Chapter 1

Introduction to Gas Turbines

Sudip Bhattrai

Assistant Professor

Institute of Engineering (IOE)
Tribhuvan University

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1. History of Gas Turbines

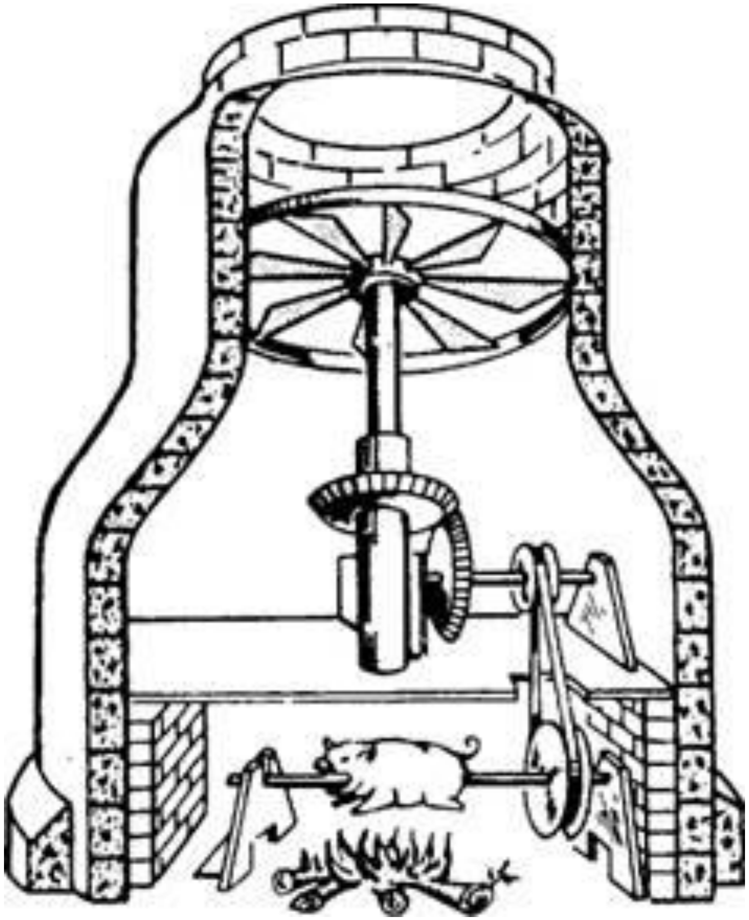
The Aeolipile

- A form of radial steam engine, first (arguably) described by ‘*Hero of Alexandria*’ (Egypt).
- Other inventions include wind-powered organ (musical instrument), and a ‘fire engine’. Famously known for deriving the area of a triangle from it’s sides.

1. History of Gas Turbines

Other Inventions

- Da Vinci’s Chimney Jack- used “to turn a roasting skewer”.



