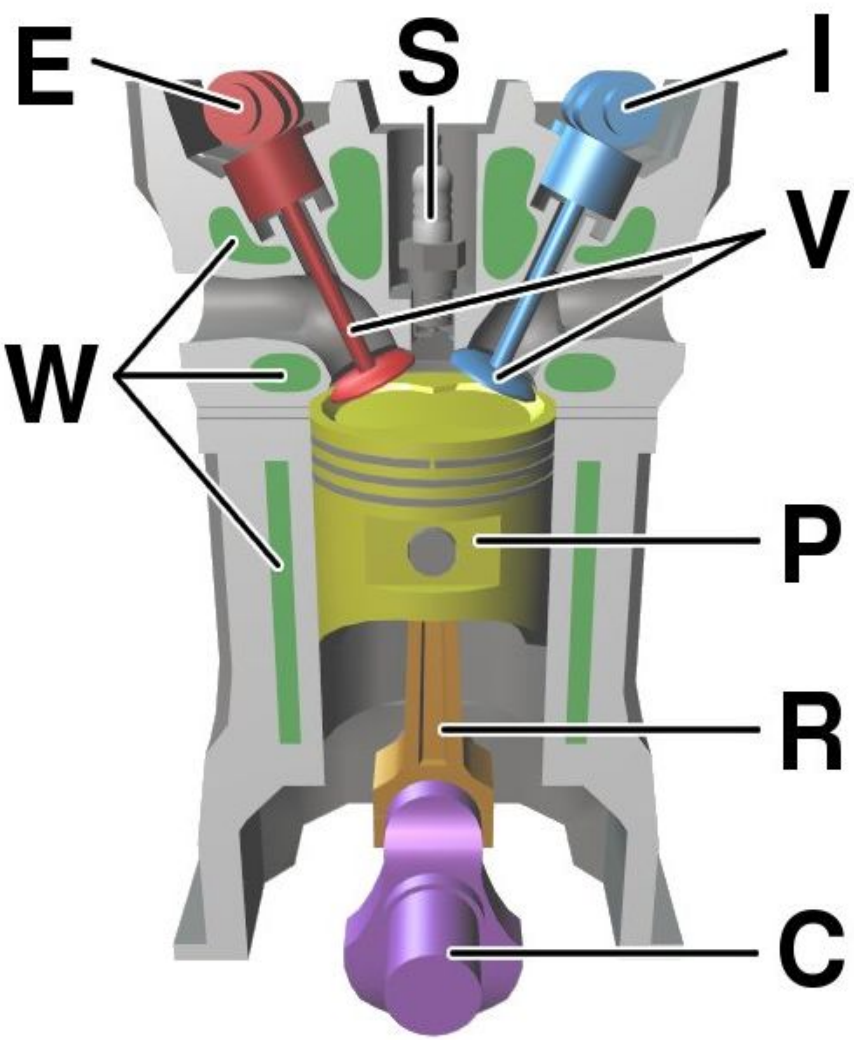
AIRCRAFT ENGINES

The term aircraft engine

- refers to reciprocating and rotary internal combustion engines used in aircraft. Jet engines and turboprops are the other common aviation power plants; while operation differs substantially, the basics here apply to all types.

Internal combustion piston engine



Components of a typical, four stroke cycle, internal combustion piston engine.

- E - Exhaust camshaft
- I - Intake camshaft
- S - Spark plug
- V - Valves
- P - Piston
- R - Connecting rod
- C - Crankshaft
- W - Water jacket for coolant flow.

Camshaft - стержень (меняющий направление движения механизма)

Spark plug - свеча зажигания

Rod-штифт

Crankshaft – коленчатый вал

Jet enjines

- A jet engine is an engine that discharges a fast moving jet of fluid to generate thrust in accordance with Newton's third law of motion.

Jet enjines

This broad definition of jet engines includes

- turbojets,
- turbofans,
- rockets,
- ramjets,
- pulse jets
- pump-jets,

Jet enjines

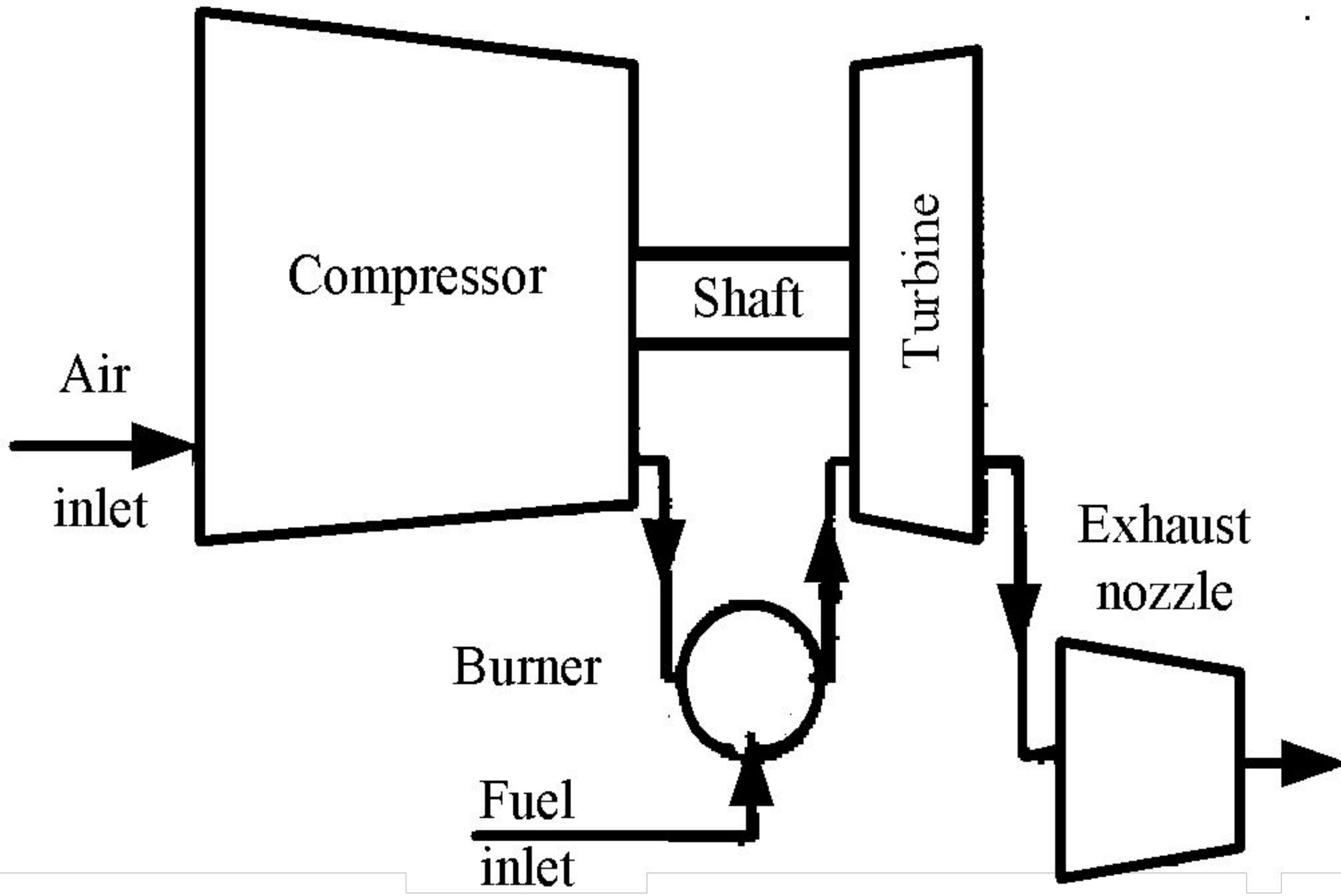
In common usage, the term generally refers to a gas turbine Brayton cycle engine, an engine with a rotary compressor powered by a turbine, with the leftover power providing thrust.

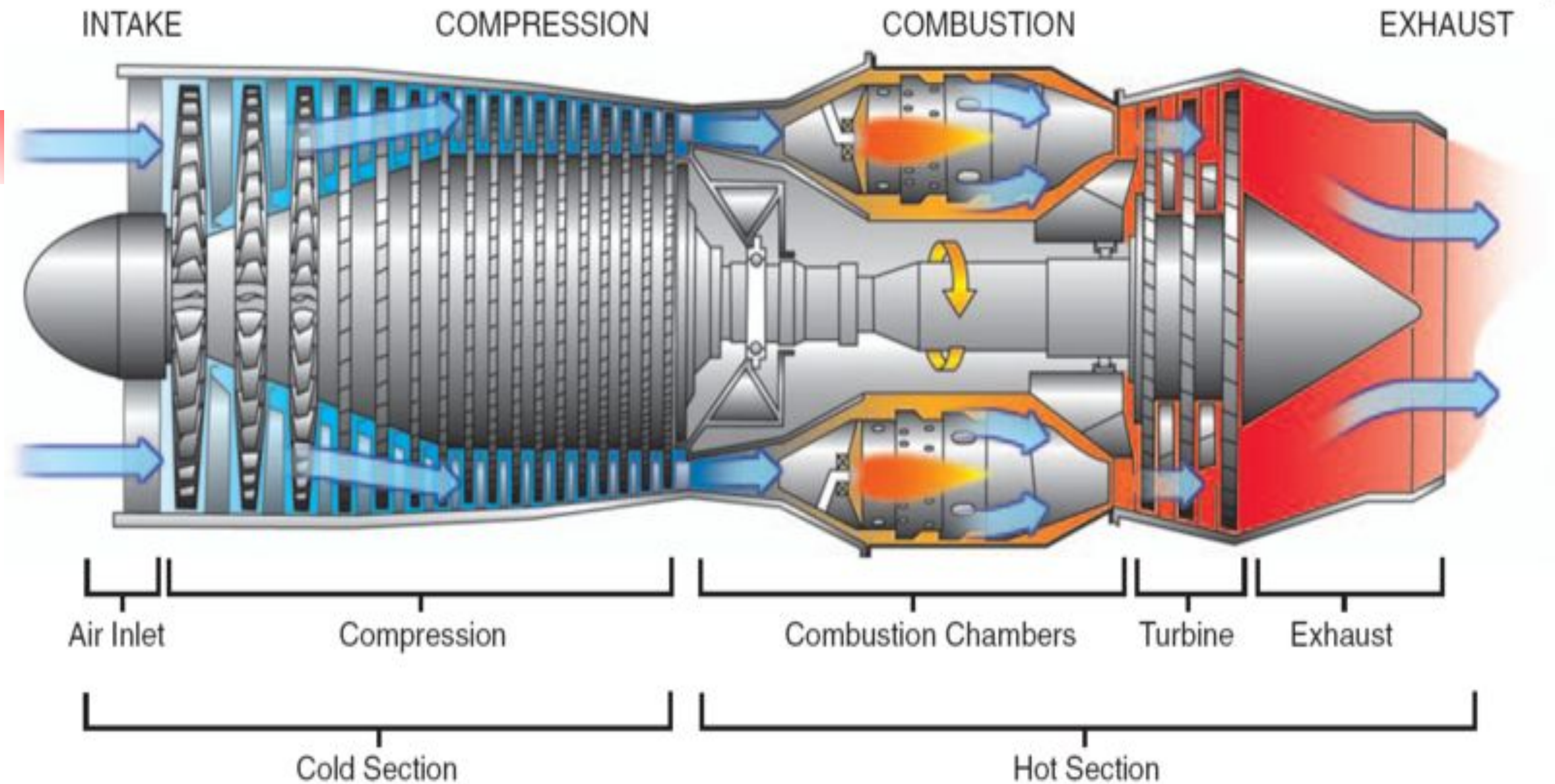
The first look

Basically, a gas turbine engine consists of five major sections:

- an ***inlet duct***,
- a ***compressor***,
- a ***combustion chamber*** (or chambers),
- a ***turbine wheel*** (or wheels),
- an ***exhaust duct***.

A turbine engine scheme




INTAKE
COMPRESSION
COMBUSTION
EXHAUST
Air Inlet
Compression
Combustion Chambers
Turbine
Exhaust
Cold Section
Hot Section

Cold Section:

Air intake

Preceding the compressor is the air intake (or inlet), which is designed to recover, as efficiently as possible, the ram pressure of the streamtube approaching the intake. Downstream of the intake, air enters the compressor.

Compressor or Fan

The compressor is made up of stages. Each stage consists of vanes which rotate, and stators which remain stationary.

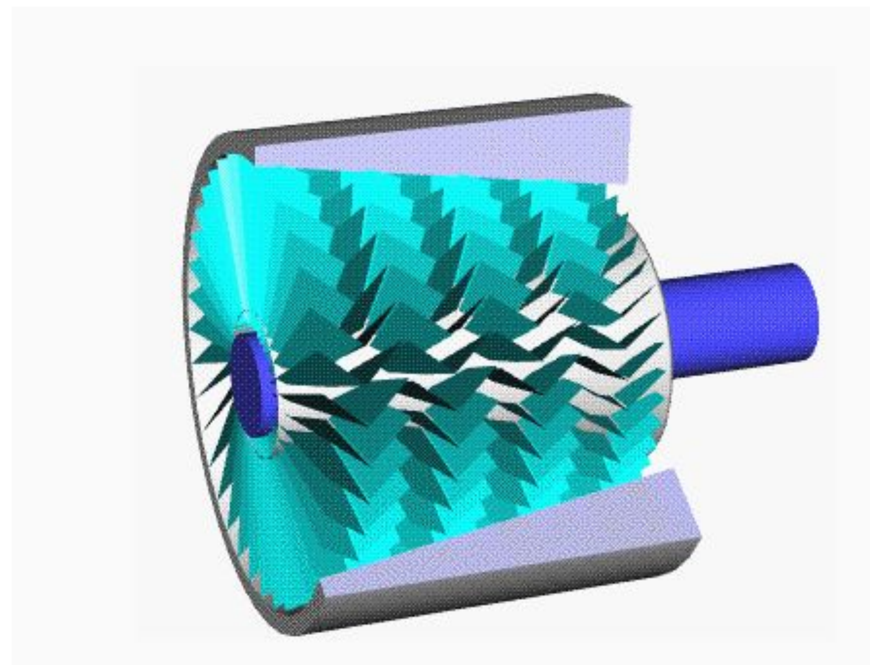
As air is drawn deeper through the compressor, its heat and pressure increases.

