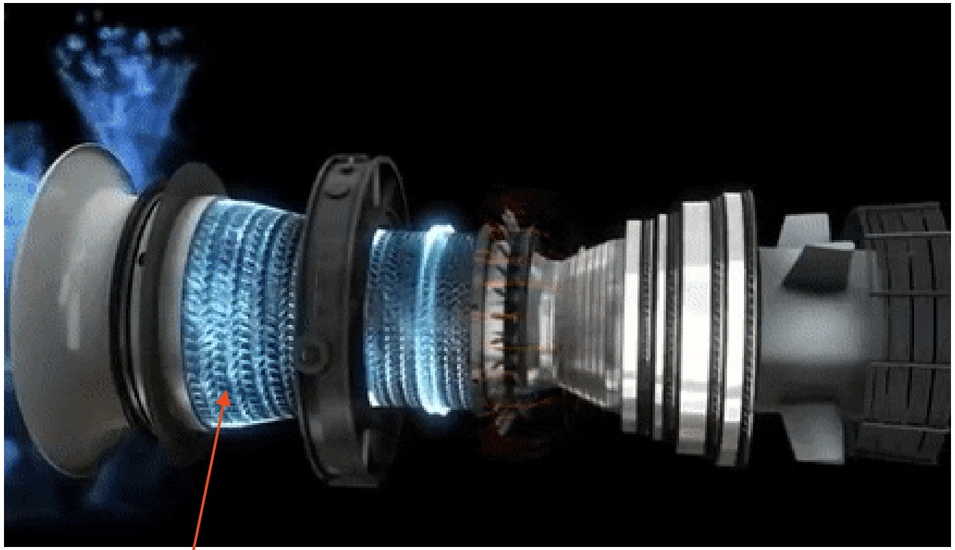


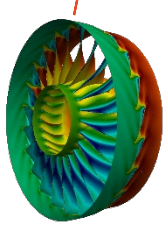


Compressor/壓氣機



- The compressor is used to:
  - Increase the air mass flow
  - Improve the combustion
  - Improve thermo-efficiency
- Components:
  - Rotor blades
  - Rotor shaft
  - Stator vanes
  - Stator casing
  - Stator seal



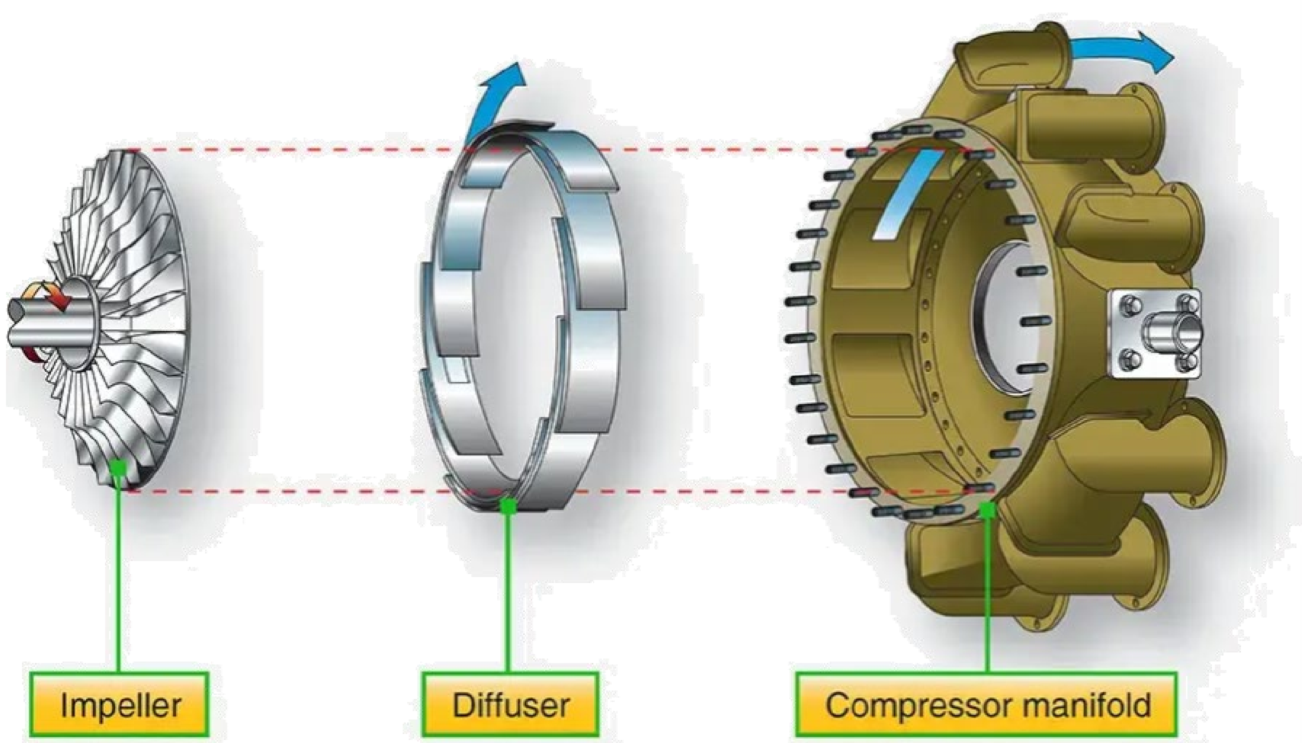


Compressor

- In a compressor, there are two major components:
  - Rotors/轉子
  - Stators/定子
- Rotors increase the velocity while the stator moderate the flow directions
- Based on the design, there are two main types of compressor
  - Radial compressor/Centrifugal compressor
  - Axial compressor

Centrifugal compressor/離心式壓氣機

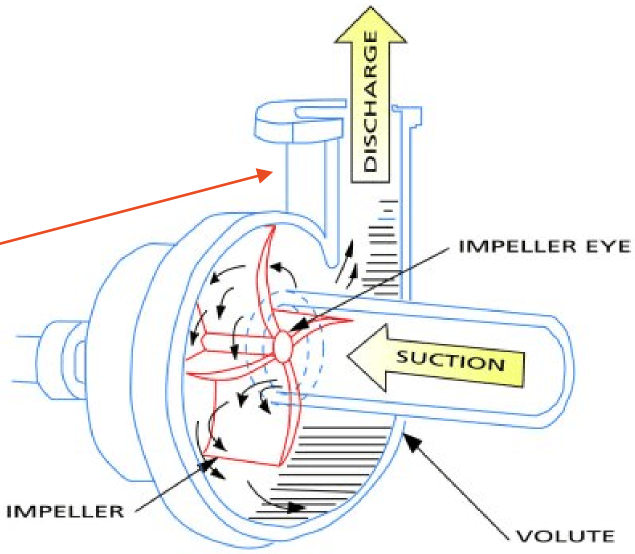
- The centrifugal compressor has been used in turbochargers(渦輪增壓器) before being used in the first turbojet engines.
- Key components of a centrifugal-flow compressor: (1) impeller, (2) diffuser and (3) Compressor manifold.



Centrifugal compressor

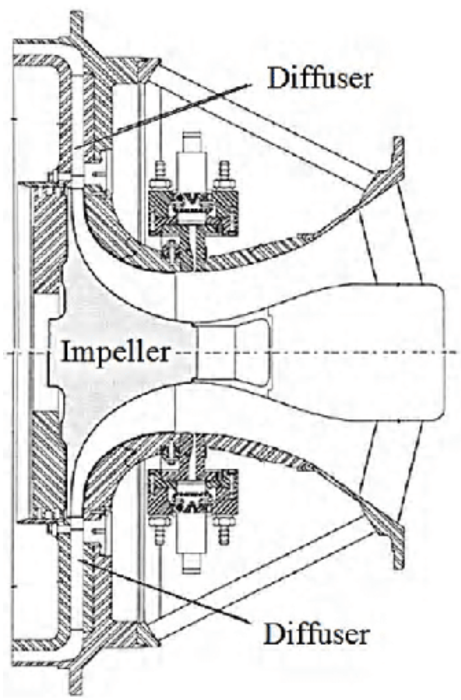
- Centrifugal compressor is so called radial compressor because the flow through the compressor is turned perpendicular to the axis of rotation – flow is radial.
- In operations, air is sucked through the intake to enter the impeller as the compressor begin rotating. As the flow travel through the centrifugal impeller, the impeller forces the flow to spin faster and faster in the outward direction - flow leaving the impeller at very high speed.

For aircraft engine compressor, the flow discharge is realized by diffusor.