1. History of Gas Turbines

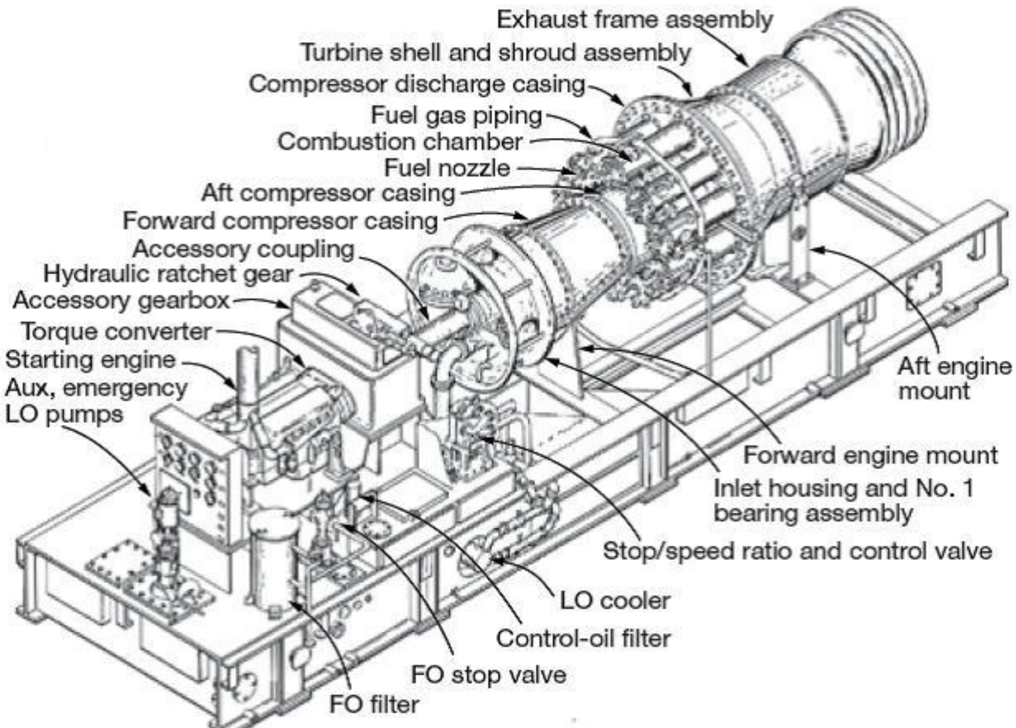
Other Inventions

- Other remarkable inventions include:
  - Steam powered Stamping Mill by Giovanni Branca (17th century). Example of impulse turbine.
  - 18th centure: Patent for a gasturbine to be used in a ‘horseless carriage’ by John Barber.

1. History of Gas Turbines

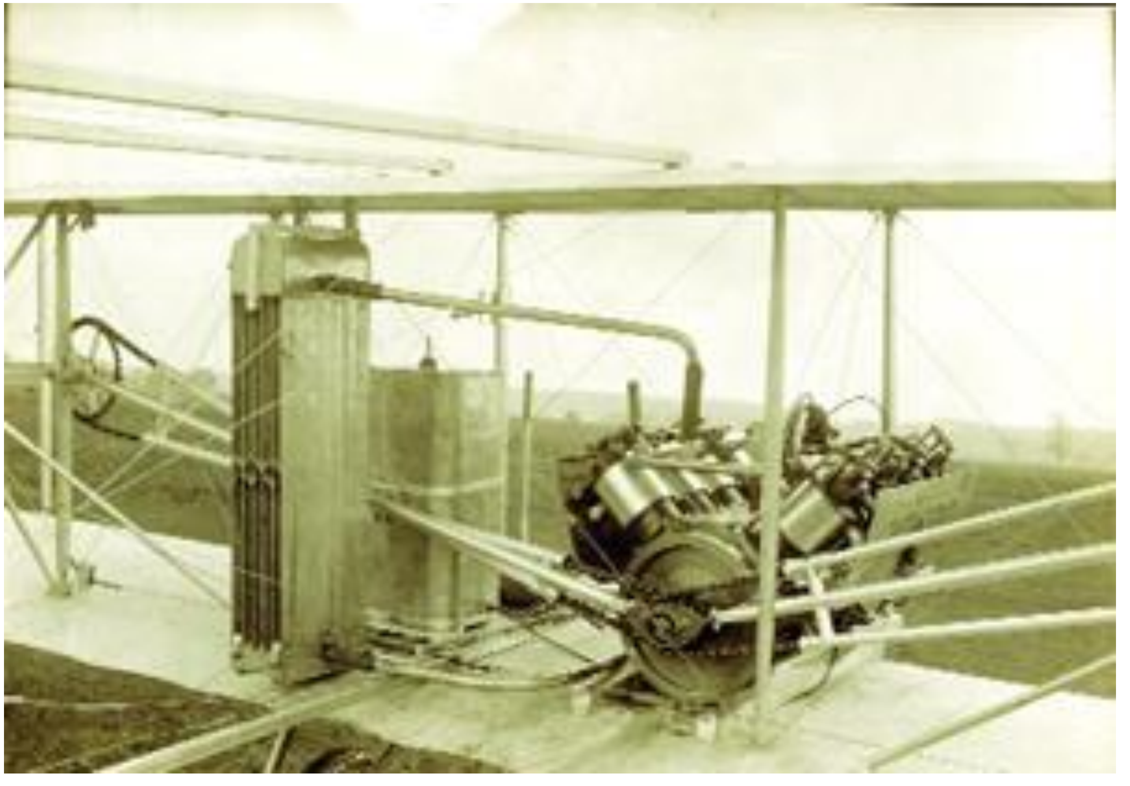
GE gets serious

- 1918 United States: GE starts research on gas turbines.
- The use of combustion (use of 'gas' instead of steam/internal combustion in contrast to external steam generation) for power production was pioneered by GE.