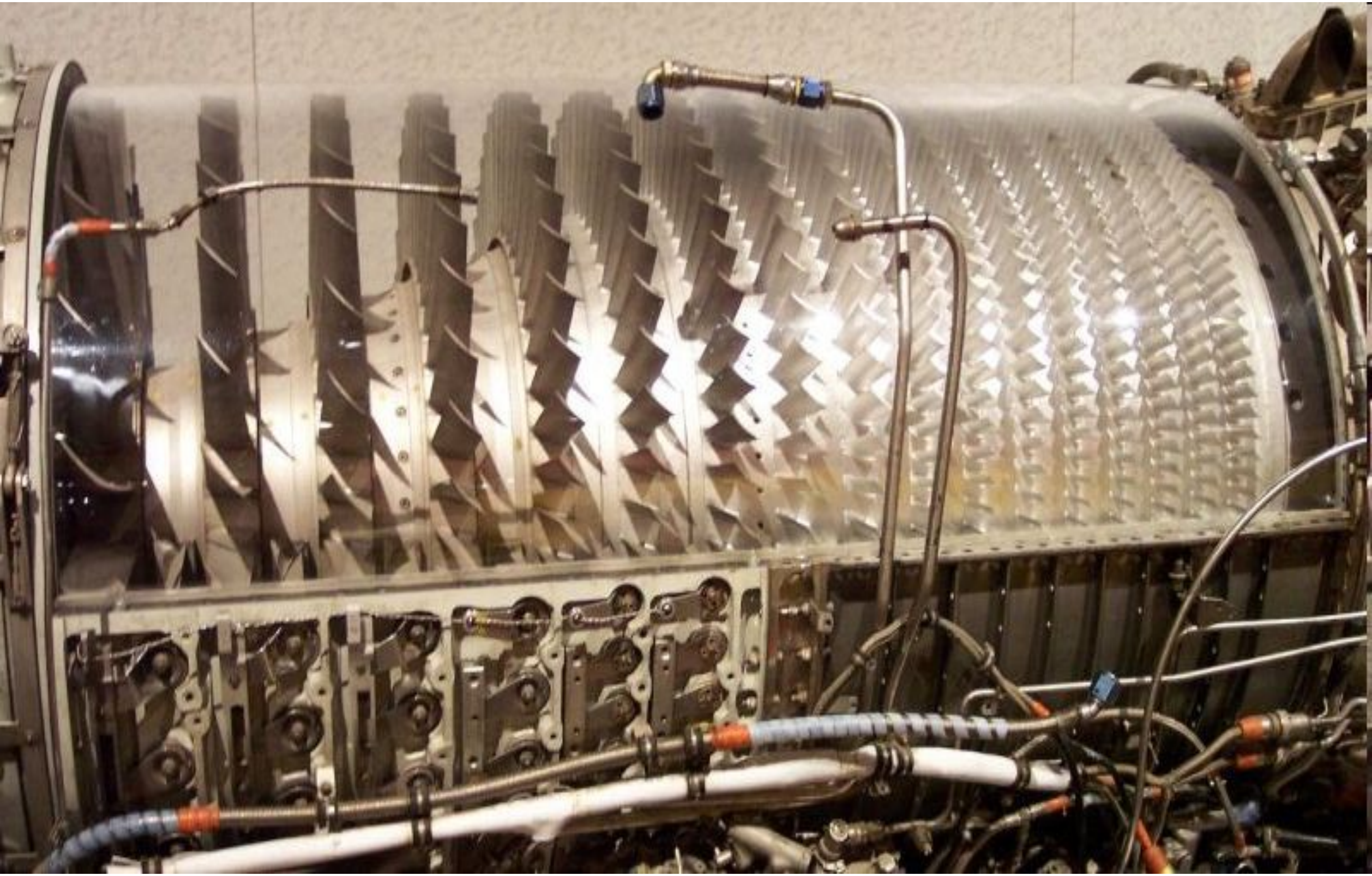
Energy is derived from the turbine (see below), passed along the shaft.

Vane - лопатка

Comressor

- The compressor, which rotates at very high speed, adds energy to the airflow, at the same time squeezing it into a smaller space, thereby increasing its pressure and temperature.





Common:

- Shaft — The shaft connects the turbine to the compressor, and runs most of the length of the engine.

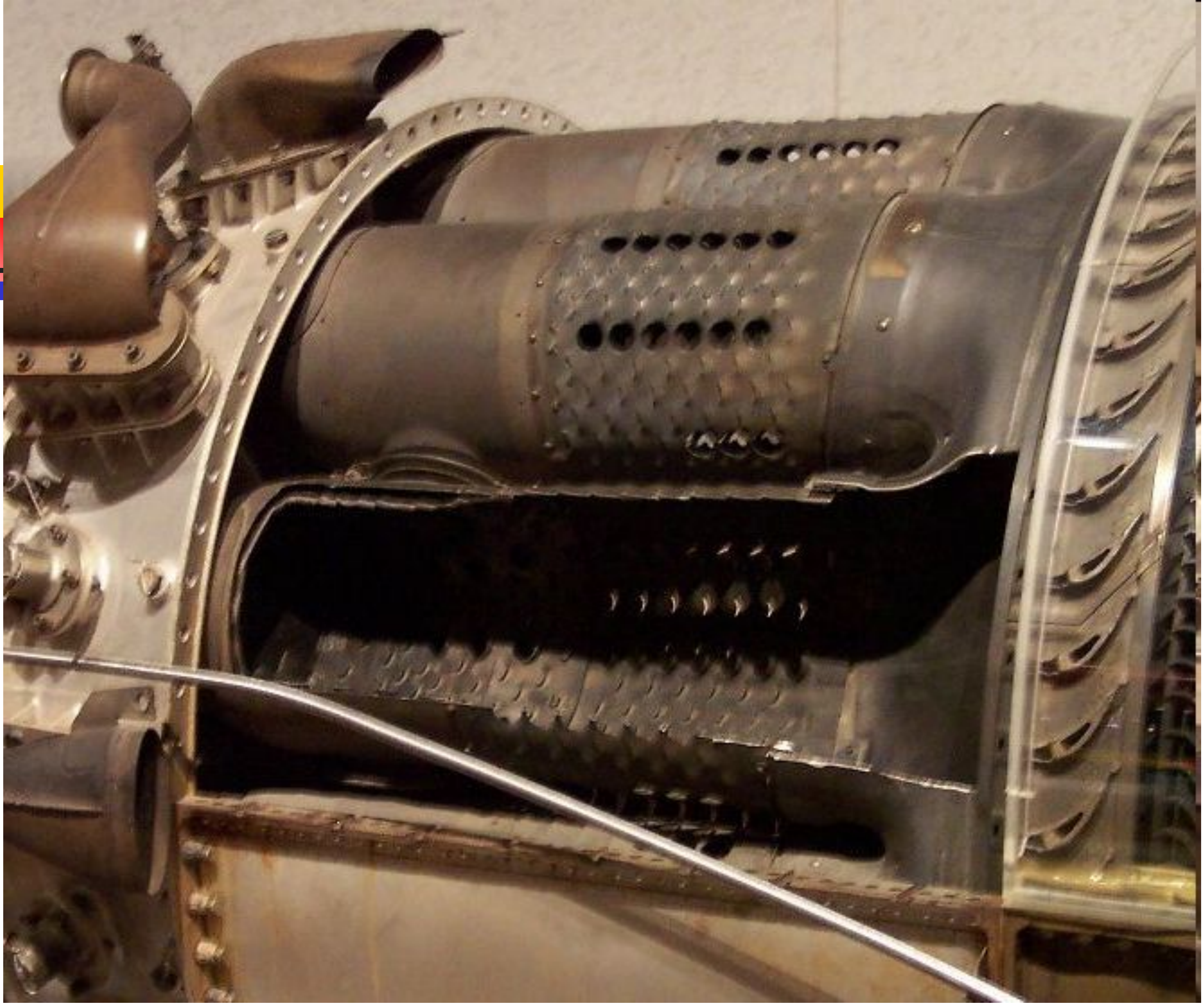
Hot section:

- Combustor
- or Can
- or Flameholders
- or Combustion Chamber —
- This is a chamber where fuel is continuously burned in the compressed air.

Combustion chamber

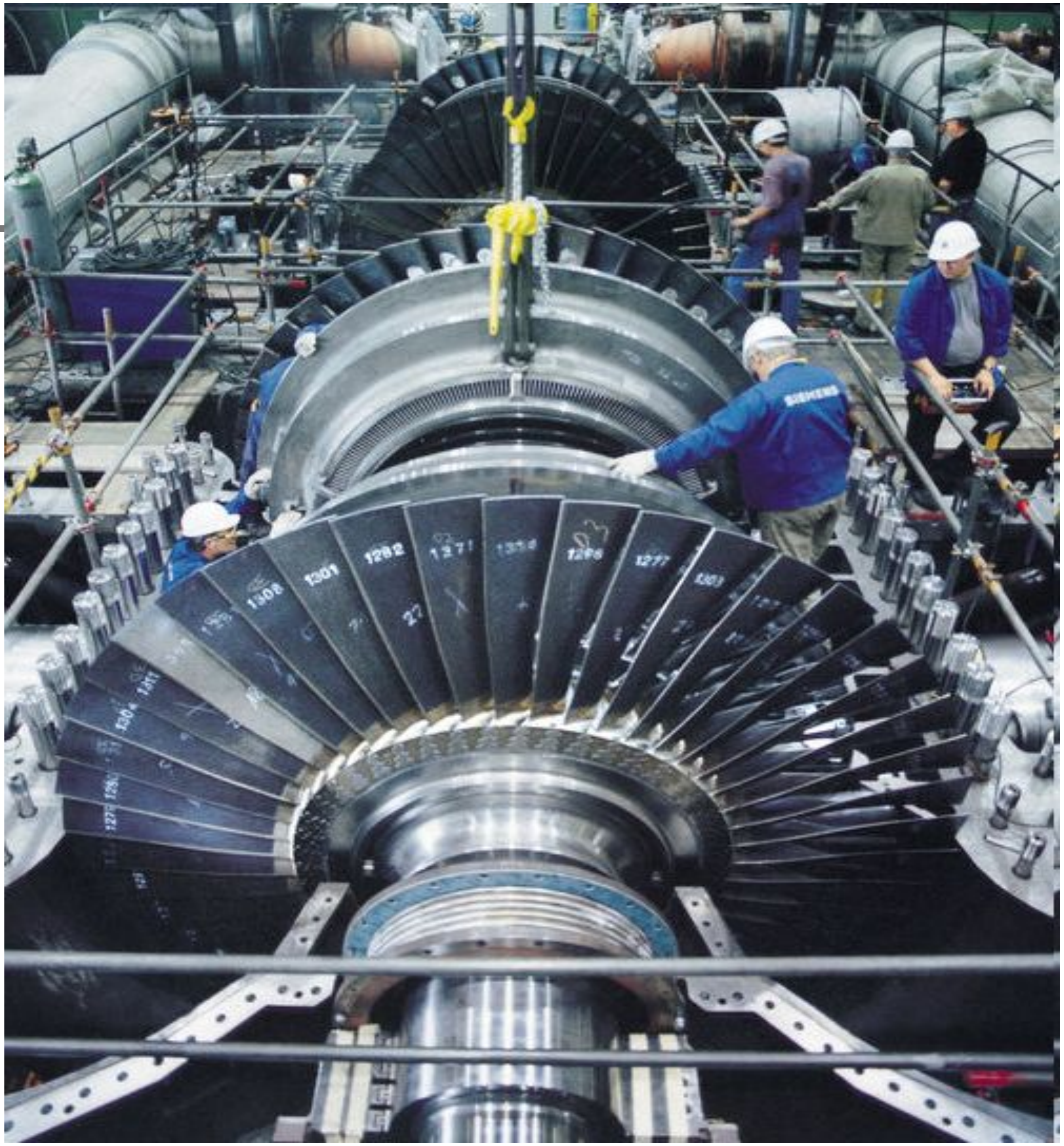
- A combustion chamber is the part of an engine in which fuel is burned.

A ring of can type combustors circles the mid section of this gas turbine.