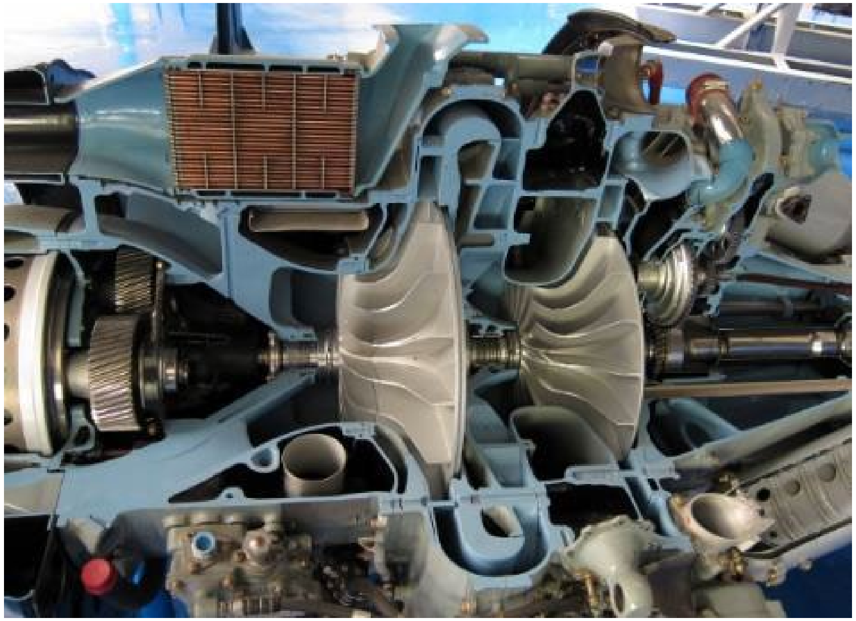
Centrifugal compressor

- The diffuser, or a stator, is an important part in the compressor to reduce the flow speed, resulting in the increase of pressure
- Compressor manifold can be viewed as the switch to regulate the air pressure.



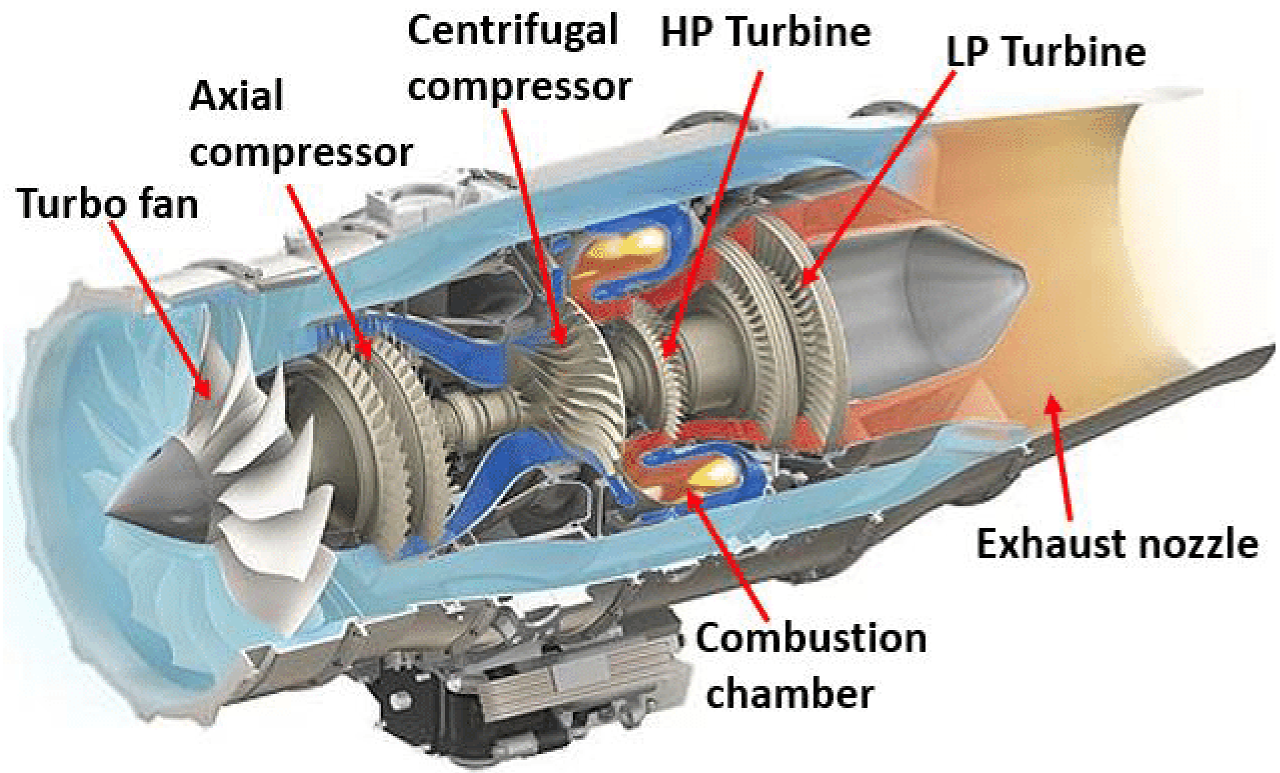
Centrifugal compressor

- The increase in velocity of the flow cause an increase in the total energy in the flow. As the flow reaches the stationary diffuser, it causes the flow to decelerate.
- The reduction in velocity causes the static pressure to rise. Most centrifugal compressors have a compression ratio of around 1:2.5 to 1:4.



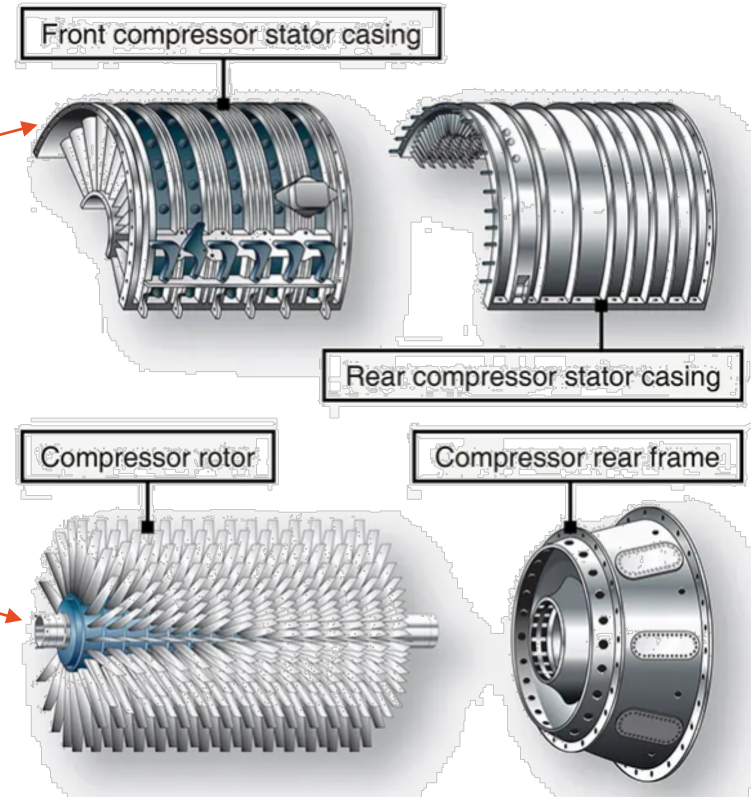
The compressor section of the Rolls Royce Dart engine was made up of two stages of centrifugal compressors.