1. History of Gas Turbines

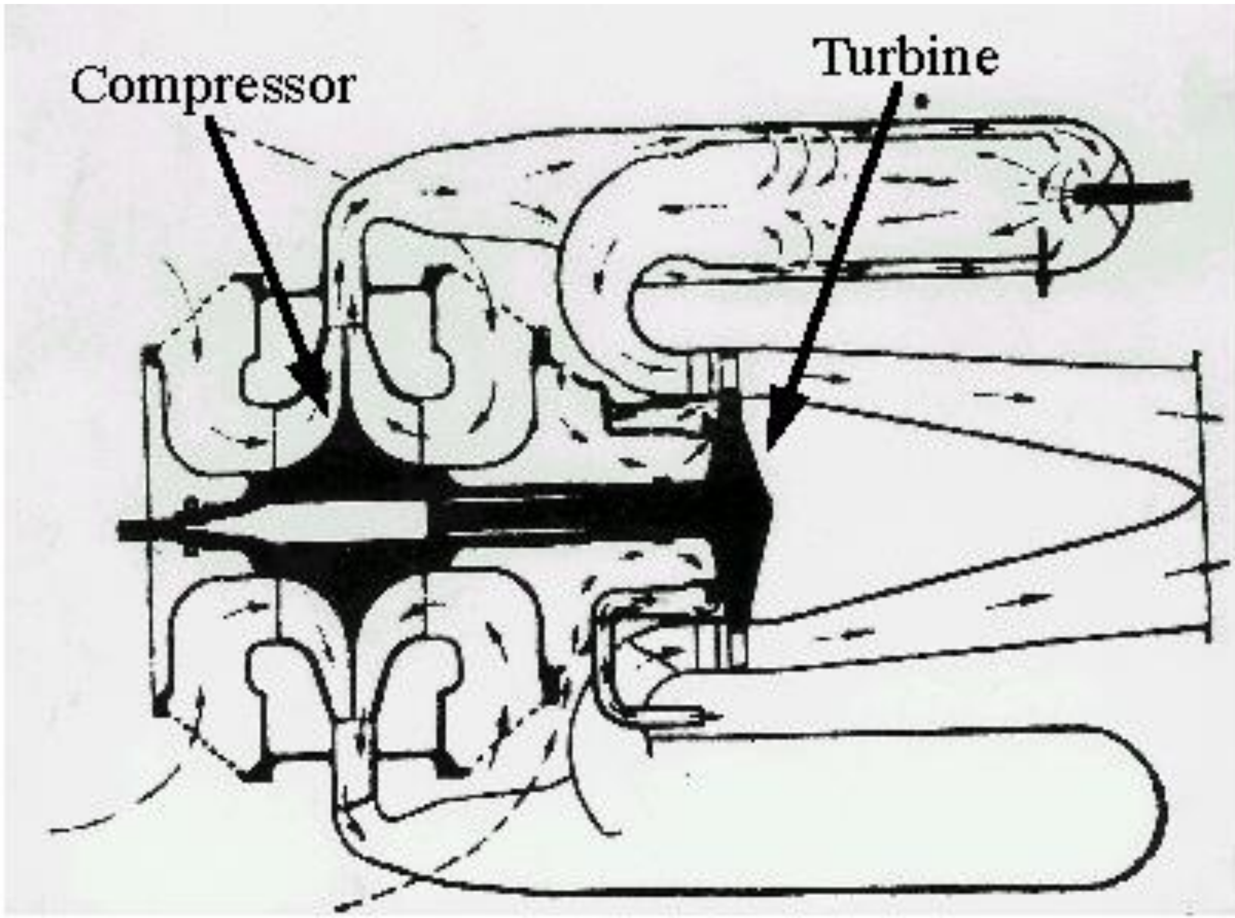
- The power onboard The Flyer was a gas powered, 12-hp reciprocating intermittent combustion engine. This type of engine, with a propeller, provided power to all (manned) aircraft until late 1930s.