Turbine

- A turbine is a rotary engine that extracts energy from a fluid flow

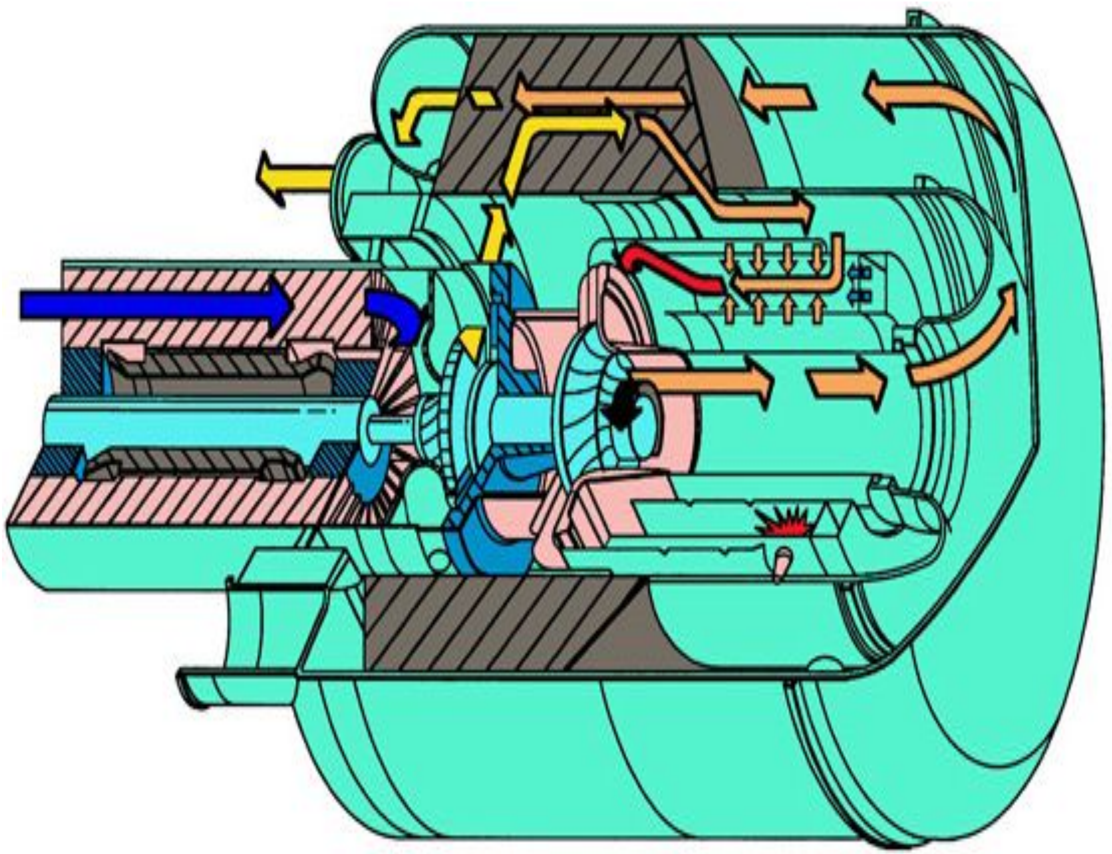


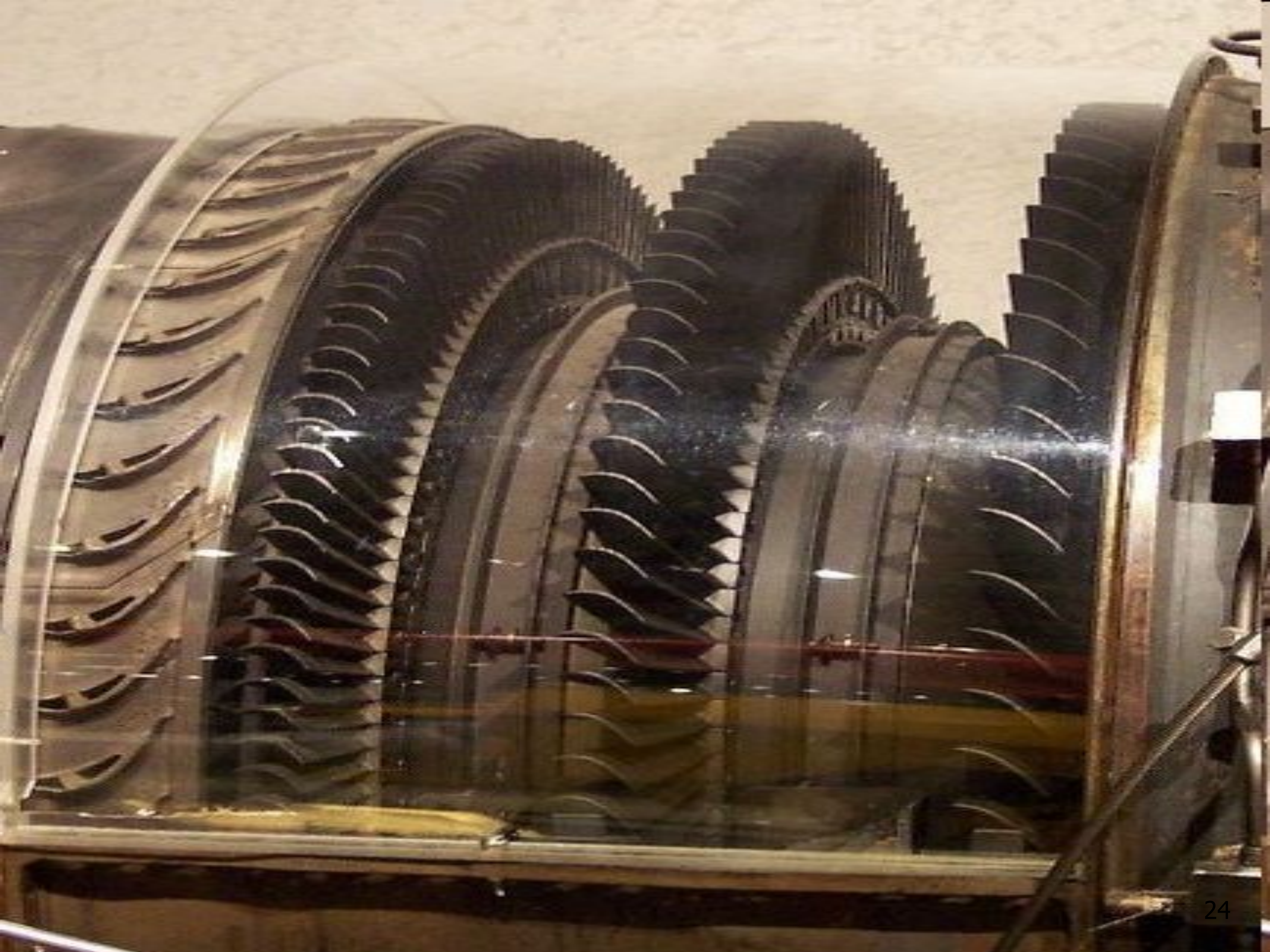
A Pelton wheel

also called a Pelton turbine, is one of the most efficient types of water turbines.

Turbine

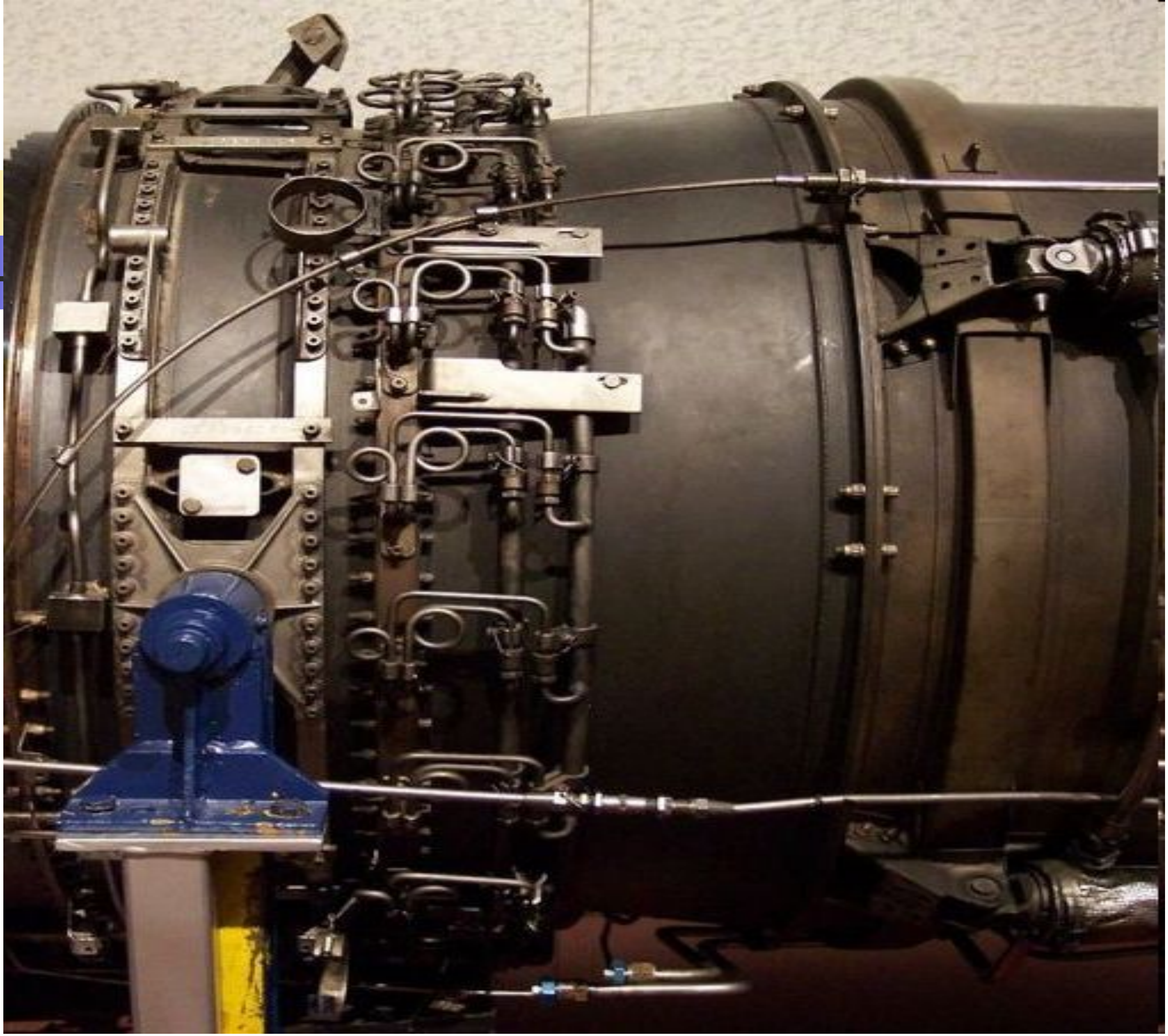
- A gas turbine extracts energy from a flow of hot gas produced by combustion of gas or fuel oil in a stream of compressed air.





An afterburner

- is an additional component added to some jet engines, primarily those on supersonic aircraft. Its purpose is to provide a temporary increase in thrust, both for supersonic flight and for takeoff



A nozzle

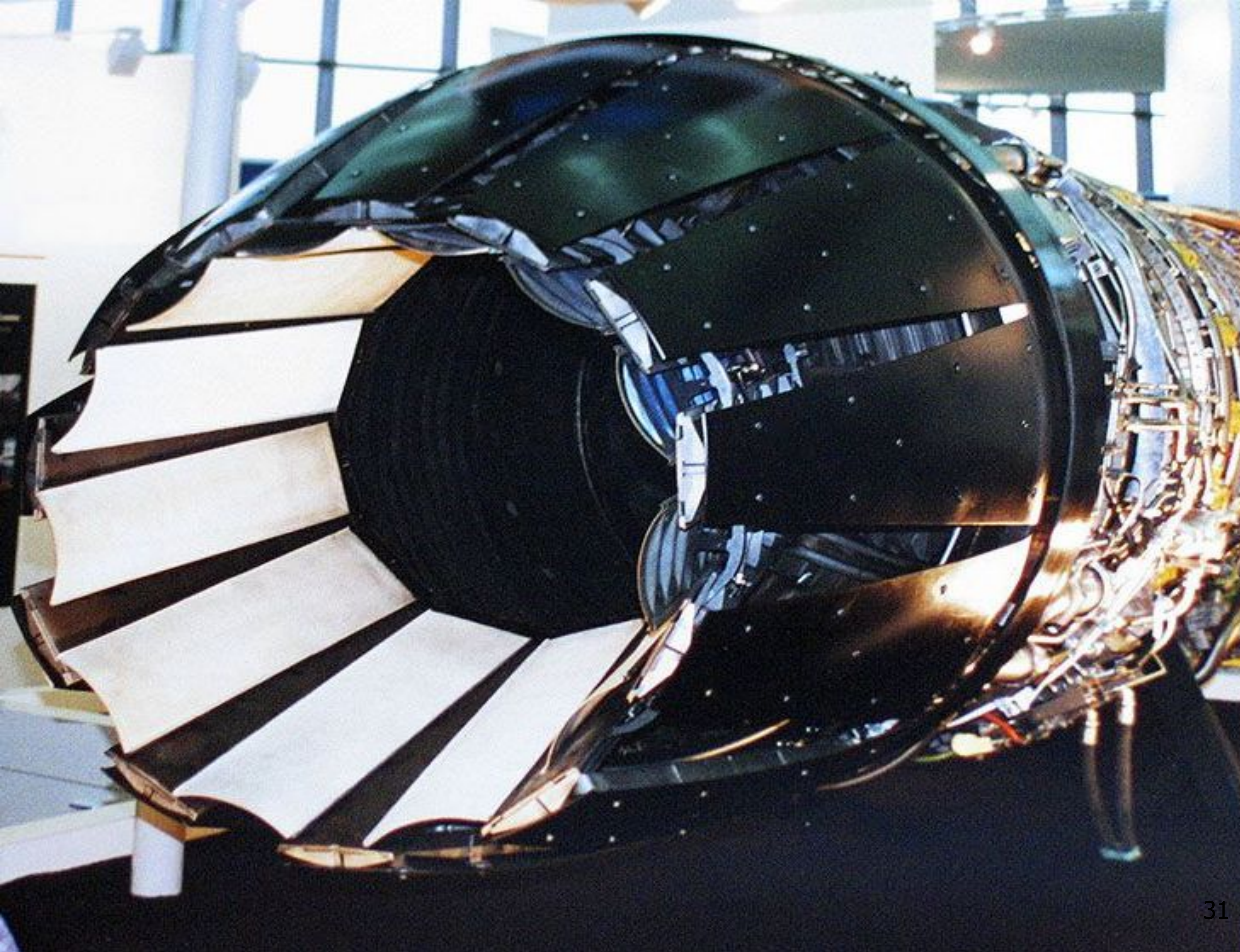
- is a mechanical device or orifice designed to control the characteristics of a fluid flow as it exits (or enters) an enclosed chamber or pipe.

A nozzle

- is often a pipe or tube of varying cross sectional area, and it can be used to direct or modify the flow of a fluid (liquid or gas).
- Nozzles are frequently used to control the rate of flow, speed, direction, mass, shape, and/or the pressure of the stream that emerges from them.

Rocket nozzle

Exhaust Nozzle of Boeing F-18



In addition to the five major sections

each gas turbine engine is equipped with
 an accessory section,

- a fuel system,
- a starting system,
- a cooling system,
- a lubrication system,
- an ignition system.

Cooling systems

- Combustion temperatures can be as high as 3500K (5841F), above the melting point of most materials.
- Cooling systems are employed to keep the temperature of the solid parts below the failure temperature.

Fuel system

- Apart from providing fuel to the engine, the fuel system is also used to control propeller speeds, compressor airflow and cool lubrication oil. Fuel is usually introduced by an atomized spray, the amount of which is controlled automatically depending on the rate of airflow.

Engine starting system

- The fuel system as explained above, is one of the 2 systems required for starting the engine. The other is the actual ignition of the air/fuel mixture in the chamber.
- Usually, an auxiliary power unit is used to start the engines. It has a starter motor which has a high torque transmitted to the compressor unit. When the optimum speed is reached, i.e. the flow of gas through the turbine is sufficient, the turbines take over.
- There are a number of different starting methods such as electric, hydraulic, pneumatic etc.

Ignition system

- Usually there are 2 igniter plugs in different positions in the combustion system. A high voltage spark is used to ignite the gases.

Lubrication system

- A lubrication system serves to ensure lubrication of the bearings and to maintain sufficiently cool temperatures, mostly by eliminating friction.

- The lubrication system as a whole should be able to prevent foreign material from entering the plane, and reaching the bearings, gears, and other moving parts. The lubricant must be able to flow easily at relatively low temperatures and not disintegrate or break down at very high temperatures.