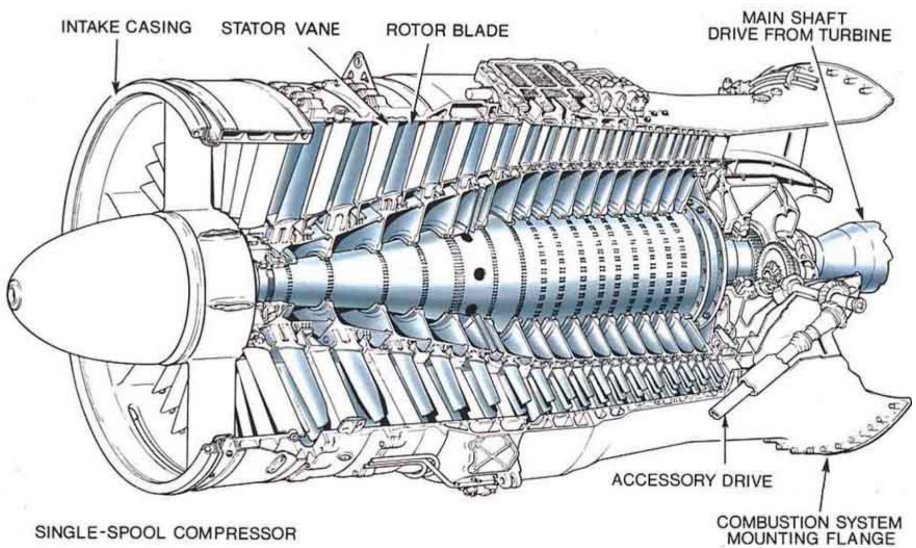
Axial and centrifugal compressors



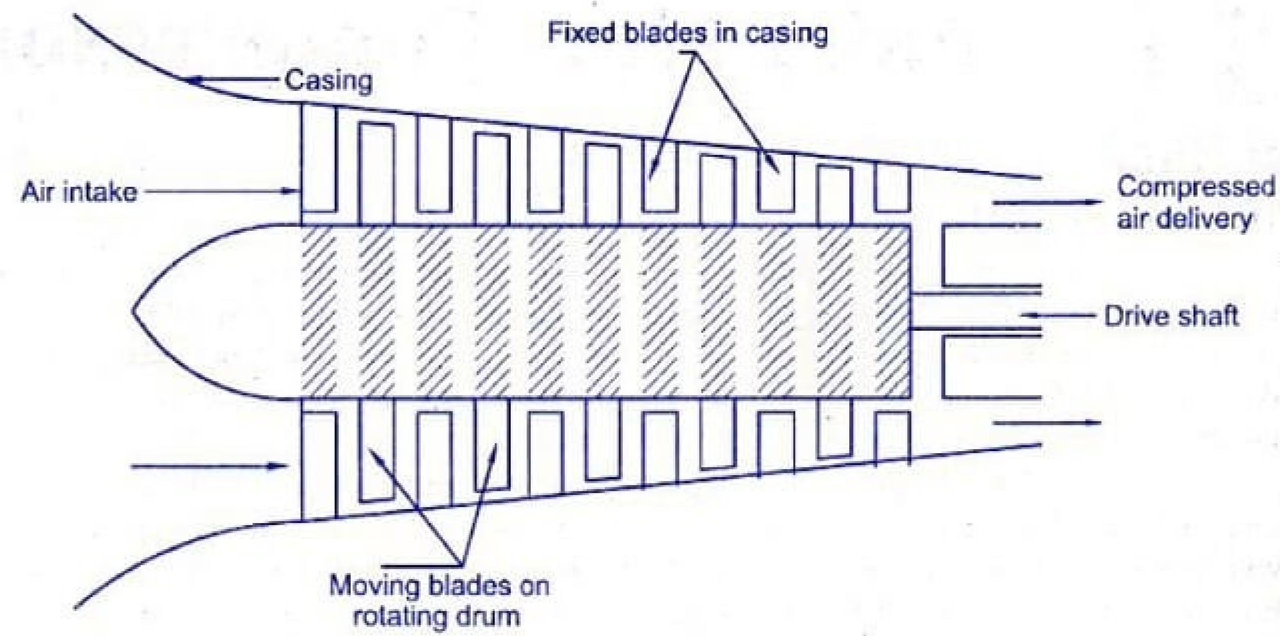
Axial compressor

- The axial compressor is made up of two major assemblies:
  - the casing with stationary blades called stators
  - the rotor with blades
- Every rotor is followed by a stator – forming a stage.



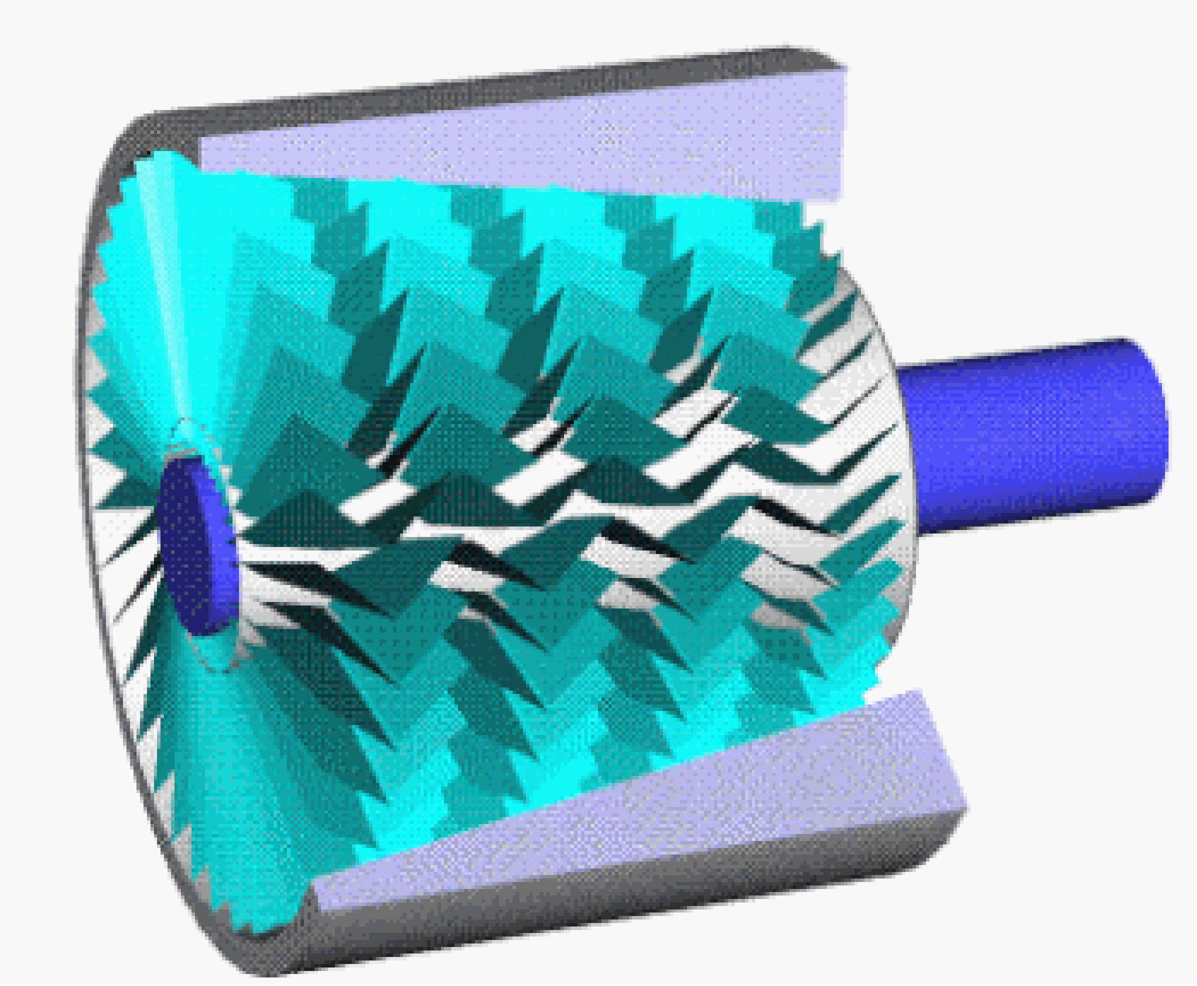


Axial compressor



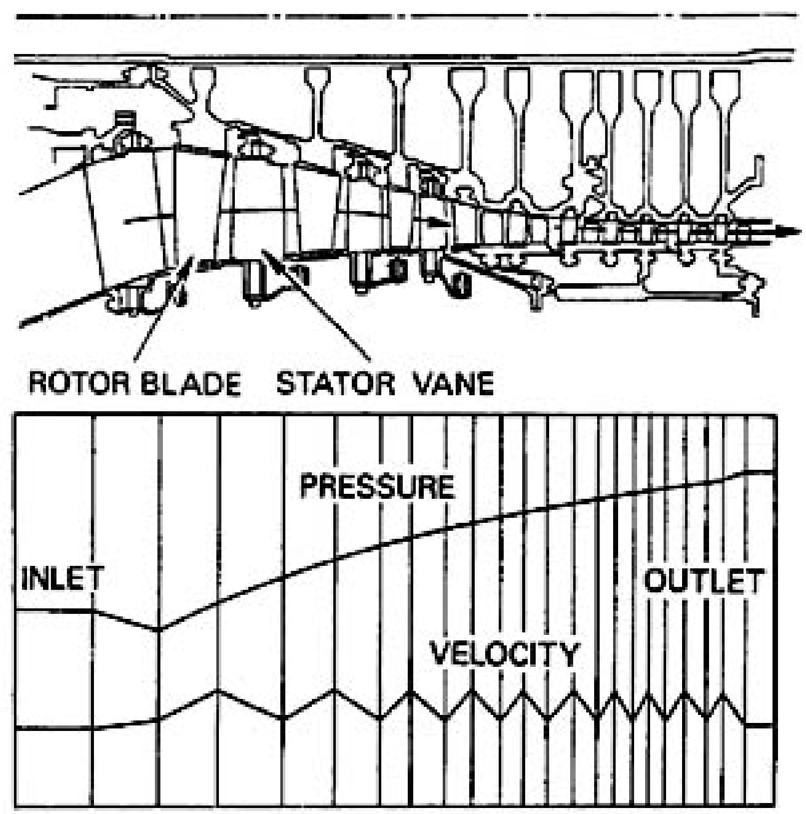
Flared stator (Drum rotor)

Rotor & stator in an axial compressor



Axial compressor

- An axial compressor continuously pressurize gases.
- It is a rotating, airfoil-based compressor, in which the air overall flows parallel to the axis of rotation.
- Each stage of the compressor incrementally boosts the pressure from the previous stage (compress ratio ~1.2-1.6).