1. History of Gas Turbines

- The history of gas turbine saw a major revolution after the invention of Turbojet in January 1930 with a patent issued by Frank Whittle in Great Britain (W-1 engine, 1941).
- Lack for funds for his project retarded Whittle's work for several years.
- Meanwhile, in an independent effort, Hans-Joachim Pabst von Ohain invented a turbojet engine in Germany that was granted a patent in 1936. Von Ogain's engine (He S-1 turbojet engine) was the first to be developed ahead of the Whittle engine and flew on the first jet-powered aircraft, Heinkel 178, in 1939.
- Von-Ohain is thus considered the "designer of first operational jet engine".
- Both Whittle and von Ohain are credited as the coinventors of airbreathing gas turbine engine.

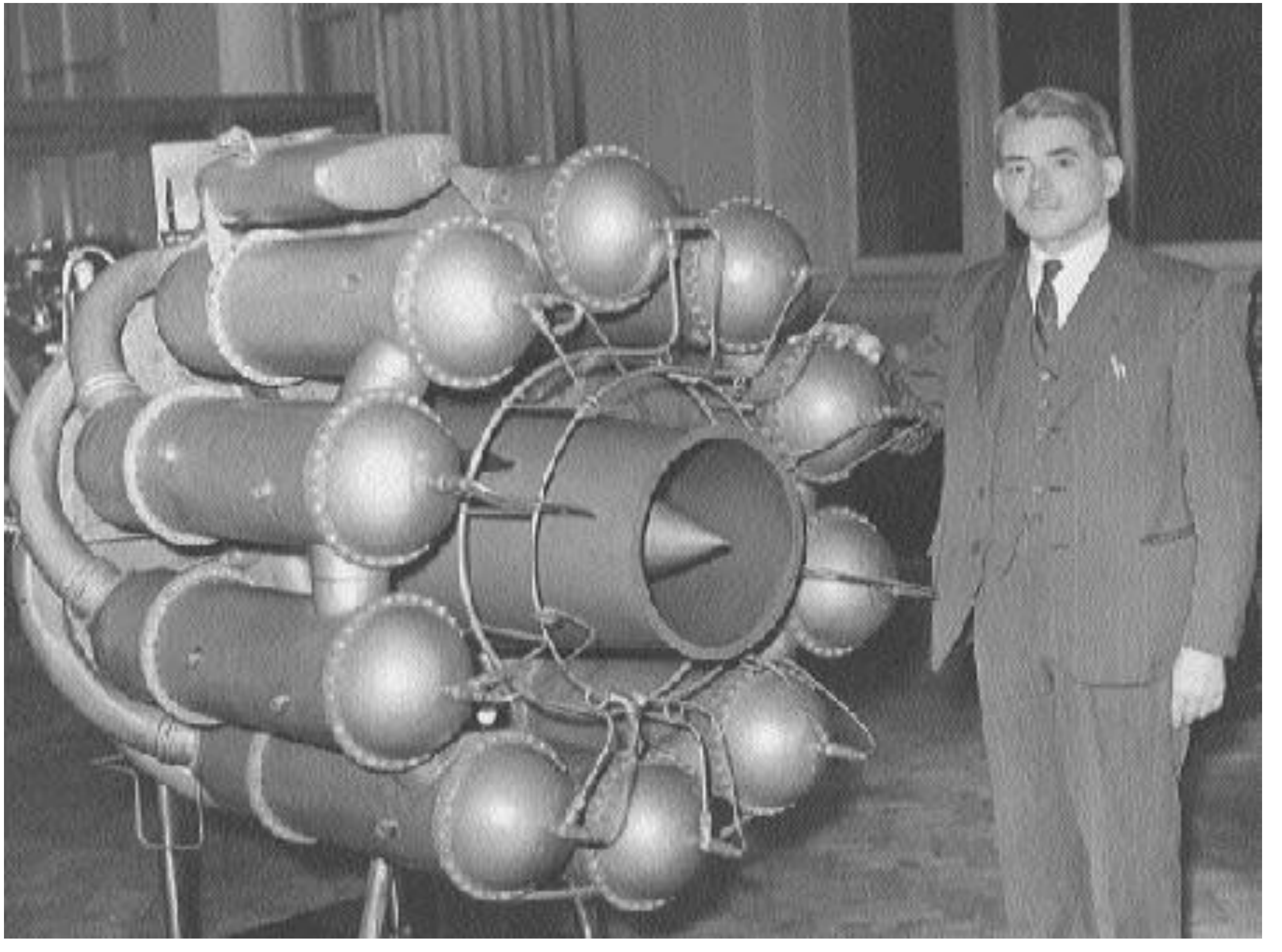
1. History of Gas Turbines



Classic Whittle Reverse-Flow Engine.