- Bearings – подшипники
- Gear – зубчатая передача

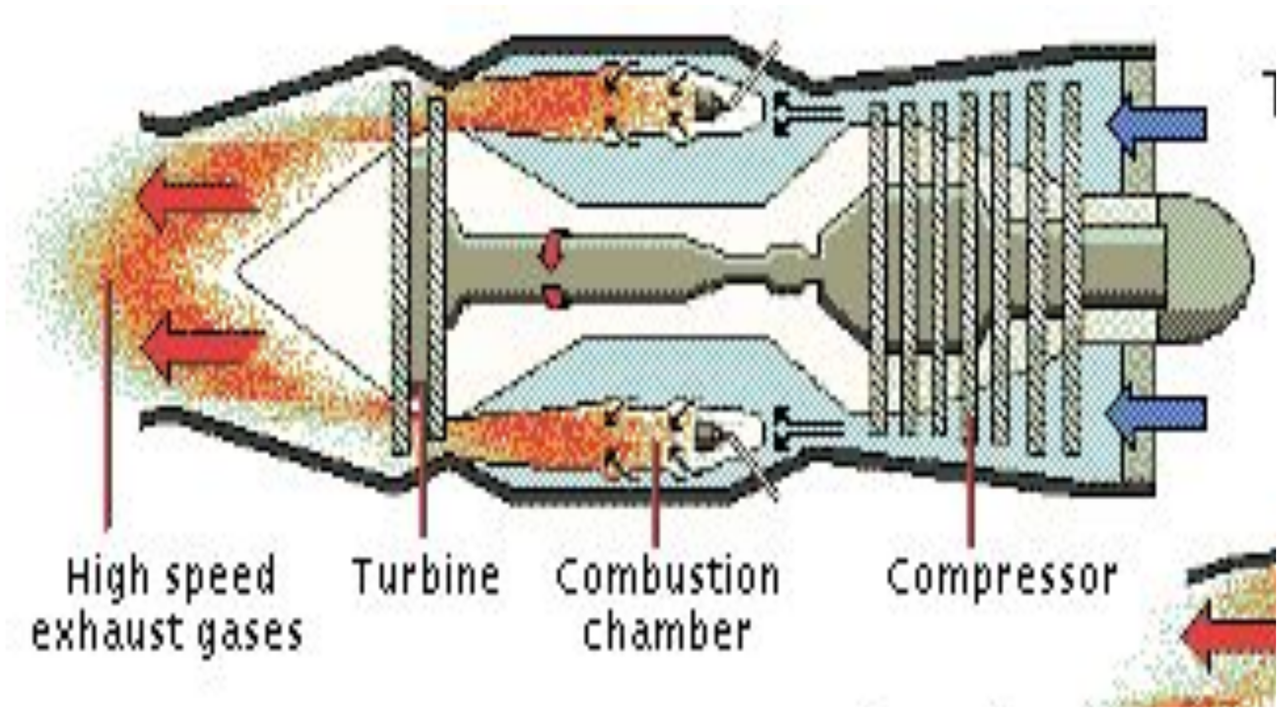
Gas turbine engines' classification. **Jet Engines**

The three most common types of jet engines are

- ***turbojet,***
- ***turboprop,***
- ***turbofan.***

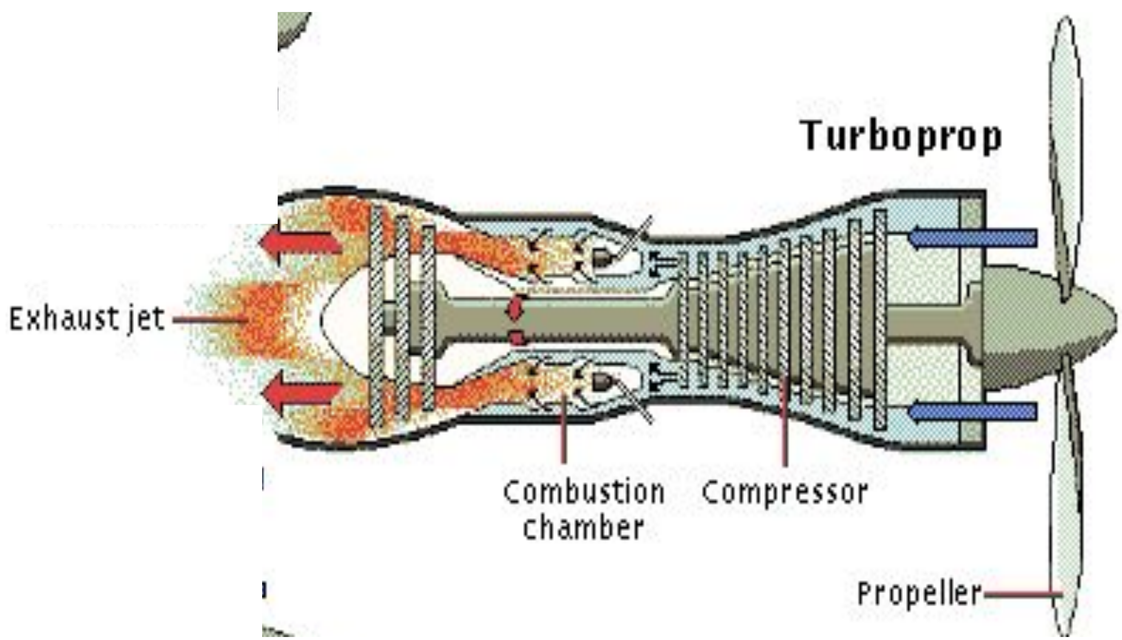
Turbojet engine

Air entering a **turbojet** engine is compressed and passed into a combustion chamber to be oxidized. Energy produced by the burning fuel spins the turbine that drives the compressor, creating an effective power cycle.



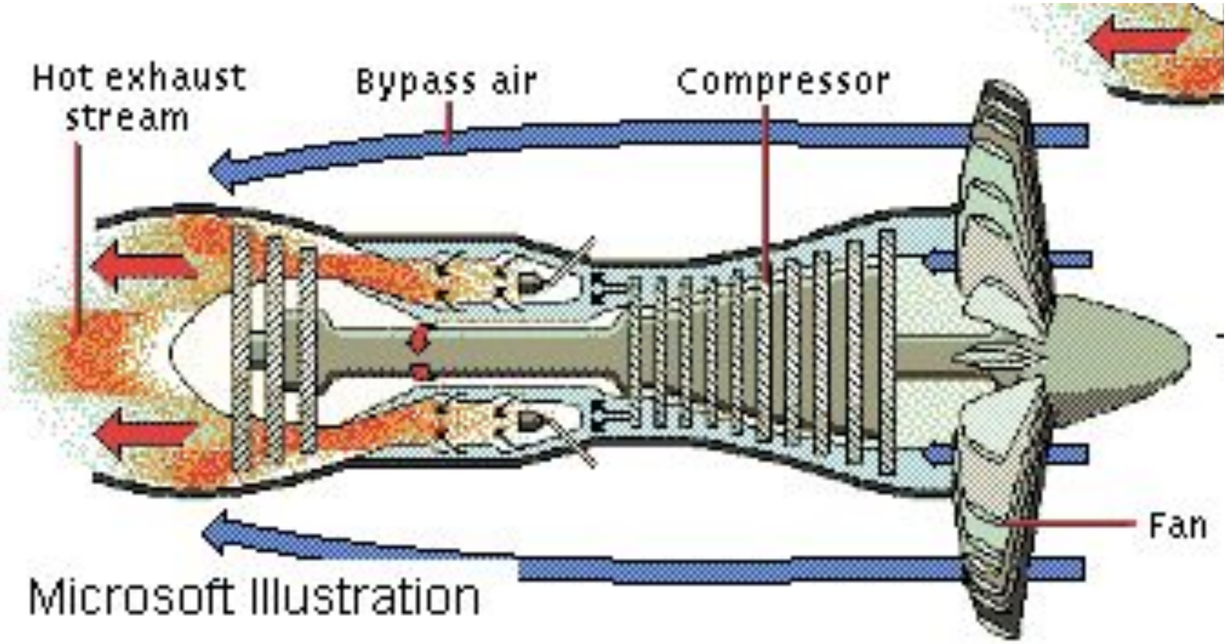
Turboprop engines

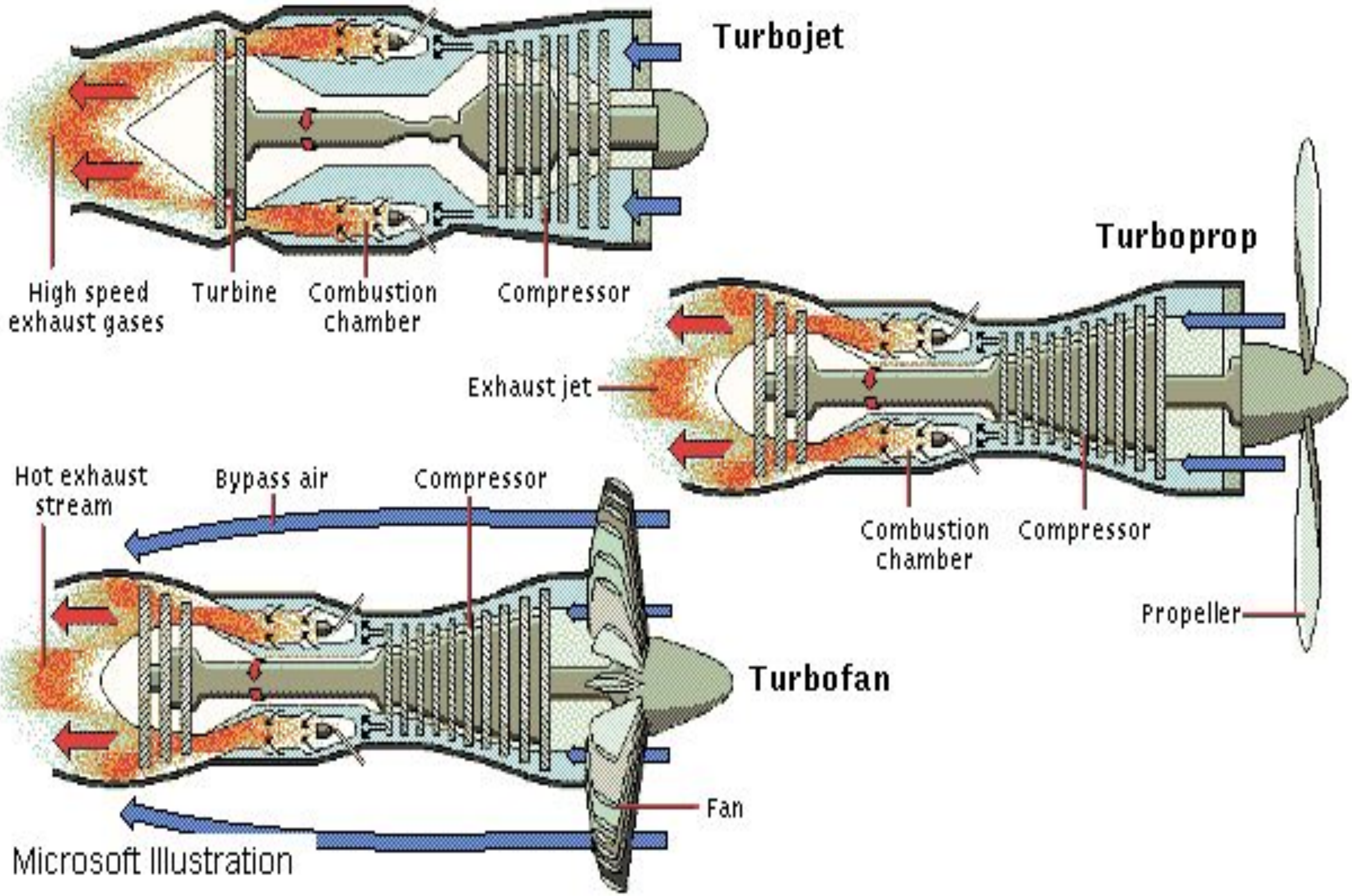
Turboprop engines are driven almost entirely by a propeller mounted in front of the engine, deriving only 10 percent of their thrust from the exhaust jet.



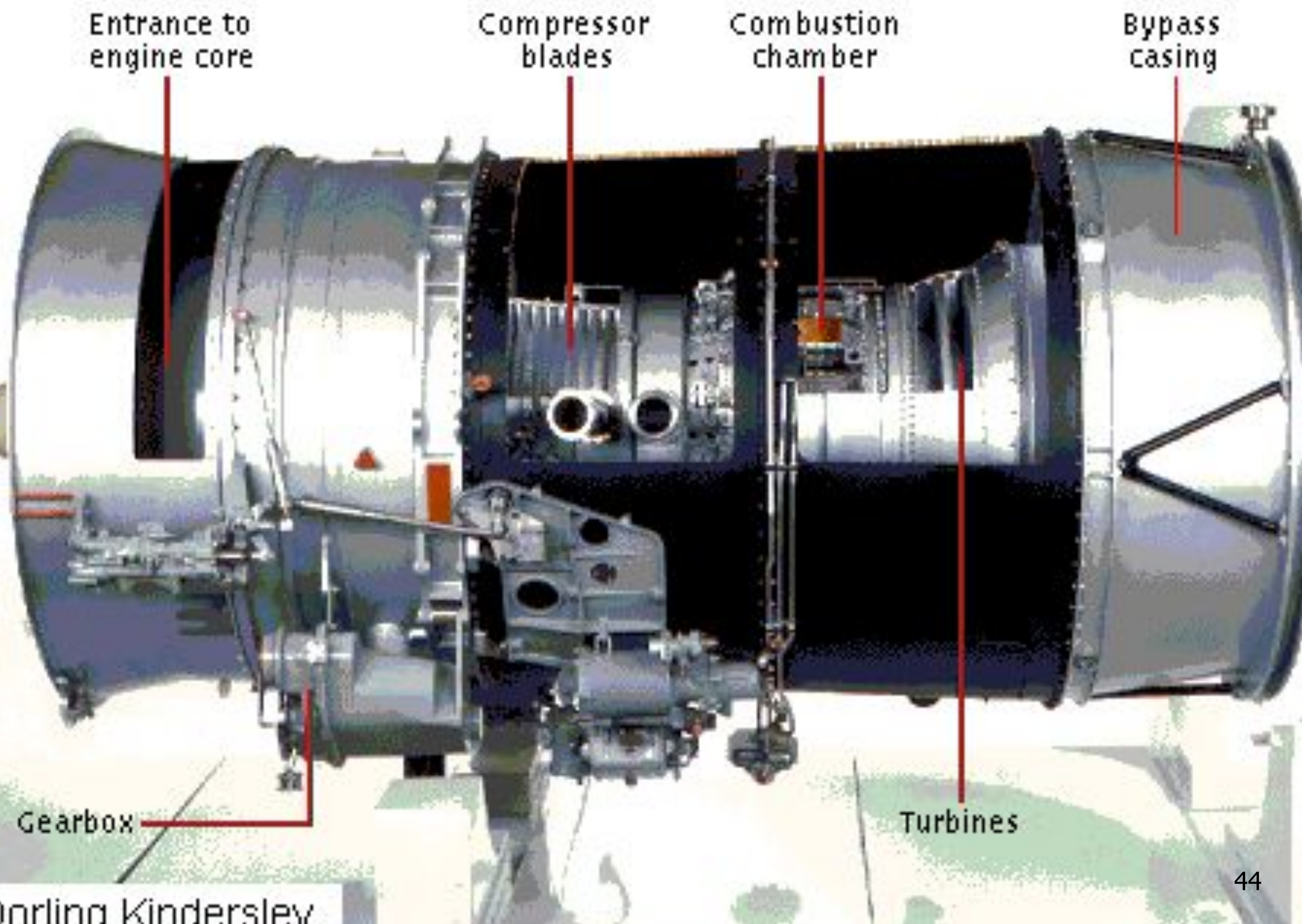
Turbofan engines

Turbofans combine the hot air jet with bypassed air from a fan, also driven by the turbine. The use of bypass air creates a quieter engine with greater boost at low speeds, making it a popular choice for commercial airplanes.