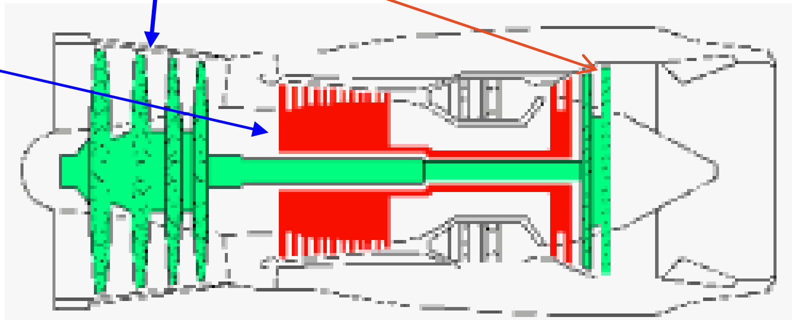


Axial compressor

- Axial flow compressors have the benefits of high efficiency and large mass flow rate.
- However, they do require several rows of stages to achieve a large pressure rise, making them complex and expensive.
  - In some aircraft gas turbine engines, the pressure of the air can rise by a factor of 30.
- The compressor is driven by turbine through a shaft. One spool is one set of independent compressor-shaft-turbine assembly.

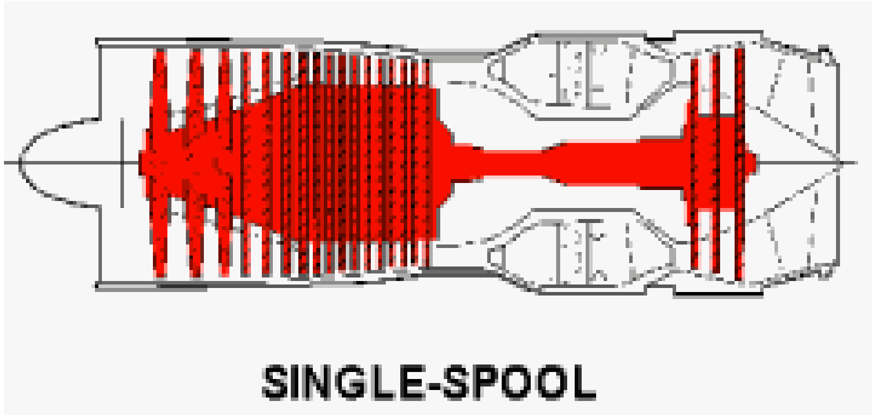
Axial compressor

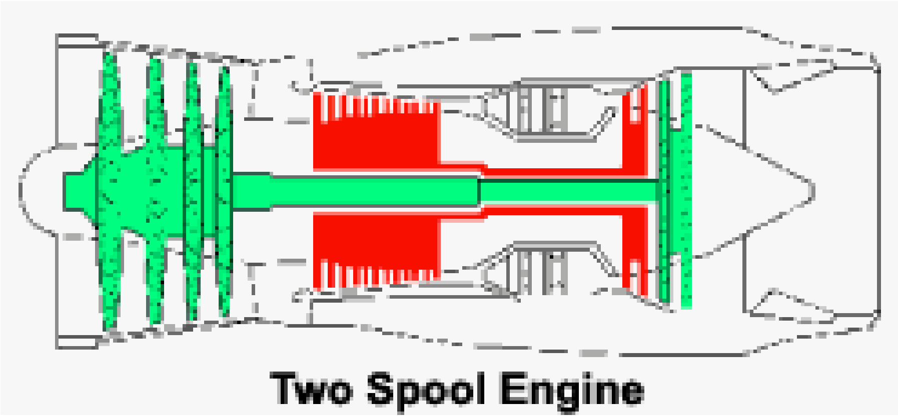
- Axial flow compressor engines may incorporate one, two, or three spools.
  - Spool is defined as a group of compressor stages rotating at the same speed.
- Two spool engine, the two rotors operate independently
  - The turbine assembly for the low-pressure compressor is the rear turbine unit .
  - This set of turbines is connected to the forward, low-pressure compressor by a shaft that passes through the hollow center of the high-pressure compressor and turbine drive shaft.

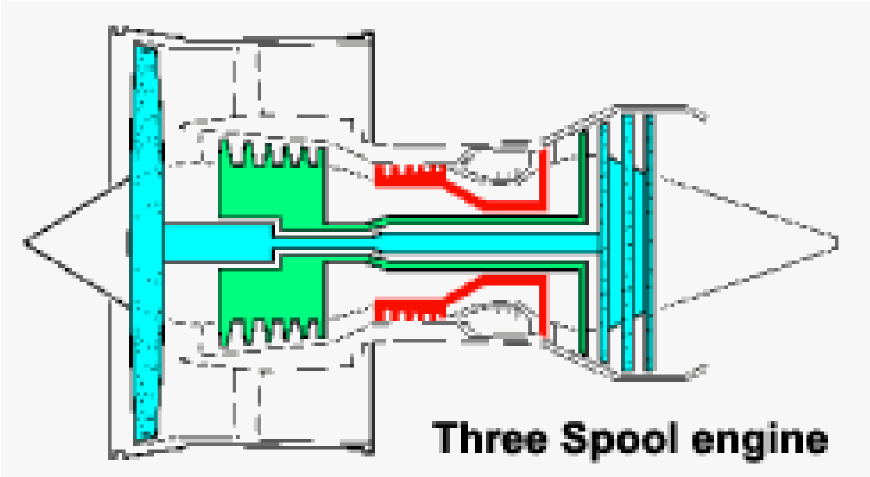


Two Spool Engine

Axial compressor



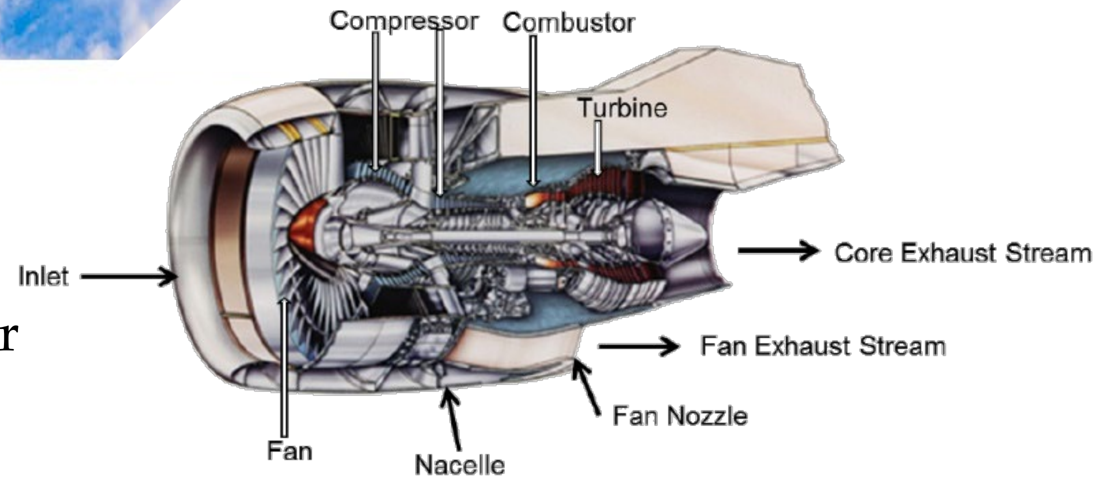


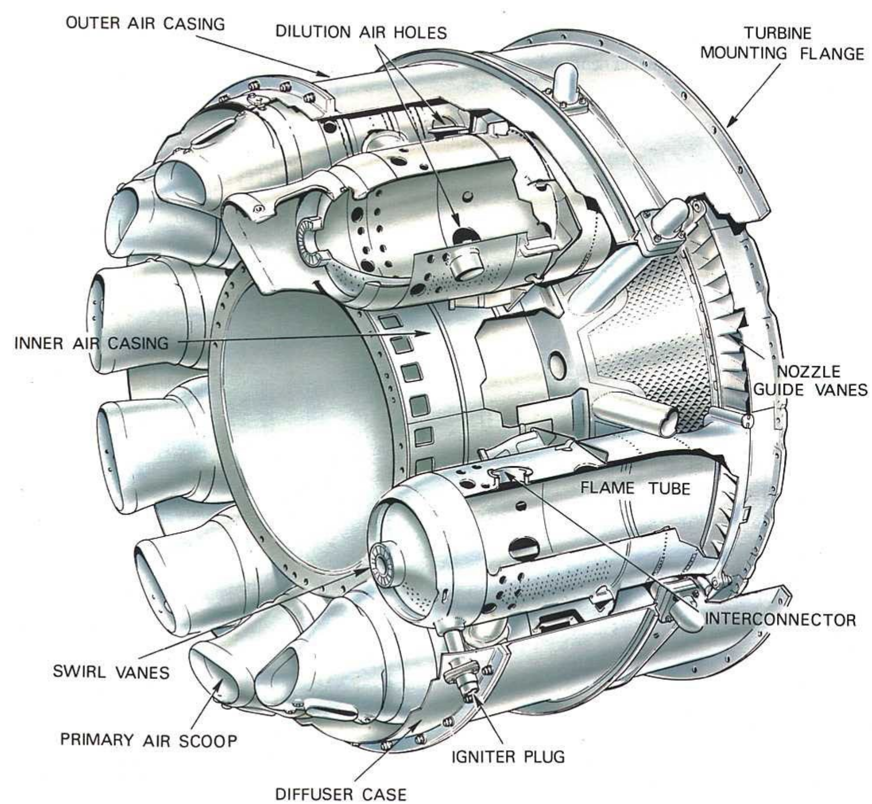


Multiple spools are used in gas turbine engines so that each spool may rotate at a different speed for optimum efficiency