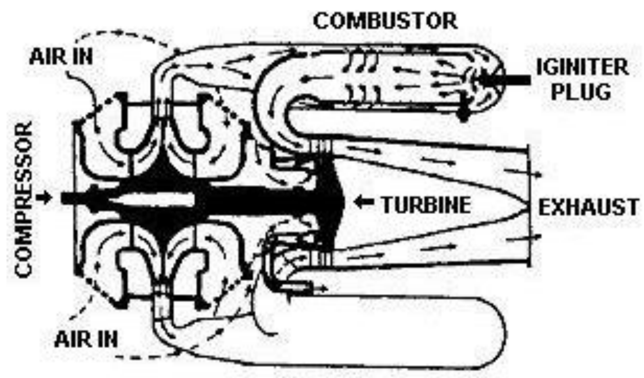
1. History of Gas Turbines

Whittle with the Power Jets W.1

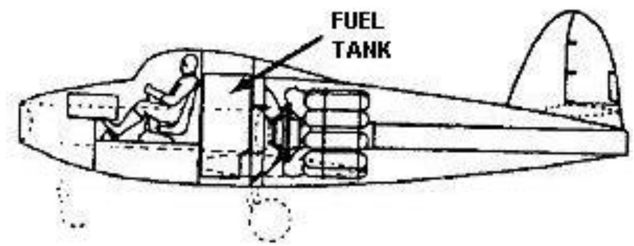


It had a single-stage double-sided centrifugal compressor, with 10 reverse-flow ‘can’ combustion chambers.