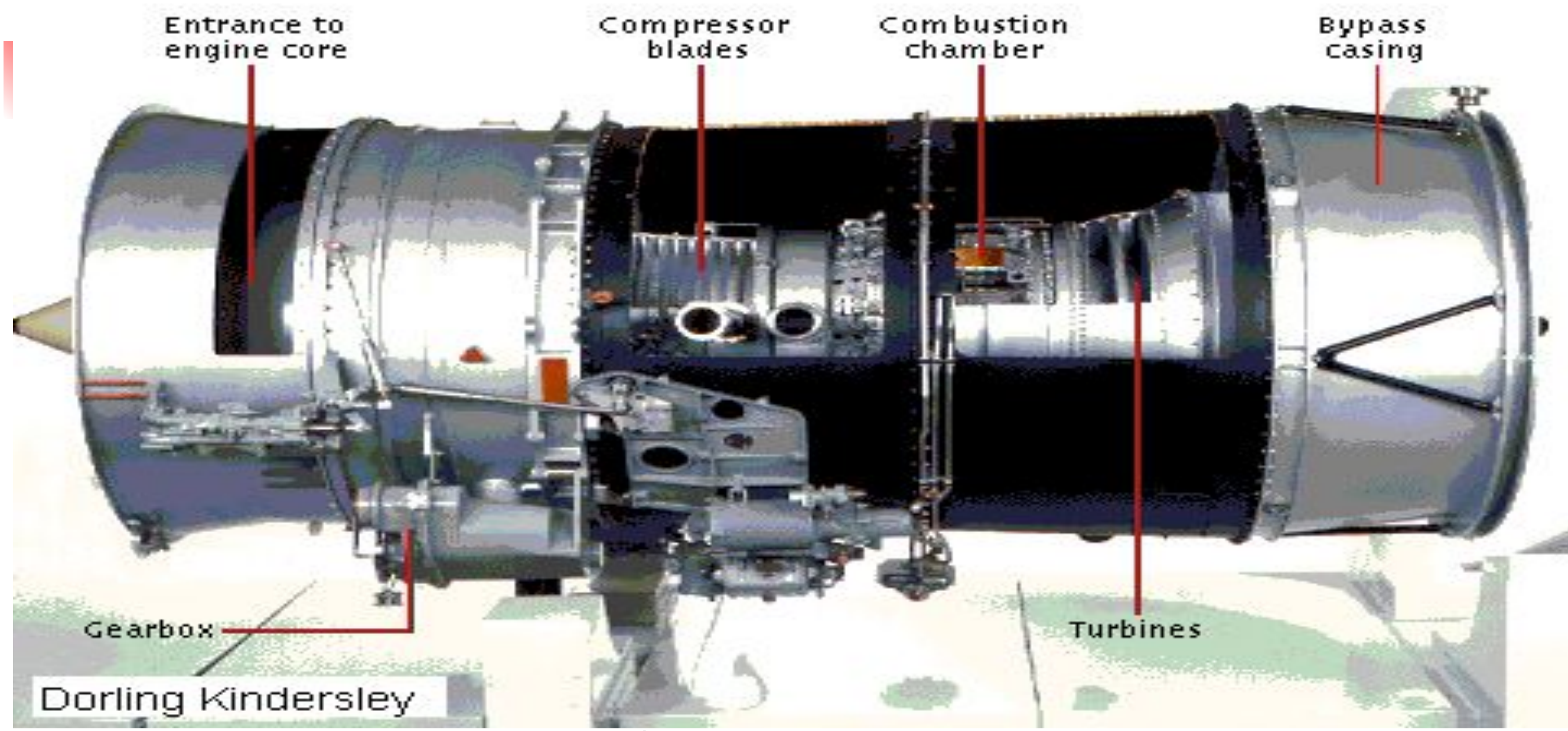

Turbojet
High speed exhaust gases
Turbine
Combustion chamber
Compressor
Turboprop
Exhaust jet
Combustion chamber
Compressor
Propeller
Hot exhaust stream
Bypass air
Compressor
Turbofan
Fan
Microsoft Illustration

Turbofan Engine



Dorling Kindersley

Turbofan Engine



This Rolls-Royce Tay turbofan engine pushes nearly three times as much air through the bypass ducts as it pushes through the central core of the engine, where the air is compressed, mixed with fuel, and ignited. Turbofan engines like the Rolls-Royce Tay are not as powerful as turbojets, but they are quieter and more efficient.

Boeing 747 jet engine up close

A Pratt & Whitney F100 turbofan engine for the F-15 Eagle and the F-16 Falcon testing

Engine design

Engines must be:

- lightweight, as a heavy engine increases the empty weight of the aircraft & reduces its payload.

Engine design

Engines must be:

- small and easily streamlined; large engines with substantial surface area, when installed, create too much drag, wasting fuel and reducing power output.

Engine design

Engines must be:

- powerful, to overcome the weight and drag of the aircraft.

Engine design

Engines must be:

- reliable, as losing power in an airplane is a substantially greater problem than an automobile engine seizing. Aircraft engines operate at temperature, pressure, and speed extremes, and therefore need to operate reliably and safely under all these conditions.

Engine design

- Engines must be:
- repairable, to keep the cost of replacement down.

Aircraft noise

is defined as sound produced by any aircraft on run-up, taxiing, take off, over-flying or landing.

- Aircraft noise is a significant concern for approximately 100 square kilometers surrounding most major airports.
- Aircraft noise is the second largest (after roadway noise) source of environmental noise.
- It is usually measured in Decibels.

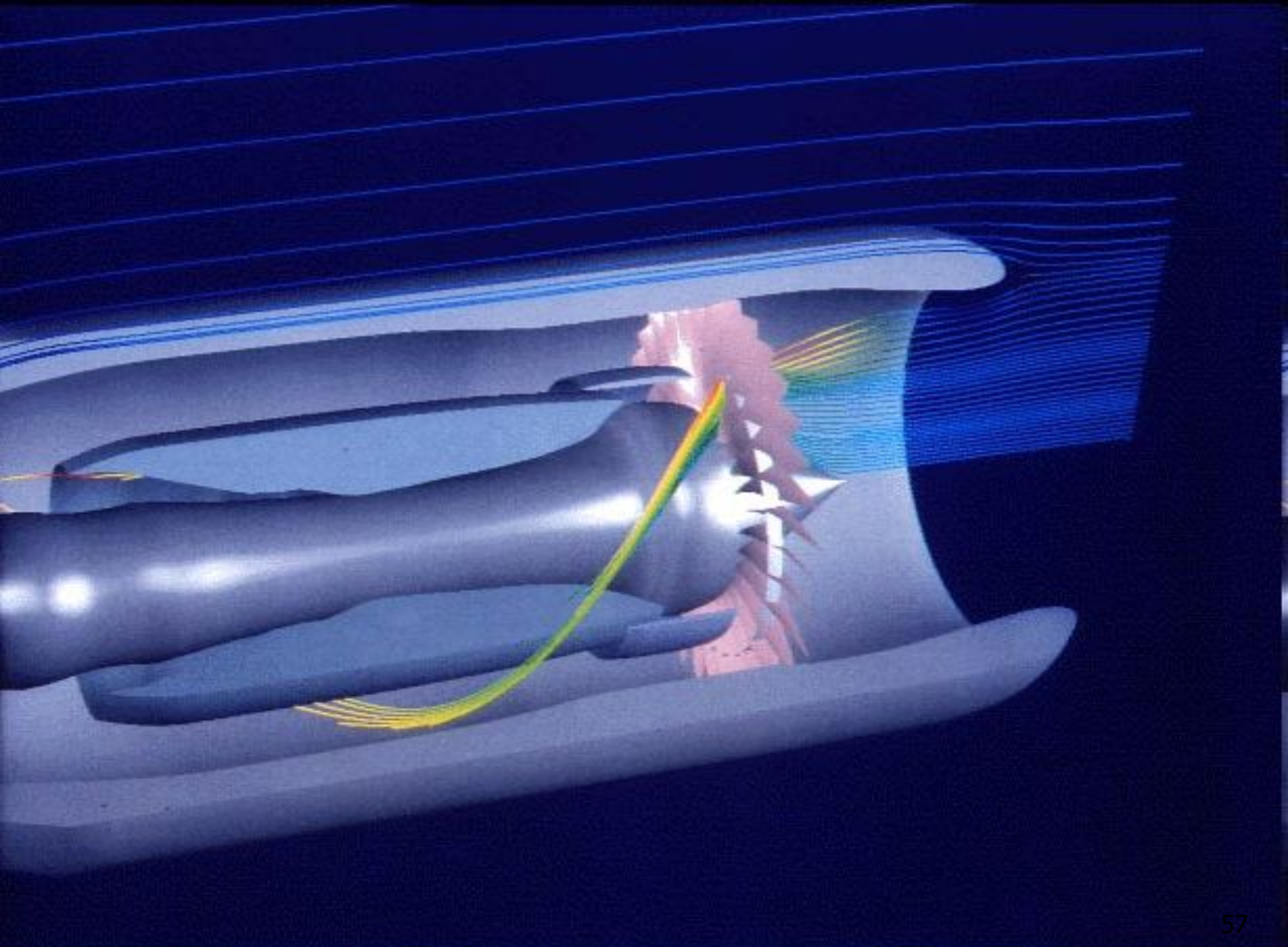
Aircraft noise

Take-off of aircraft may lead to a sound level of more than 100 decibels at the ground, with approach and landing creating lower levels.

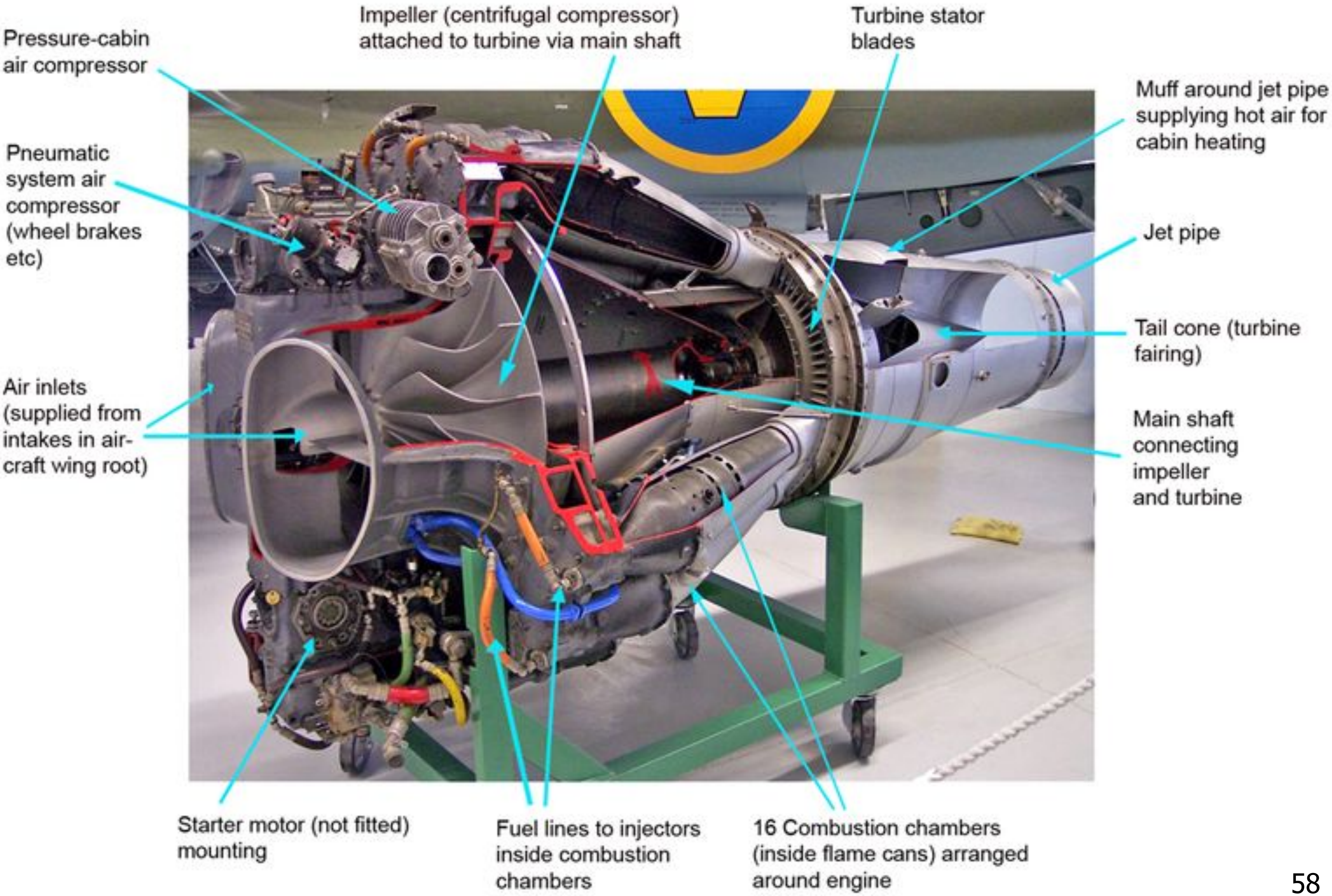
- The W2/700 engine flew in the Gloster E.28/39, the first British aircraft to fly with a turbojet engine, and the Gloster Meteor.

The Gloster E.28/39

(also referred to as the "Gloster Whittle", "Gloster Pioneer", or "Gloster G.40") was the first jet engined aircraft to fly in the United Kingdom



Internal components



Type	Description	Advantages	Disadvantages
Water jet	Squirts water out the back through a nozzle	Can run in shallow water, powerful, less harmful to wildlife, (indeed used by squid)	Can be less efficient than a propeller, more vulnerable to debris
Motorjet	Most primitive airbreathing jet engine. Essentially a supercharged piston engine with a jet exhaust.	Higher exhaust velocity than a propeller, offering better thrust at high speed	Heavy, inefficient and underpowered
Turbojet	Generic term for simple turbine engine	Simplicity of design, efficient at supersonic speeds (~M2)	A basic design, misses many improvements in efficiency and power for subsonic flight, relatively noisy.
Turbofan	First stage compressor greatly enlarged to provide bypass airflow around engine core, and it provides significant amounts of thrust. Most common form of jet engine in use today- used in airliners like the Boeing 747 and military jets, where an afterburner is often added for supersonic flight.	Quieter due to greater mass flow and lower total exhaust speed, more efficient for a useful range of subsonic airspeeds for same reason, cooler exhaust temperature.	Greater complexity (additional ducting, usually multiple shafts), large diameter engine, need to contain heavy blades. More subject to FOD and ice damage. Top speed is limited due to the potential for shockwaves to damage engine.
Rocket	Carries all propellants and oxidants on-board, emits jet for propulsion	Very few moving parts, Mach 0 to Mach 25+, efficient at very high speed (> Mach 10.0 or so), thrust/weight ratio over 100, no complex air inlet, high compression ratio, very high speed (hypersonic) exhaust, good cost/thrust ratio, fairly easy to test, works in a vacuum- indeed works best exoatmospheric which is kinder on vehicle structure at high speed, fairly small surface area to keep cool, and no turbine in hot exhaust stream.	Needs lots of propellant- very low specific impulse — typically 100-450 seconds. Extreme thermal stresses of combustion chamber can make reuse harder. Typically requires carrying oxidiser on-board which increases risks. Extraordinarily noisy.
Ramjet	Intake air is compressed entirely by speed of oncoming air and duct shape (*divergent*)	Very few moving parts, Mach 0.8 to Mach 5+, efficient at high speed (> Mach 2.0 or so), lightest of all air-breathing jets (thrust/weight ratio up to 30 at optimum speed), cooling much easier than turbojets as no turbine blades to cool.	Must have a high initial speed to function, inefficient at slow speeds due to poor compression ratio, difficult to arrange shaft power for accessories, usually limited to a small range of speeds, intake flow must be slowed to subsonic speeds, noisy, fairly difficult to test, finicky to keep lit.
Turboprop (Turboshaft similar)	Strictly not a jet at all — a gas turbine engine is used as powerplant to drive propeller shaft (or Rotor in the case of a Helicopter)	High efficiency at lower subsonic airspeeds (300 knots plus), high shaft power to weight	Limited top speed (aeroplanes), somewhat noisy, complex transmission
Propfan/ Unducted Fan	Turboprop engine drives one or more propellers. Similar to a turbofan without the fan cowling.	Higher fuel efficiency, potentially less noisy than turbofans, could lead to higher-speed commercial aircraft, popular in the 1980s during fuel shortages	Development of propfan engines has been very limited, typically more noisy than turbofans, complexity
Pulsejet	Air is compressed and combusted intermittently instead of continuously. Some designs use valves.	Very simple design, commonly used on model aircraft	Noisy, inefficient (low compression ratio), works poorly on a large scale, valves on valved designs wear out quickly