Combustion chamber

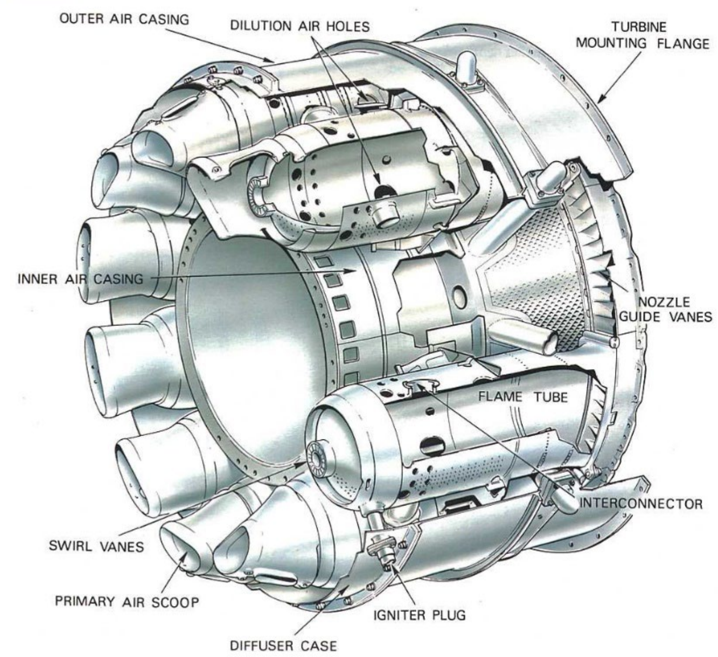
- The combustion chamber, or combustor, is used to:
  - Complete the combustion
  - Contain flame
  - Exhaust hot gases
  - Prevent back fire

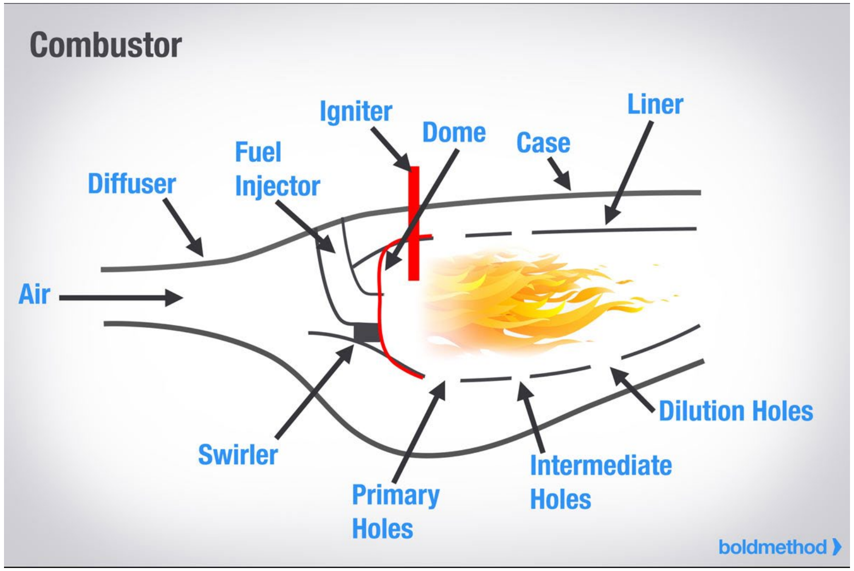




Combustion chamber

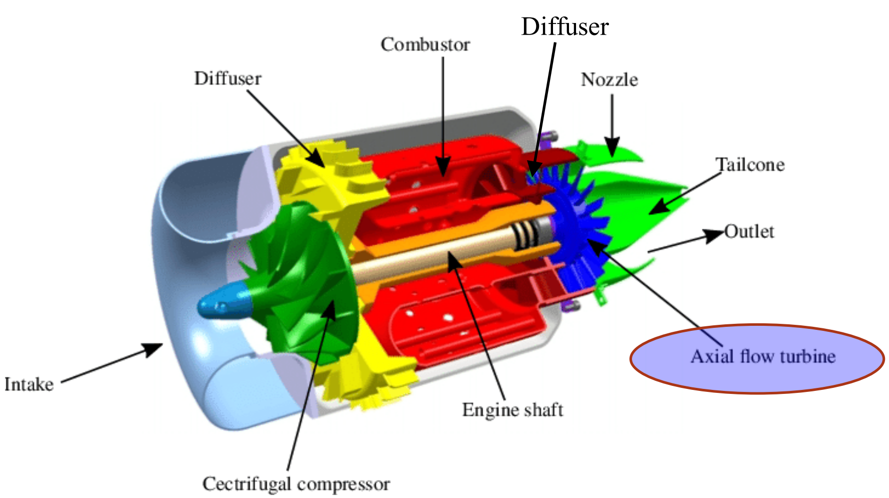
- A combustor mainly contains:
  - Outer casing
  - Outer liner
  - Diffuser
  - Inner casing
  - Inner liner
- The combustor shape can affect the flow **instability**, **turbulence**, **flame instability**, etc.
- Incomplete combustion can cause fuel particles strike at turbine blades and making hot spot.

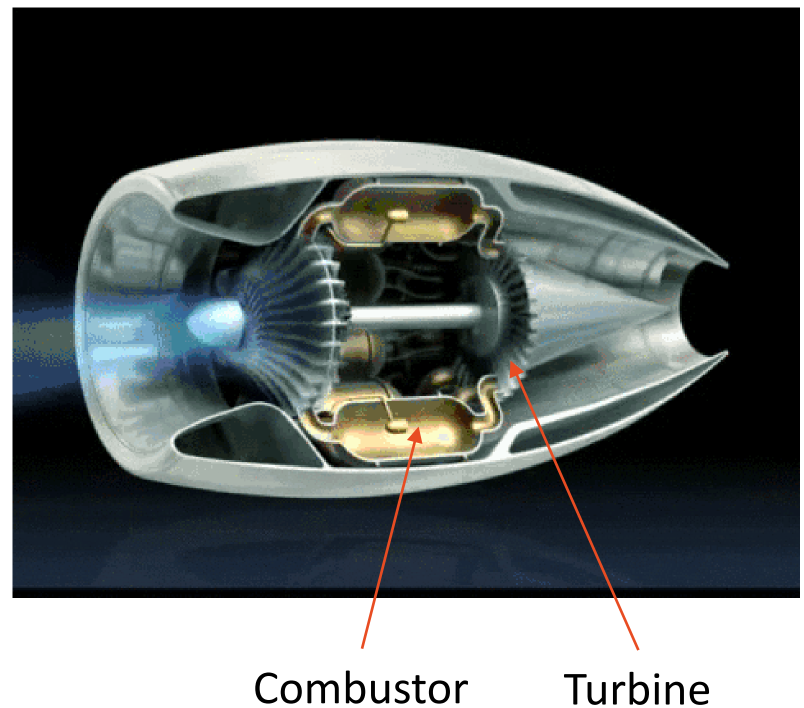




Turbine/渦輪/透平

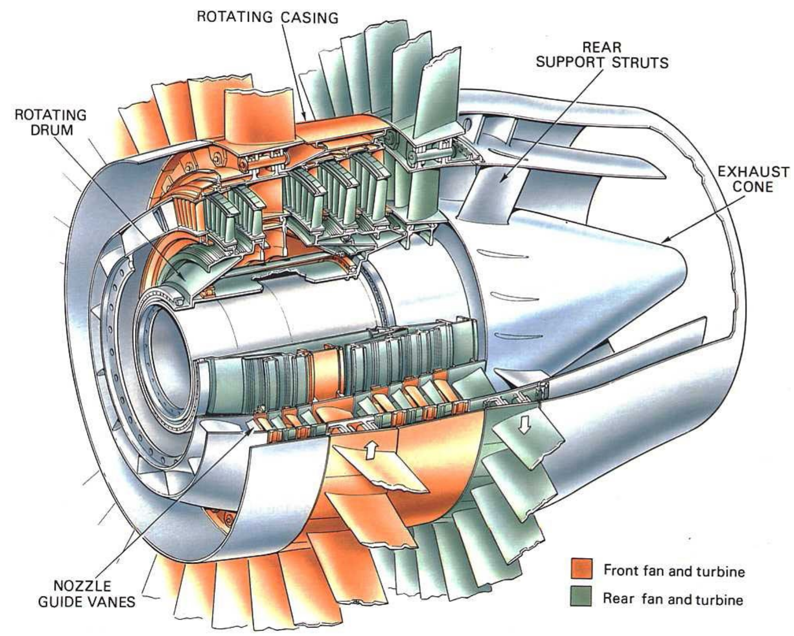
- Turbine is used to converts heat the kinetic energy generated into mechanical work via gas expansion
  - The mechanical work is used to drove compressors and other devices