1. History of Gas Turbines

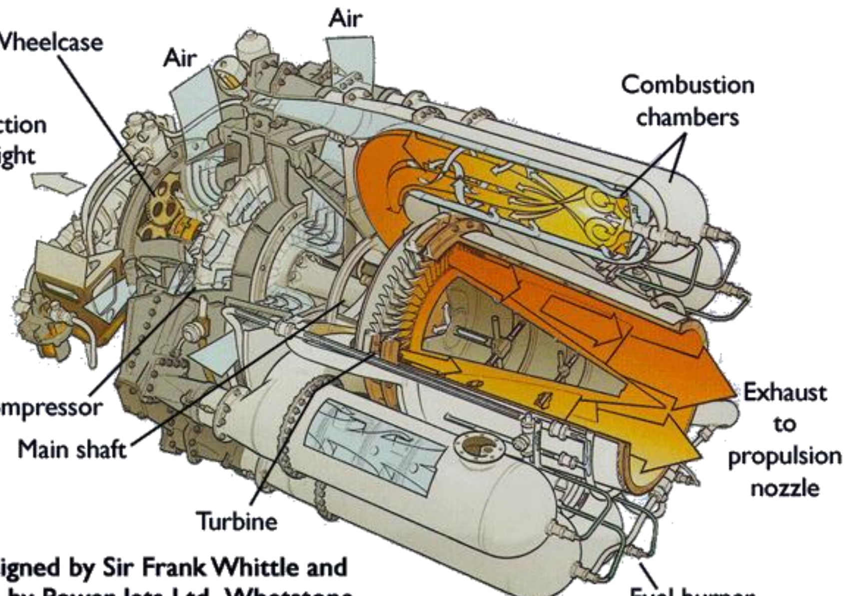


Whittle's Reverse-Flow Combustion Chamber



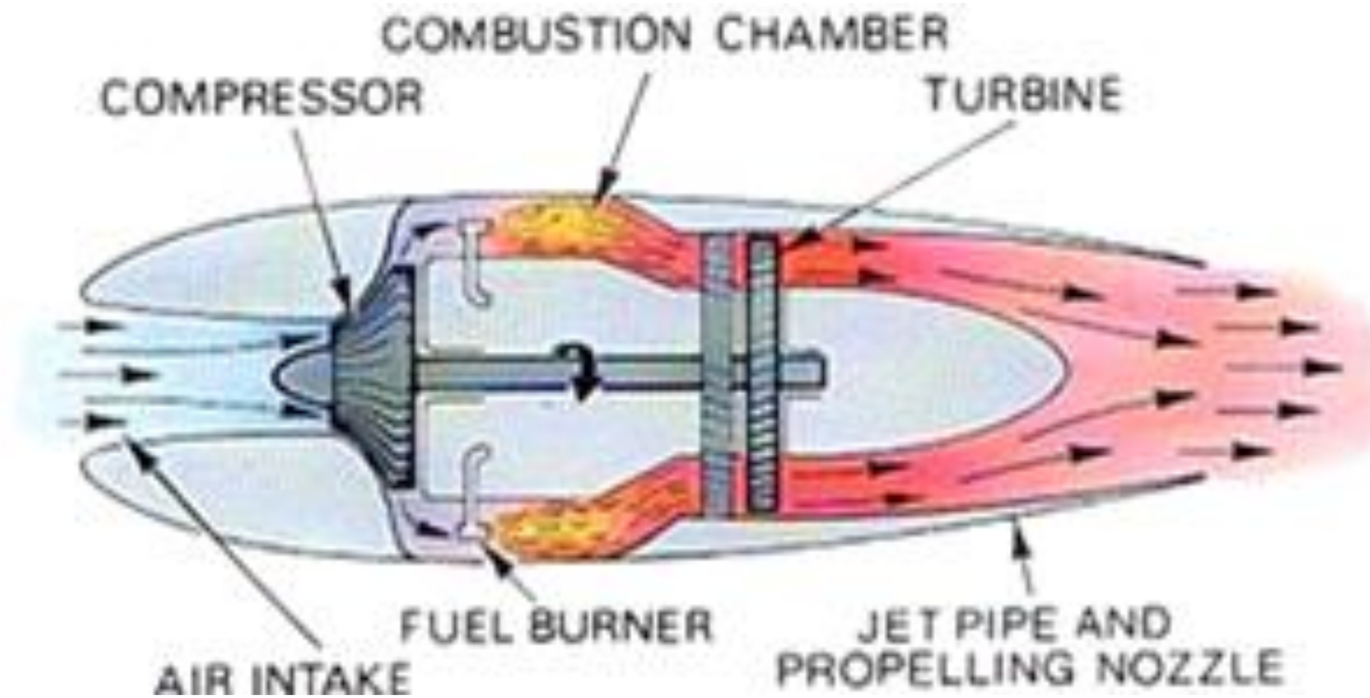
Fuselage Arrangement of the E28/39 Experimental

W.2/700 JET AERO ENGINE



Designed by Sir Frank Whittle and built by Power Jets Ltd., Whetstone

1. History of Gas Turbines



Schematic Diagram of He S-1 Turbojet Engine (von Ohain)

- The first production jet aircraft was the Messerschmitt Me 262 powered by two Jumbo 004B turbojet engines, based in von Ohain’s patent. It’s first flight was in 1942.

2. Types of Engines used in Aircrafts Operating in Nepal

- Turboprop

  Examples: de Havilland Canada DHC-6 Twin Otter, ATR, Dronier Do 228, Beechcraft, Hawker Siddeley (HS) 748 (Nepal Army), etc.

- Turbofan

  Examples: B737, B757, B777, A330, A320 series, etc.