Pulse detonation engine	Similar to a pulsejet, but combustion occurs as a detonation instead of a deflagration, may or may not need valves	Maximum theoretical engine efficiency	Extremely noisy, parts subject to extreme mechanical fatigue, hard to start detonation, not practical for current use
Air-augmented rocket	Essentially a ramjet where intake air is compressed and burnt with the exhaust from a rocket	Mach 0 to Mach 4.5+ (can also run exoatmospheric), good efficiency at Mach 2 to 4	Similar efficiency to rockets at low speed or exoatmospheric, inlet difficulties, a relatively undeveloped and unexplored type, cooling difficulties, very noisy, thrust/weight ratio is similar to ramjets.
Scramjet	Similar to a ramjet without a diffuser; airflow through the entire engine remains supersonic	Few mechanical parts, can operate at very high Mach numbers (Mach 8 to 15) with good efficiencies[2]	Still in development stages, must have a very high initial speed to function (Mach >6), cooling difficulties, very poor thrust/weight ratio (~2), extreme aerodynamic complexity, airframe difficulties, testing difficulties/expense
Turborocket	A turbojet where an additional oxidizer such as oxygen is added to the airstream to increase maximum altitude	Very close to existing designs, operates in very high altitude, wide range of altitude and airspeed	Airspeed limited to same range as turbojet engine, carrying oxidizer like LOX can be dangerous. Much heavier than simple rockets.
Precooled jets / LACE	Intake air is chilled to very low temperatures at inlet in a heat exchanger before passing through a ramjet or turbojet engine. Can be combined with a rocket engine for orbital insertion.	Easily tested on ground. Very high thrust/weight ratios are possible (~14) together with good fuel efficiency over a wide range of airspeeds, mach 0-5.5+; this combination of efficiencies may permit launching to orbit, single stage, or very rapid, very long distance intercontinental travel.	Exists only at the lab prototyping stage. Examples include RB545, SABRE, ATREX. Requires liquid hydrogen fuel which has very low density and heavily insulated tankage.

BOEING ENGINES

717-200

BOEING

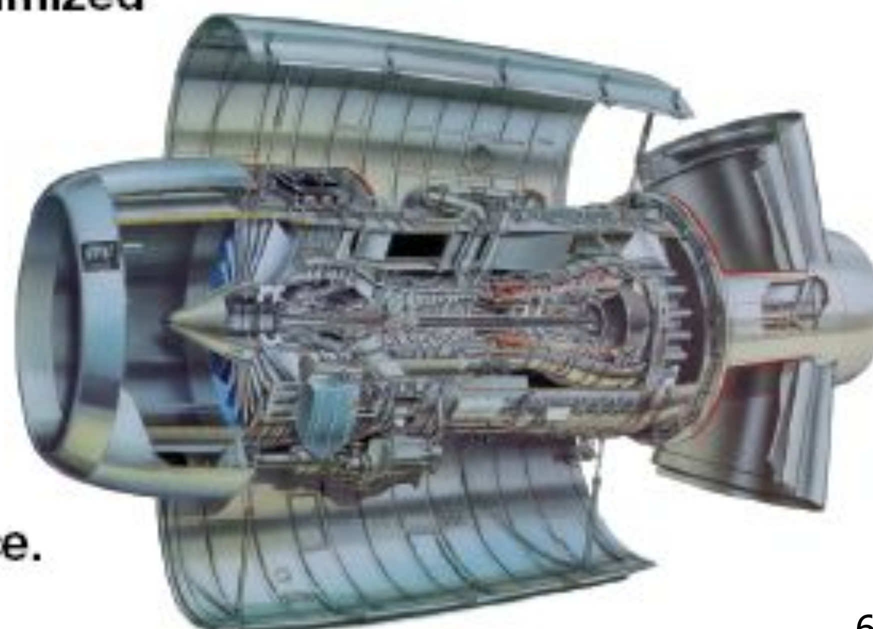
BOEING 717 ENGINE

BR715 Benefits for Operators

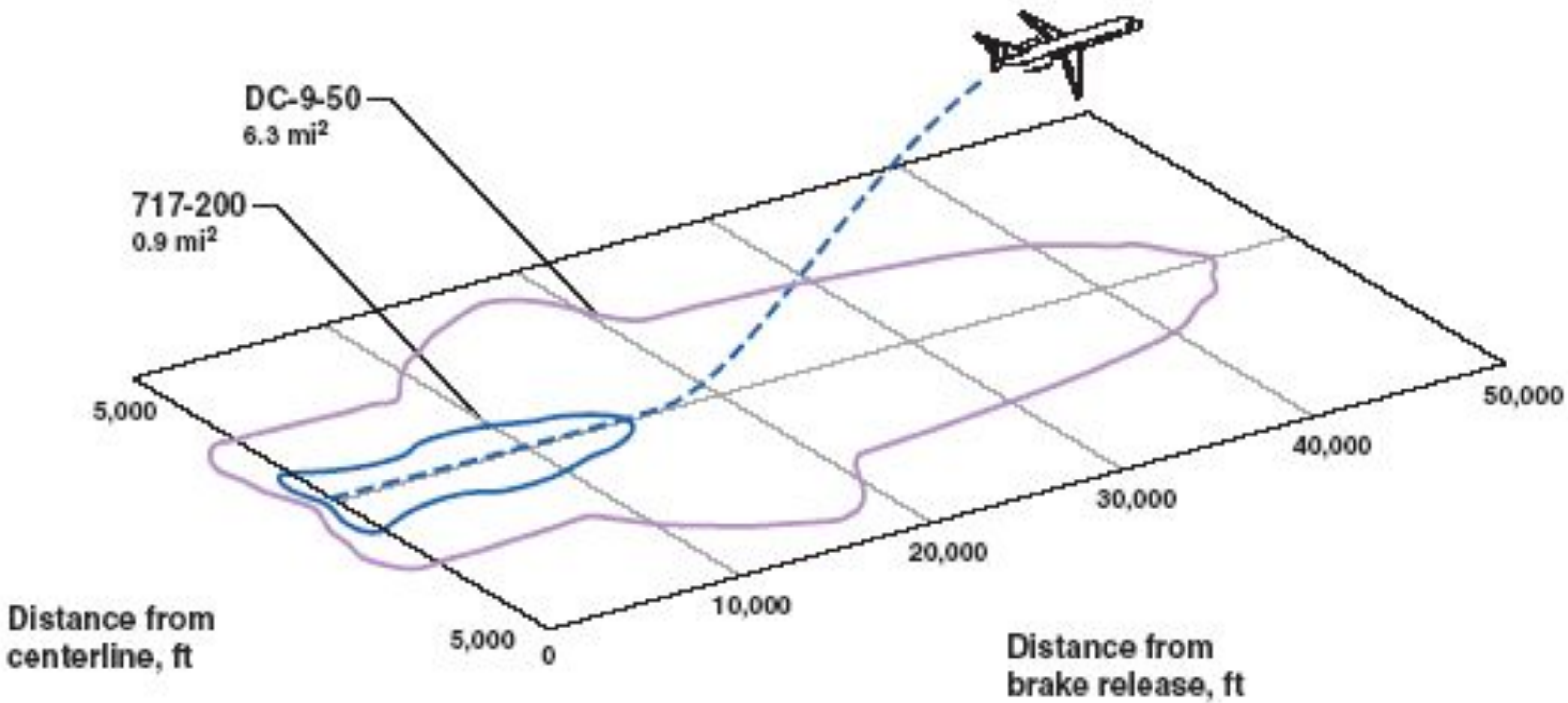
Cost-Effective Technology With Low Risk

The only new-generation engine optimized for 80- to 130-seat airplanes offers

- Low cost.
- Low fuel consumption.
- Low maintenance costs.
- Low noise and emissions.
- Low-risk design philosophy.
- Proven BR700-series performance.



717-200 Noise Area Reduced by 85% Over DC-9-50



- Maximum TOGW; 100% load factor
- 85-dBA contour comparison; takeoff with cutback

BOEING 737 FAMILY

737

BOEING

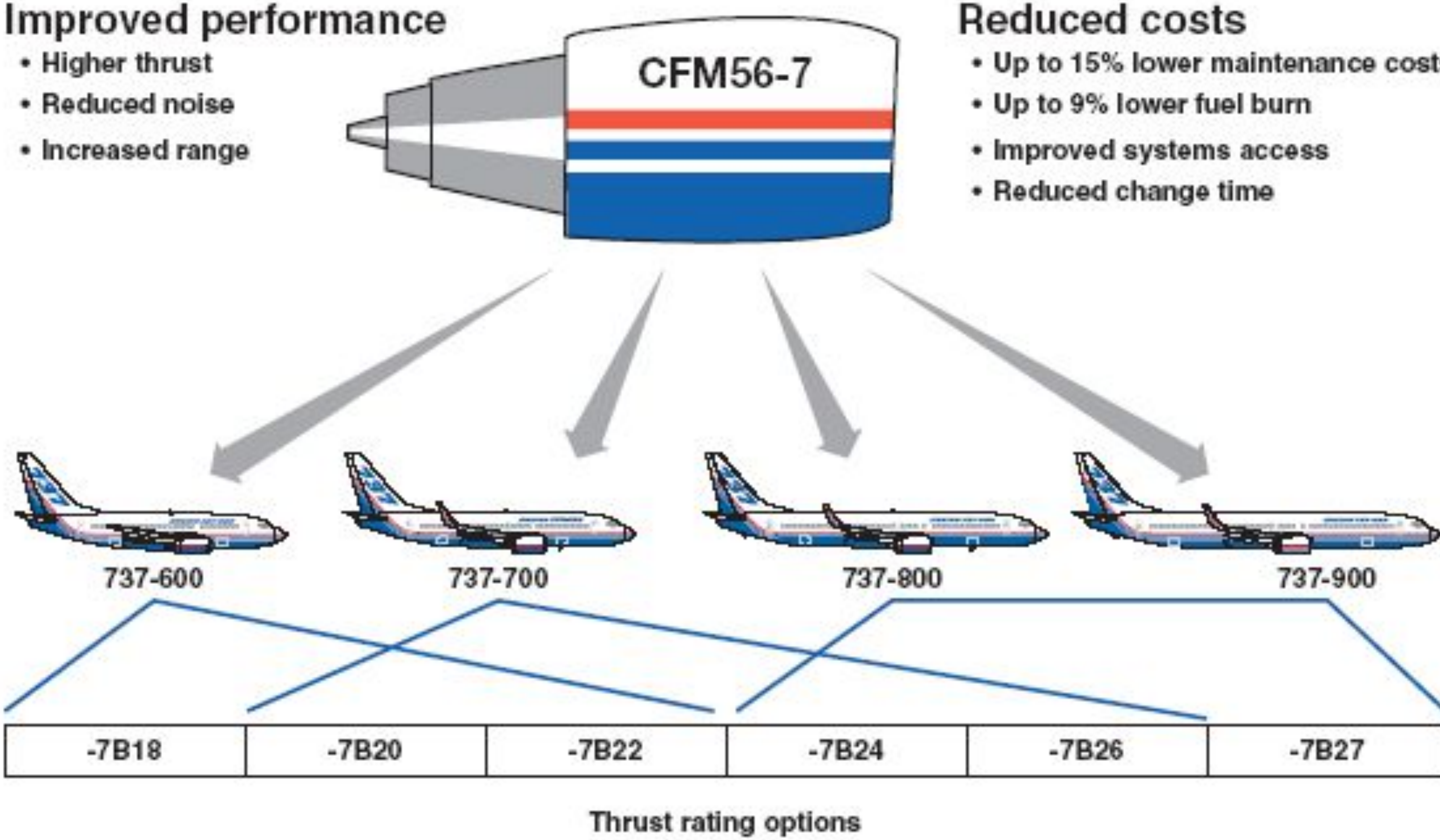
New Common Engine Improves Performance and Reduces Costs

Improved performance

- Higher thrust
- Reduced noise
- Increased range

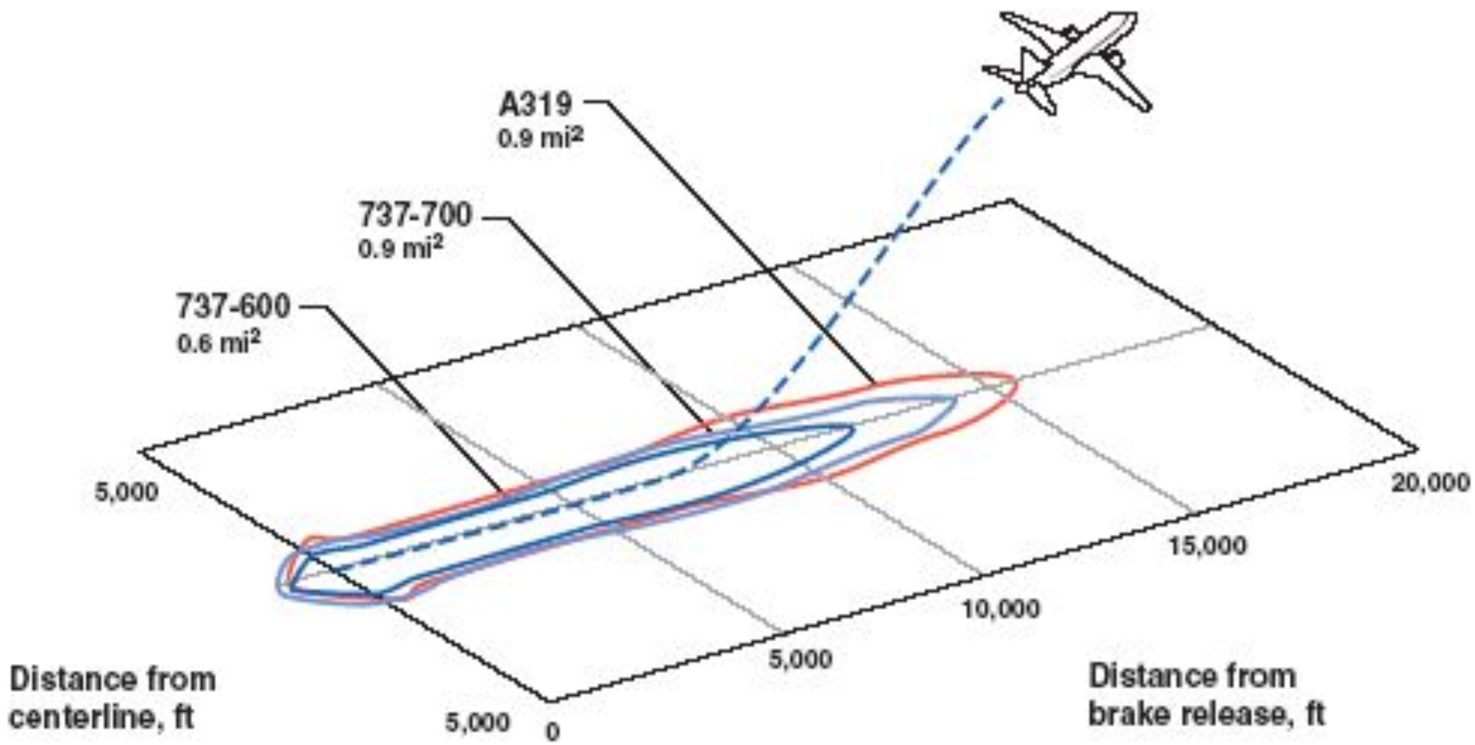
Reduced costs

- Up to 15% lower maintenance costs
- Up to 9% lower fuel burn
- Improved systems access
- Reduced change time