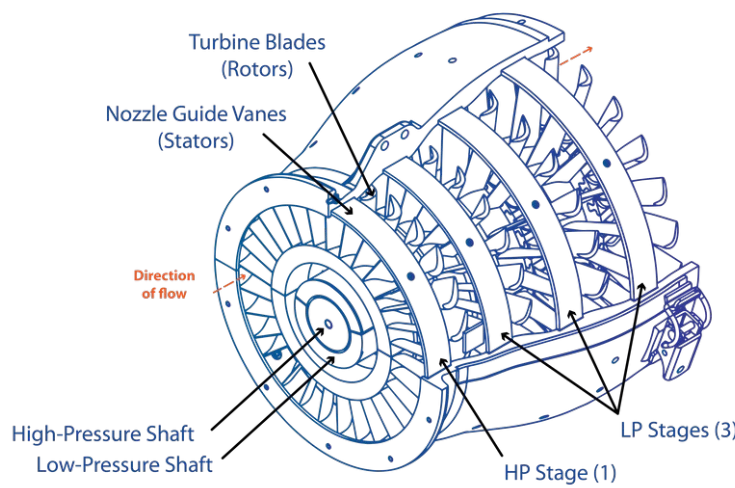




Turbine

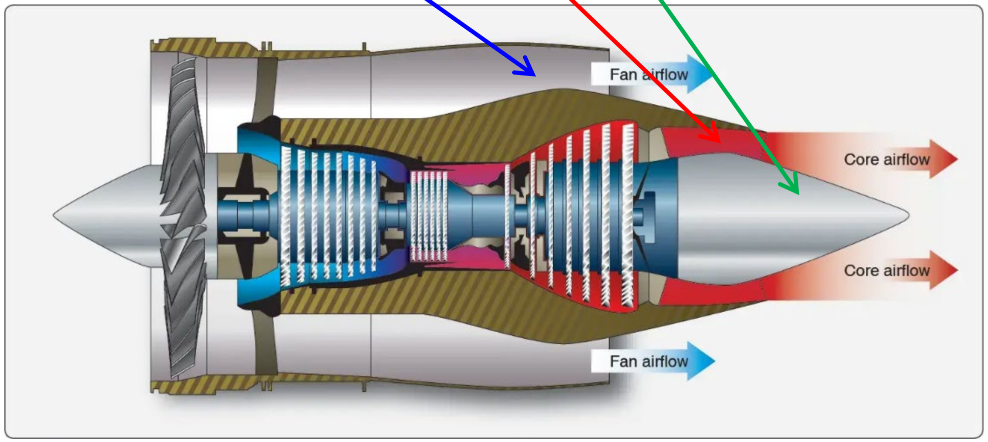
- A turbine contains the components
  - Nozzle guide vane:
    - To increase the velocity in the stream direction
    - To reduce the pressure and temperature
  - Blades:
    - To allow the gas expansion
    - To stabilize the flow
  - Shroud:
    - Protect casing via clearance
    - Sealing to prevent the leakage





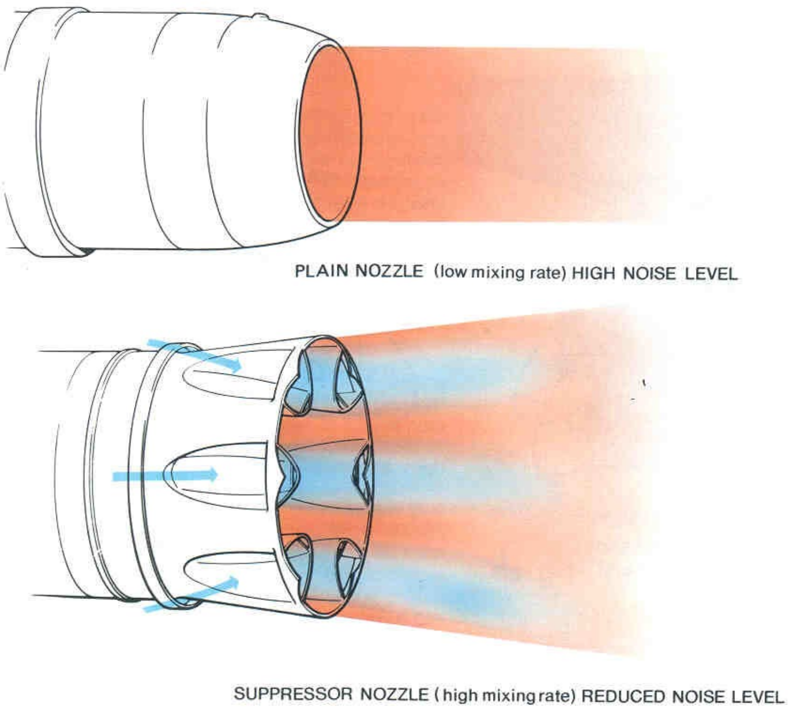
Exhaust system

- The nozzle is located at the end of the engine. It is used to
  - Accelerate hot gases to increase thrust
  - Clear the exhausted gases to prevent back pressure
- It contains:
  - Propelling nozzle (flow guiding)
  - Exhaust nozzle (flow acceleration)
  - Exhaust core (flow guiding)



Exhaust system

- The nozzle duct can also be classified to the non-mixing type or mixer type.
- The later can also be called the exhauster mixer, which can help reducing the jet noise
  - It help reducing the velocity of the core exiting air

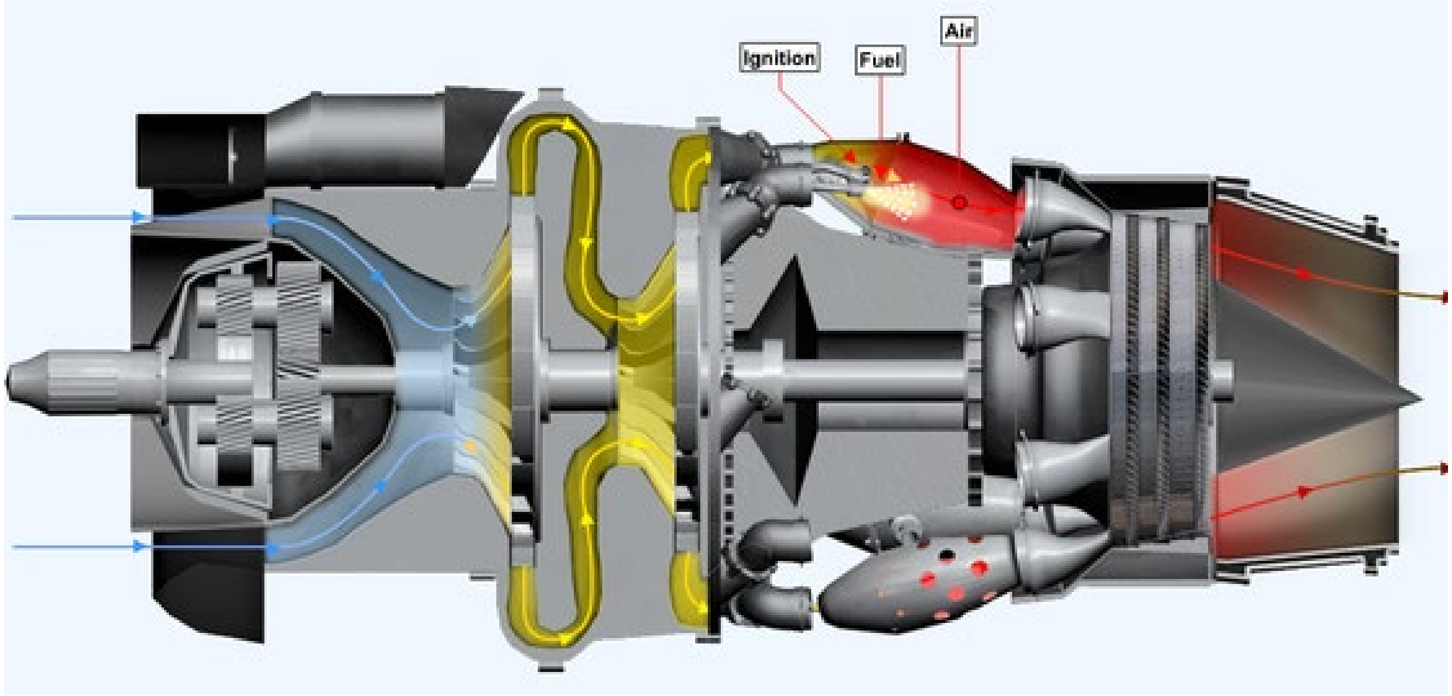


Exhaust mixer of a JT8D engine of a Boeing 737-200

Engine starting/引擎啓動

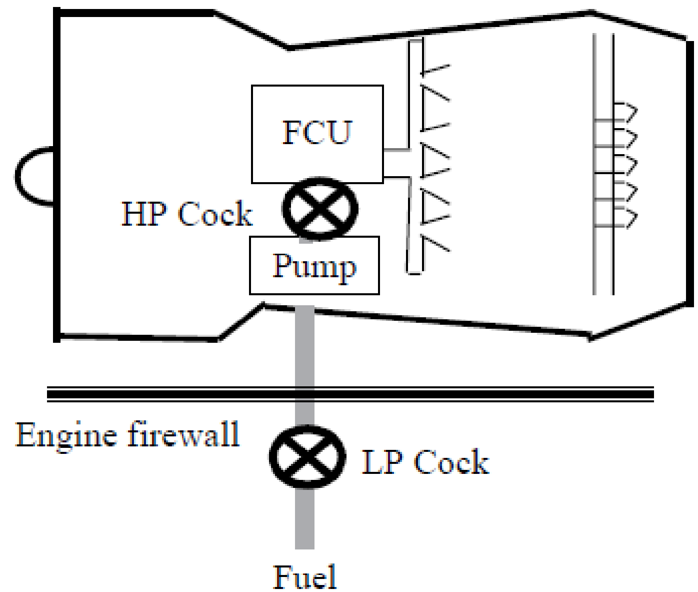
Engine starting

- The engine starting involves a sequence of events to allow the fuel flow, rotate the engine and provide ignition energy. It can be:
  - Performed manually with the pilot
  - Realized automatically by the engine control unit