Takeoff Noise Area Comparison

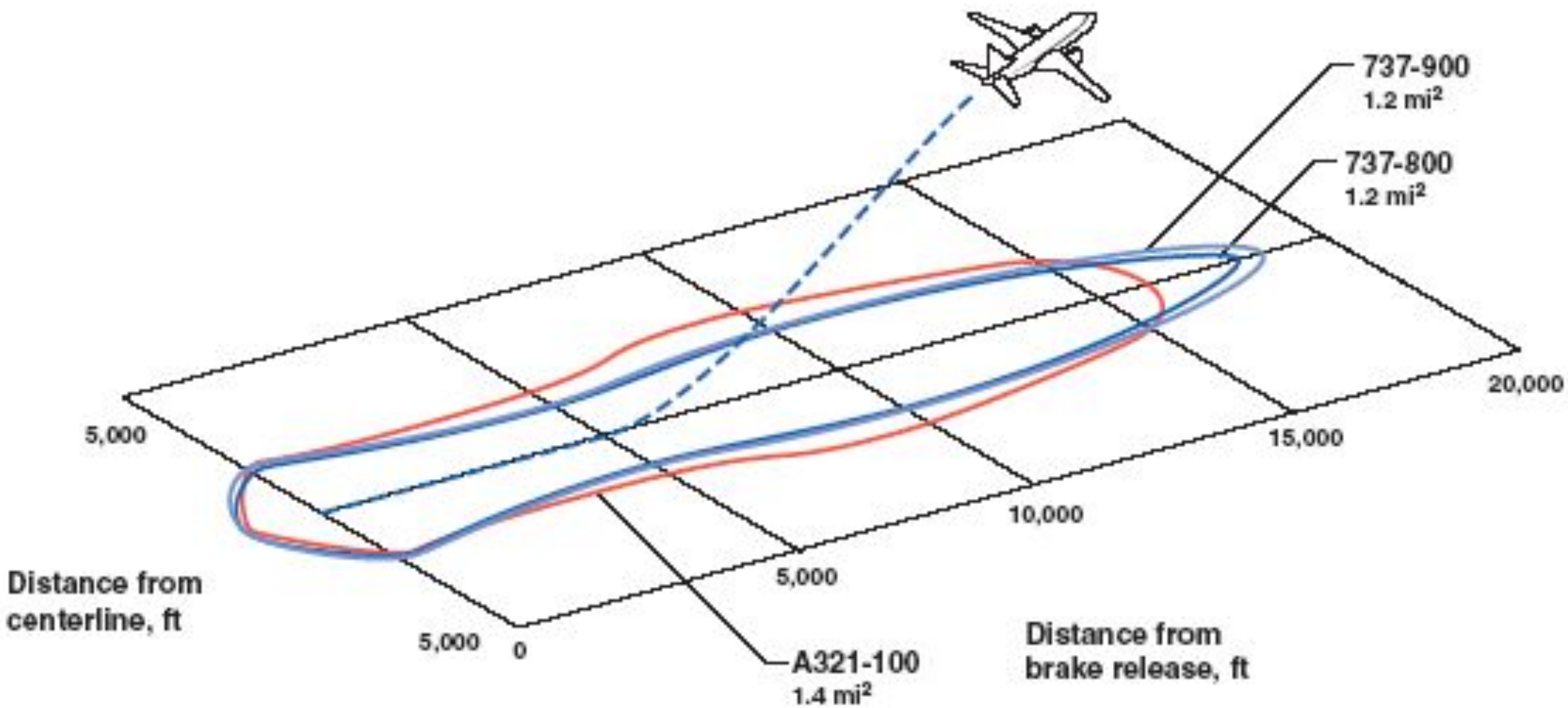
737-600 Noise Area Reduced by 33% Over A319



- Maximum TOGW; 100% load factor; without winglets
- 85-dBA contour comparison; takeoff with cutback

Takeoff Noise Area Comparison

737-800 Noise Area Reduced by 14% Over A321-100



- Maximum TOGW; 100% load factor; without winglets
- 85-dBA contour comparison; takeoff with cutback

BOEING 747 FAMILY

747

Engines From Three Major Manufacturers Are Available on the 747-400

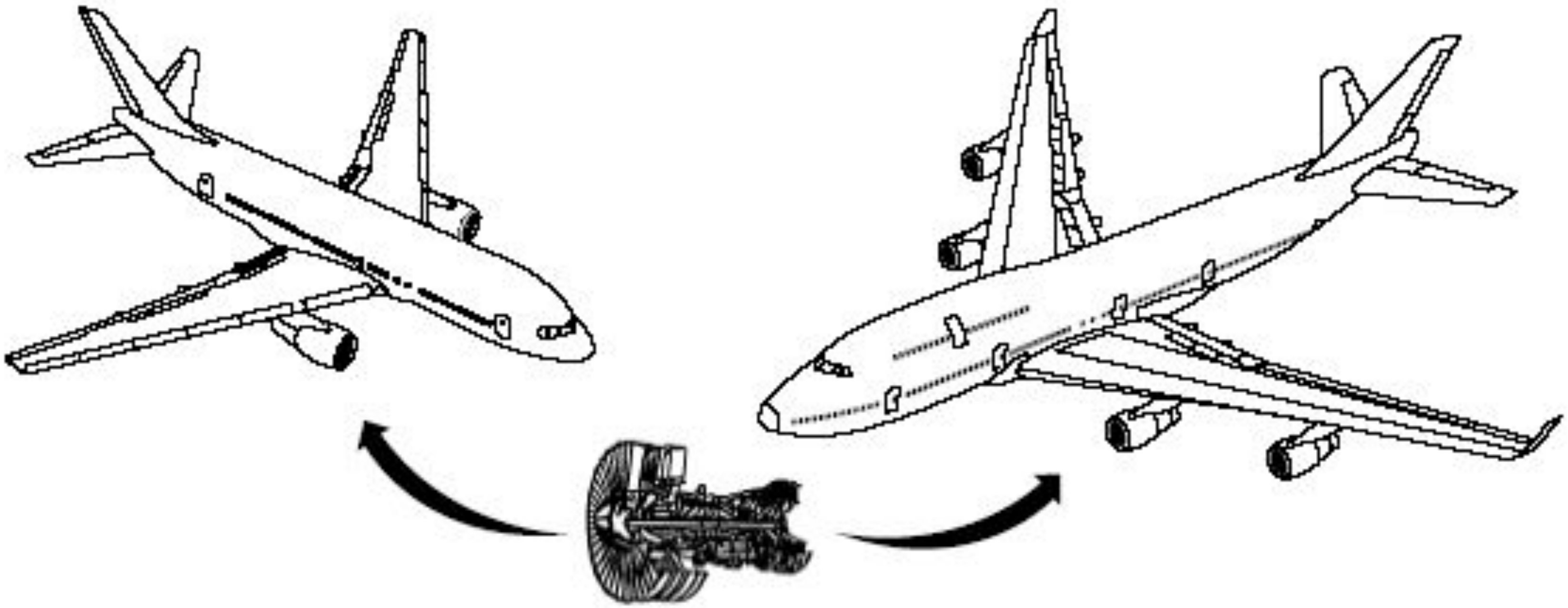
PW4000

CF6-80C2

RB211-524G/H-T

Engine Commonality

Same Basic Engines, Different Rating



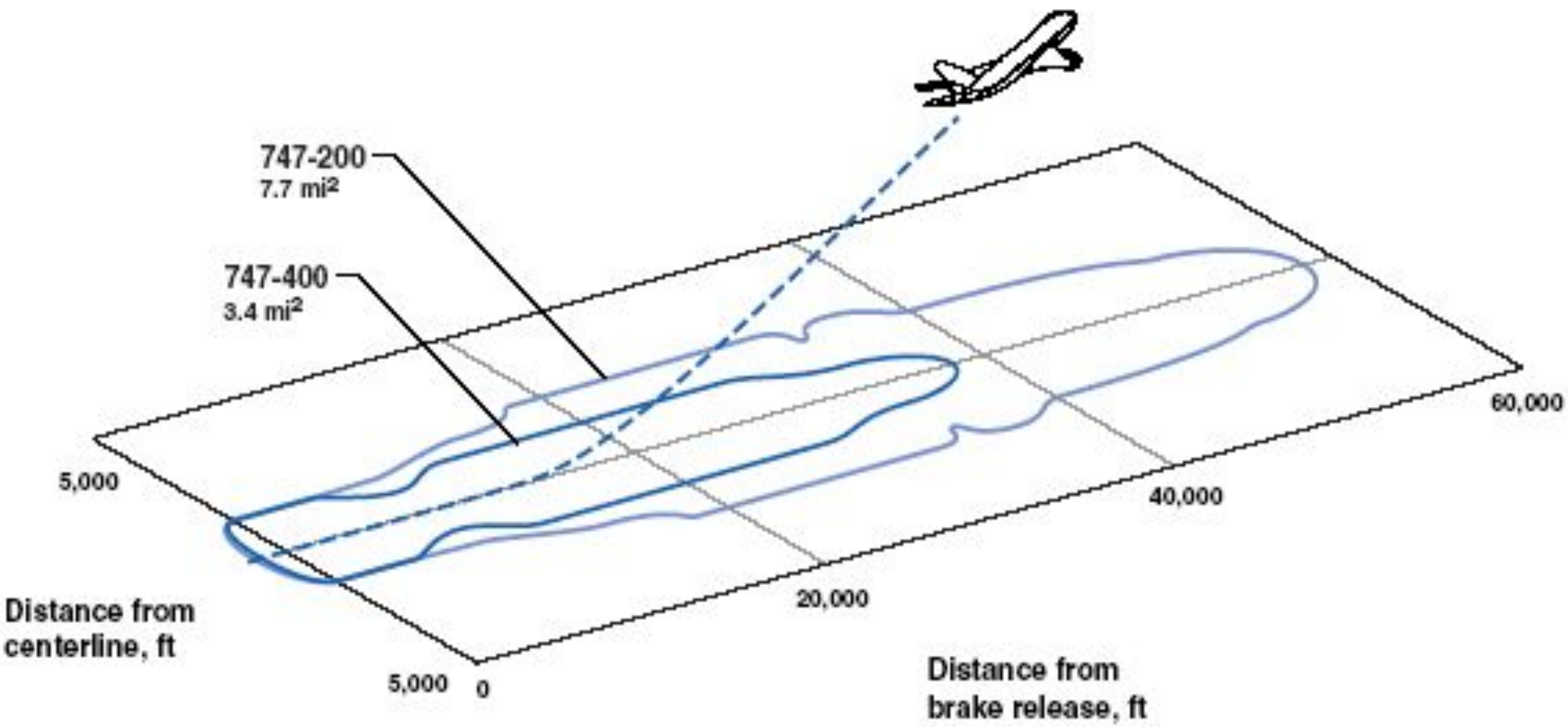
747 and 767 engines are interchangeable within the same basic engine model.

- Same engine buildup
- Common nacelles
- Common generators
- Same tools

The total number of spare engines required to support combined fleets of 767s and 747-400s is substantially reduced.

Takeoff Noise Area Comparison

747-400 Noise Area Reduced by 56% Over 747-200



- Maximum TOGW; 100% load factor
- 85-dBA contour comparison; takeoff with cutback

BOEING 757 FAMILY

757-200

BOEING

Two Engine Manufacturers to Satisfy Airline Requirements

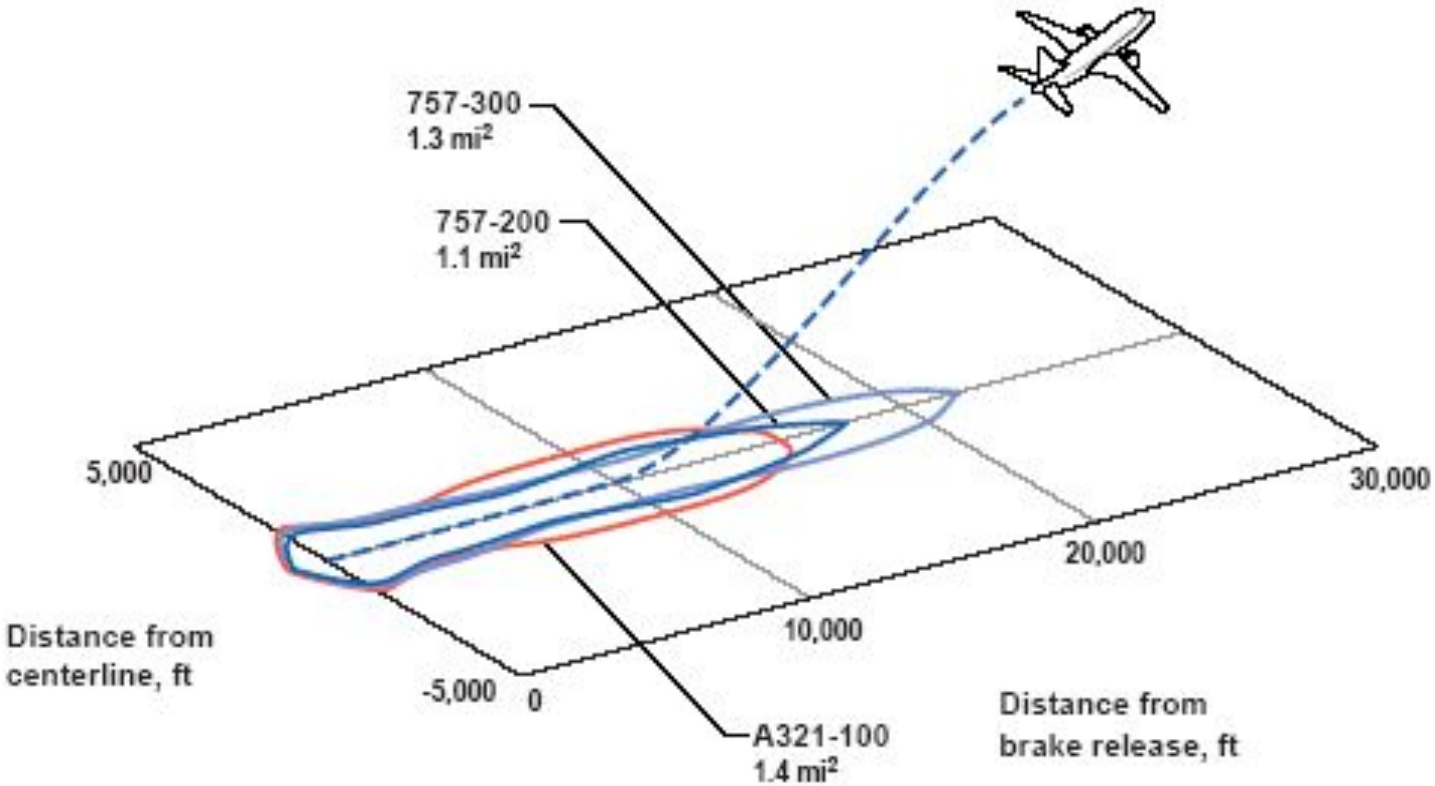
757 Engine Options

	Engine model	Thrust rating BET,* lb	Flat-rated temperature, °F (°C)	757 models -200	-200PF/F	-300
Pratt & Whitney	PW2037	36,600	87 (31)	✓	✓	
	PW2040	40,100	87 (31)	✓	✓	✓
	PW2043	42,600	96 (36)			✓
Rolls-Royce	RB211-535E4	40,200	84 (29)		✓	✓
	RB211-535E4-B	43,500	77 (25)	✓	✓	✓

* BET (Boeing-equivalent thrust) is based on takeoff installed net thrust at Mach 0.25. It is included only as reference, not as a guarantee of performance.

Takeoff Noise Area Comparison

757-200 Noise Area Reduced by 20% Over A321



- Maximum TOGW 100% load factor
- 85-dBA contour comparison; takeoff with cutback

BOEING 767 FAMILY

767-300

All 767 Engines Are 180-Minute FAA and JAA Approved for ETOPS Operations

PW4000

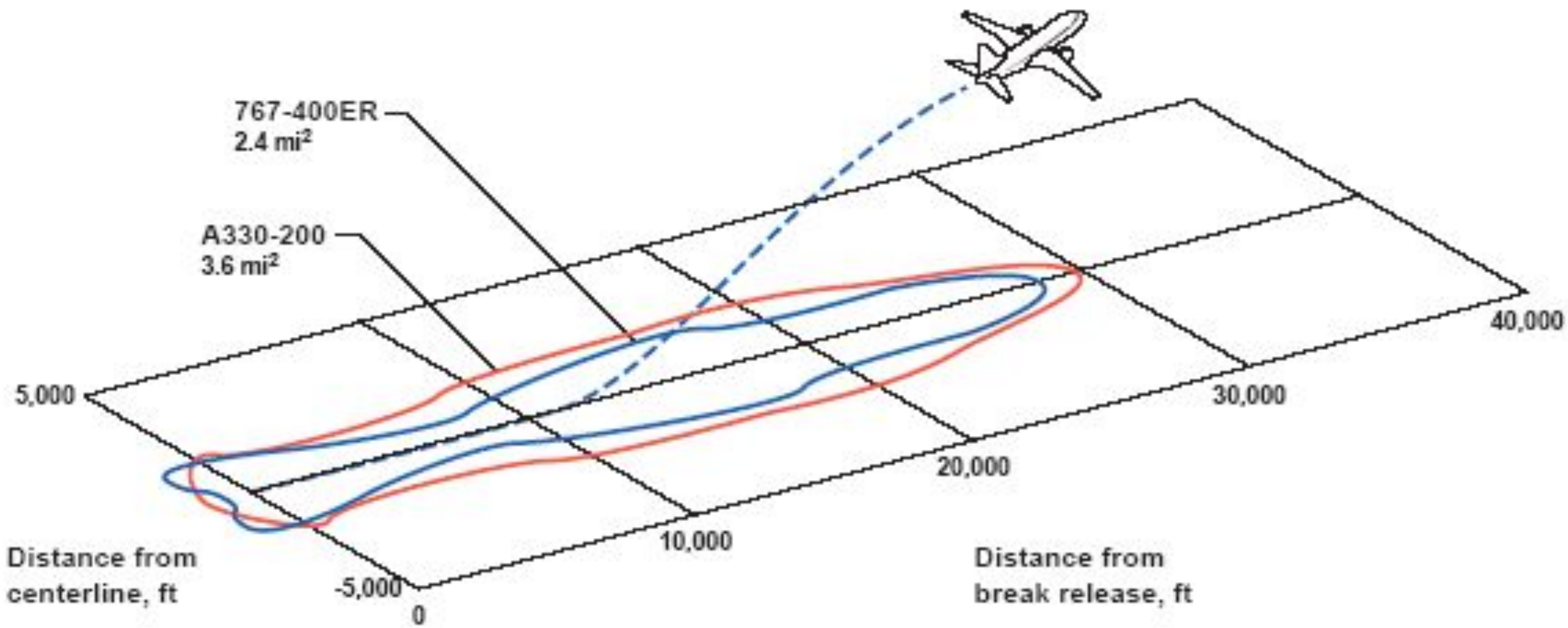
CF6-80C2

RB211-524G/H
767-300ER only

747/767 engine options

Takeoff Noise Area Comparison

767-400ER Noise Area Reduced by 33% Over A330-200



- Maximum MTOW 100% load factor
- 85-dBA contour comparison; takeoff with cutback

777

BOEING

Available Engine Options Supporting the 777 Family

	Pratt & Whitney Takeoff thrust, lb	General Electric Takeoff thrust, lb	Rolls-Royce Takeoff thrust, lb
777-200	74,400 (PW4074)[1] 74,400 (PW4074D)[2] 77,000 (PW4077)[1] 77,000 (PW4077D)[2]	77,000 (GE90-77B)[3]	73,400 (Trent 875)[4] 76,000 (Trent 877)[4]
777-200ER	84,400 (PW4084) 84,400 (PW4084D)[2] 90,000 (PW4090) 97,900 (PW4098)[6]	84,700 (GE90-85B)[3] 90,000 (GE90-90B)[3] 93,700 (GE90-94B)	83,600 (Trent 884)[4] 90,000 (Trent 892)[4] 93,400 (Trent 895)
777-200LR		110,100 (GE90-110B1)[5]	
777-300	90,000 (PW4090) 97,900 (PW4098)	93,700 (GE90-94B)[7]	83,600 (Trent 884)[4] 90,000 (Trent 892)[4] 93,400 (Trent 895)[6]
777-300ER		115,300 (GE90-115B)	

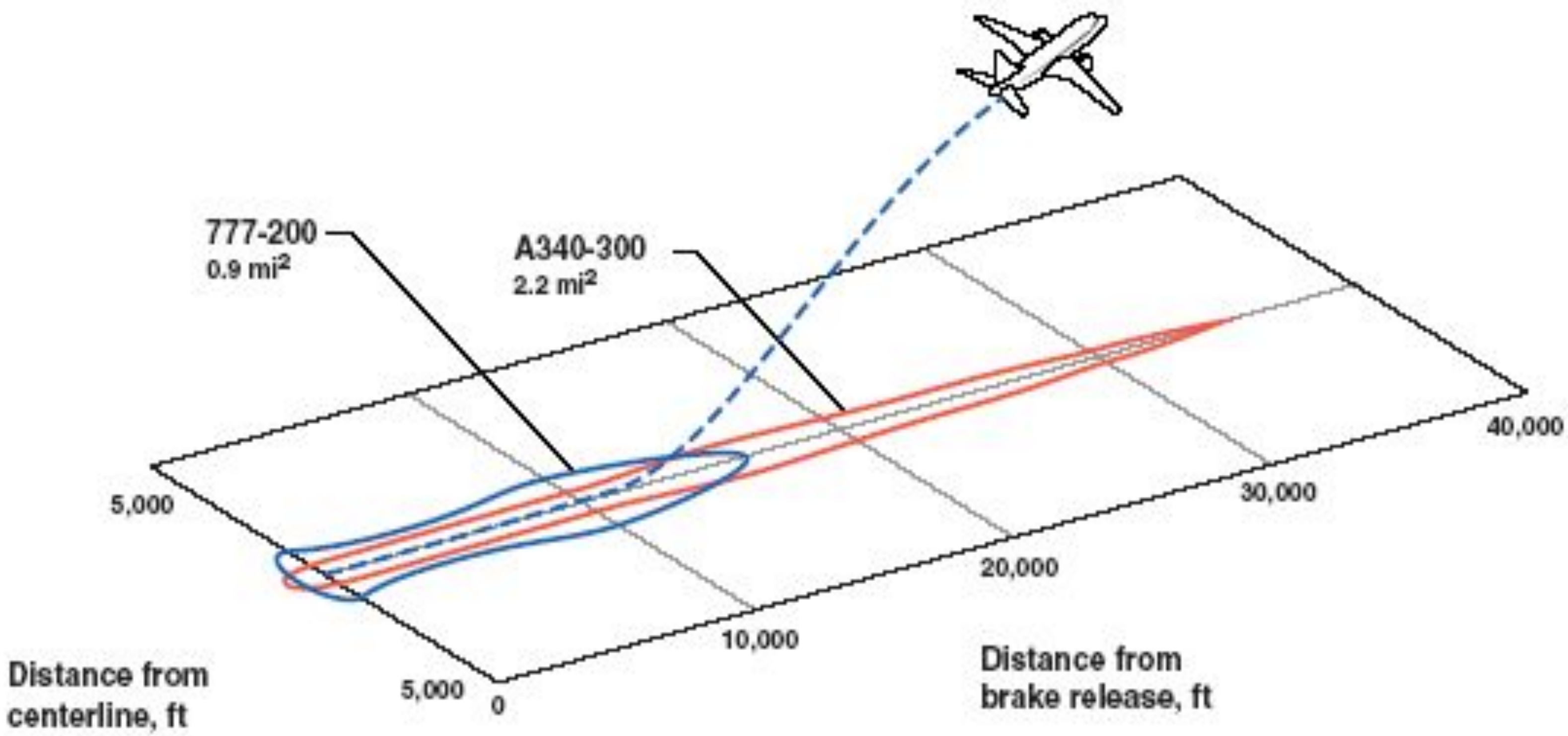
- All thrusts are Boeing equivalent.

[1] PW4084 bill of materials
[2] PW4090 bill of materials
[3] GE90-94B bill of materials
[4] Trent 895 bill of materials
[5] GE90-115B bill of materials
[6] Subject to certification lead times
[7] Subject to engineering and certification lead times

777-PP-0027-
11-15-01-JWG/LL

Takeoff Noise Area Comparison

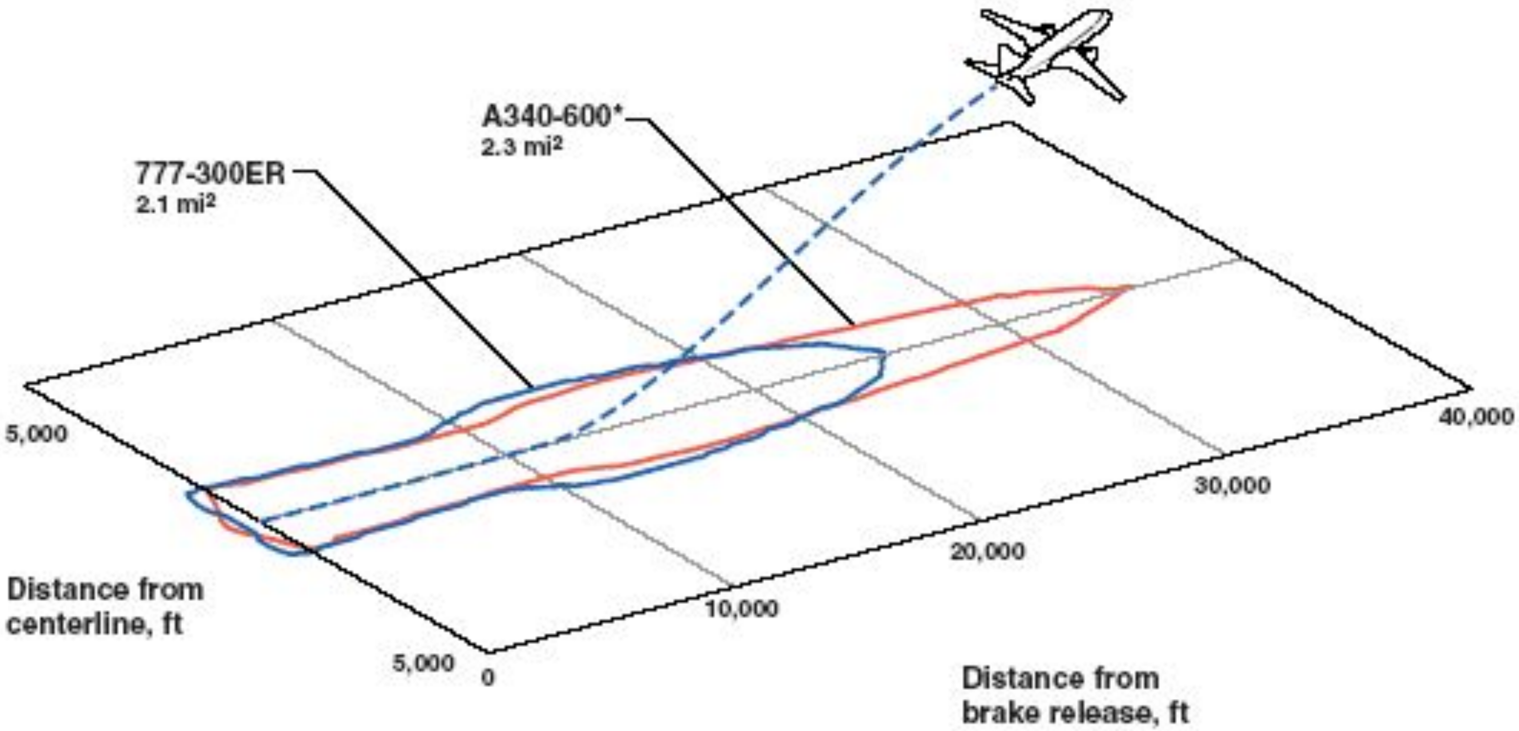
777-200 Noise Area Reduced by 41% Over A340-300



- Maximum TOGW; 100% load factor
- 85-dBA contour comparison; takeoff with cutback

Takeoff Noise Area Comparison

777-300ER Noise Area Reduced by 10% Over A340-600



- Maximum TOGW; 100% load factor
- 85-dBA contour comparison; takeoff with cutback

* Estimated airplane and engine performance

Rolls Royce Trent

- is a family of high bypass turbofan engines manufactured by Rolls-Royce.
- Versions of the Trent are in service on the Airbus A330, A340, A380 and Boeing 777, and variants are in development for the forthcoming 787 and A350.

Rolls-Royce Trent 900 on A380 prototype

A pulse jet engine (or pulsejet) is a very simple type of jet engine in which combustion occurs in pulses.