Fuel control

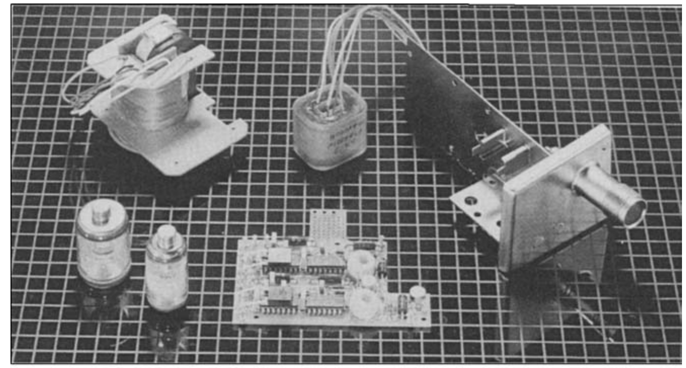
- During the staring, the fuel to the engine feed line is interrupted by two shut-off valves:
  - The low-pressure valve (i.e., the LP cock) or firewall shut-off valve: to isolate the engine.
  - The high-pressure valve (i.e., the HP cock) to open and close the fuel feed. It is close to the engine at the fuel control unit.

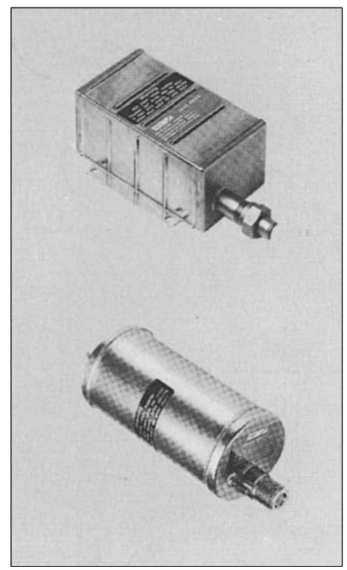


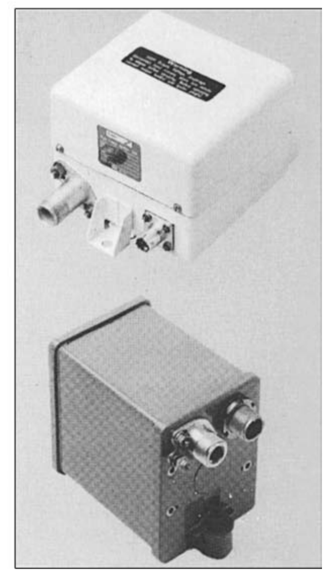
Aircraft shutoff valve

Ignition control

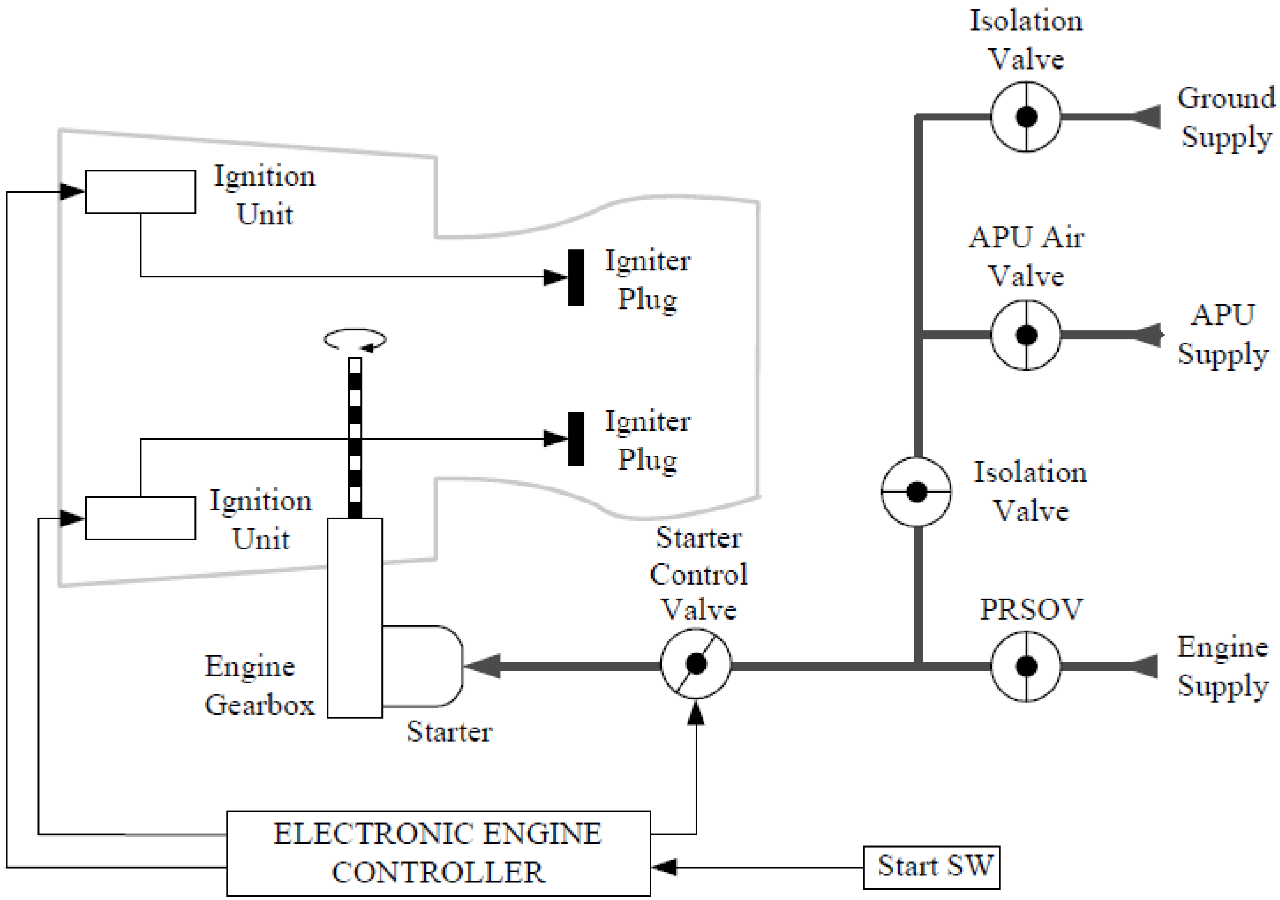
- The ignition system/點火系統 consists of high-energy ignitor that is switched on for a period during the start cycle.
  - The fuel vapor in the combustion chamber is ignited
- Ignitor: an electrically controlled plug to provide stored energy
  - High-energy system is used for starting
  - Low-energy system is used for maintain the engine ignition in heavy rain, icing, etc.





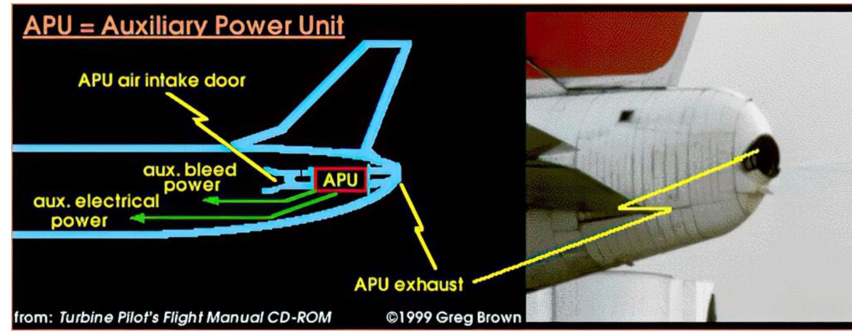


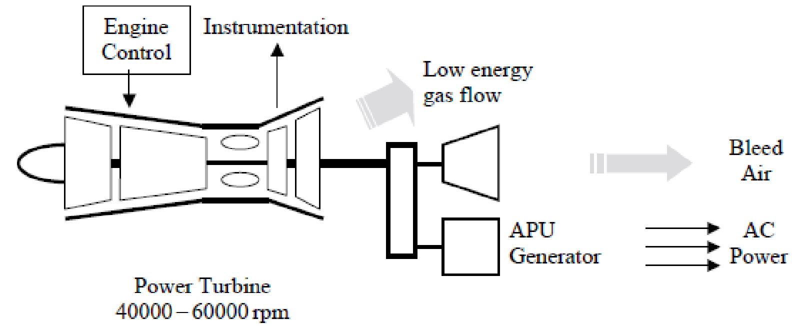
Ignition control

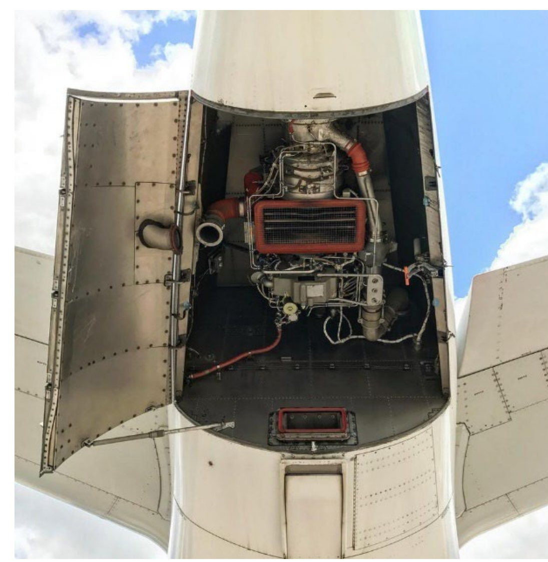


Engine rotation

- During the engine starting, the engine blades need to be rotated until the fuel is ignited and the temperature is high enough for combustion.
  - This state is called the self-sustaining of the engine.
- This process is often realized by using **external air source** or internal **auxiliary power unit**
- Auxiliary power unit (APU): a small gas turbine that is started prior to the engine start.
- APU is also helpful to relight the failed engine or to provide hydraulic energy during the relight process.

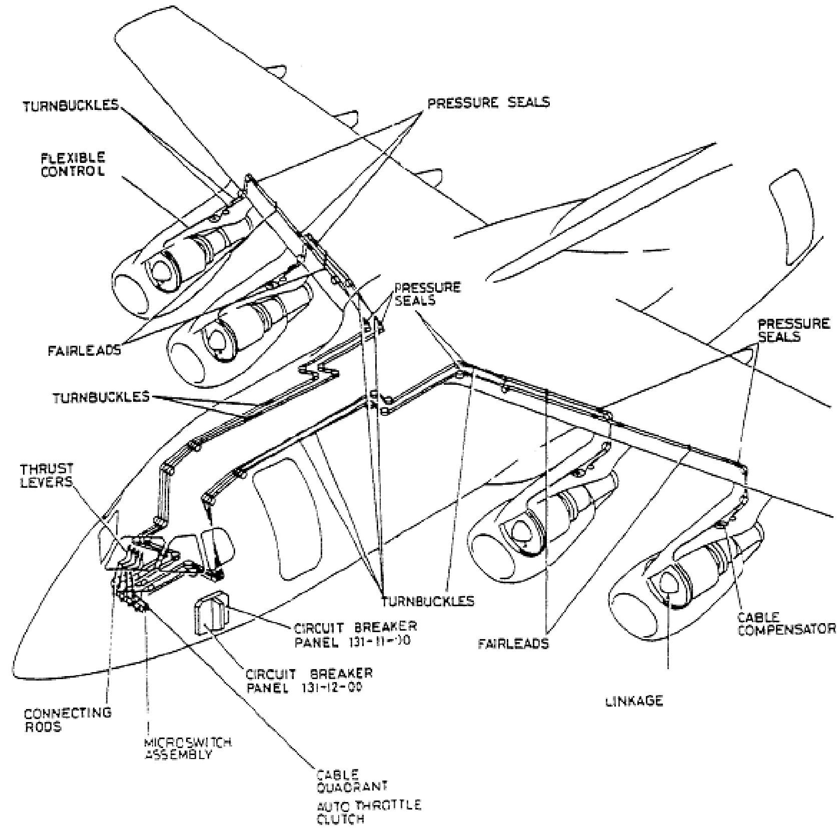






Throttle levers/氣流控制杆

- Throttle lever assembly is used to incorporate HP valve switches
  - The pilot has instinctive control of the fuel supply to the engine
  - Microswitches on the throttle box are used to shut the valves
- Push the levers forward operates the switches to open the fuel valves, which remains open during the normal operation
- The levers should be pulled back to its after position to allow the level to travel to shut off the fuel valve.



A Typical Mechanical Engine Control System.

Engine starting sequence

- A typical engine starting sequence is:
  - Open LP valves
  - Rotate the engine via APU
  - Supply ignition energy
  - Set throttle levers to idle- to open HP valves
  - Switch off ignition when self-sustaining
  - Switch off rotation power source

Engine performance: brief introduction

Engine performance

- The thrust generated by the jet engines are related to the large-volume high-speed exhaust gases at the exit
- The thrust overcomes the drag experienced by the airplane
- The net thrust estimation:

$$F_{net} = (\dot{m}_{\text{air}} + \dot{m}_{\text{fuel}}) \cdot V_{\text{jet}} - \left(\dot{m}_{\text{air}} \cdot V_{\text{airplane}}\right)$$

Net thrust of engine

Total mass flow rate at jet

Exhaust velocity

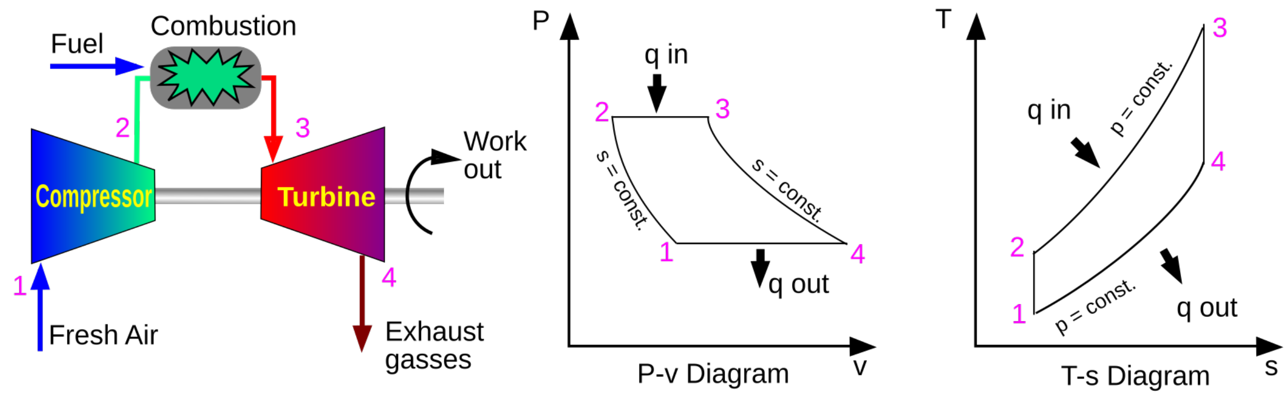
Mass flow rate of incoming air

Flight speed

George Brayton

Engine performance

- A part of the engine power is used to drive the turbine
- The process is the so-called Brayton Cycle
  - – 1 - 2 Adiabatic compression in the inlet and compressor;
  - – 2 - 3 Constant pressure fuel combustion
  - – 3 - 4 Adiabatic, quasi-static (or reversible) expansion in the turbine
  - – 4 - 1 Cool the air at constant pressure back to its initial condition.



Engine performance

- In addition to producing high-speed jet flow, engine also provides:
  - Electrical power
  - Hydraulic power
  - Pneumatic power and pressurization
  - Hot-air for anti-ice protection, etc.

Engine performance

- The engine thrust can be measured by Engine pressure ratio (EPR):
  - Ratio of the total pressure at exhaust to the total pressure in front the compressor. It is often used to indicate the engine thrust.

$$\mathrm{EPR} = \frac{\mathrm{P_{T_7}}}{\mathrm{P_{T_2}}}$$

  - It is a primary thrust setting parameter in PW and RR engines

$$\boxed{P_{\mathrm{T}} = P_s + \frac{1}{2}\rho V^2 = P_s + \frac{1}{2}\underbrace{[\rho V]}_{\dot{m}} \cdot V}$$

In engine, the dynamic pressure effect on thrust is much higher than static pressure

Engine performance

- Propulsive efficiency

$$\eta_p = \frac{\text{propulsive work to aircraft}}{\text{mechanical work by engine}}$$

- Thermal efficiency

$$\eta_t = \frac{\text{mech. energy output}}{\text{available heat energy of the consumed fuel}}$$

- Overall efficiency:

$$\eta_{\text{total}} = \eta_p \times \eta_t$$

- Specific fuel consumption (SFC): the amount of fuel required to produce on pound of thrust in one hour

Details to describe the engine performance should be covered by other specific courses.

Summary

Summary

- Types of the aircraft are introduced
  - Turbojet, turbofan, turboprop, turboshaft
- Key coating components of the aircraft engine are introduced
- Key construction components of aircraft engine are introduced
- Engine starting
- Brief introduction to the parameters related to engine performance