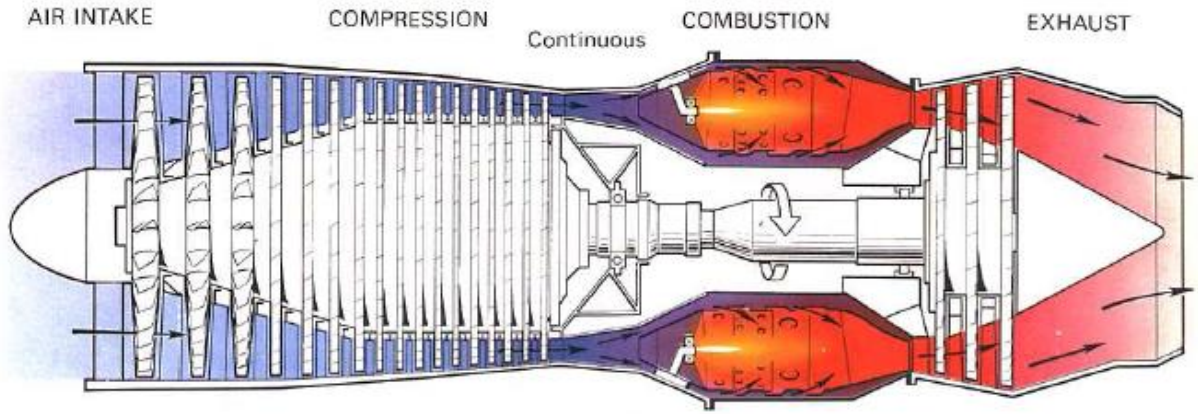
- Turboshaft

  Russian MI-17 and MI-8 (Nepal Army), Indian HAL Dhruv, etc.

3. Classification and Nomenclature of Aircraft Engine

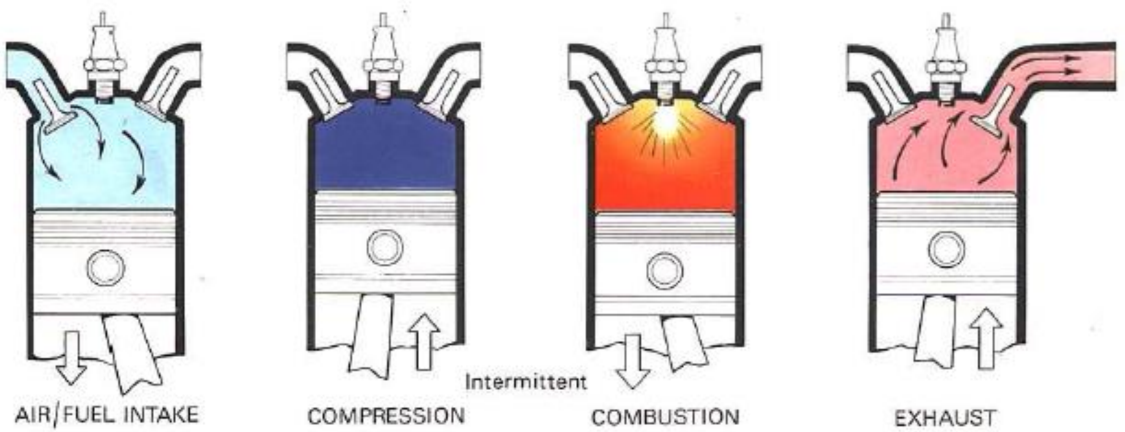
- Reciprocating Combustion Engine/Piston Engine
- Continuous Combustion Engines
  - Turbojet
  - Turboshaft
  - Turboprop
  - Turbofan
  - One Spool Mixed Flow Turbofan
  - Two Spool Unmixed Flow Turbofan
  - Two Spool Mixed Flow Turbofan
  - Variable Cycle Engine
- Pulse Combustion/Detonation Engines
- Advanced Propulsion Systems

3. Classification and Nomenclature of Aircraft Engine



Turbo Engine

Continuous



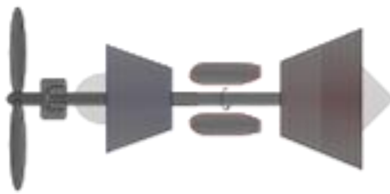
Piston Engine

Intermittent

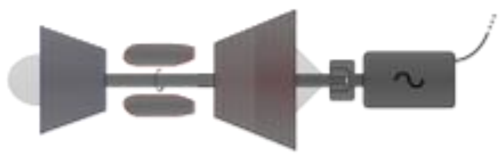
3. Classification and Nomenclature of Aircraft Engine

Gas turbine classifications based on applications

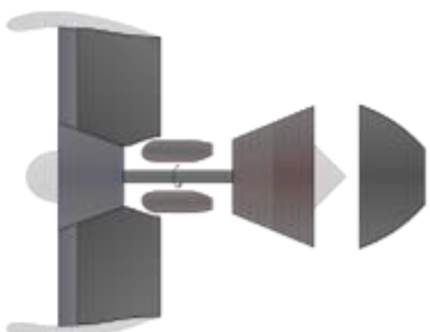
Turbojet



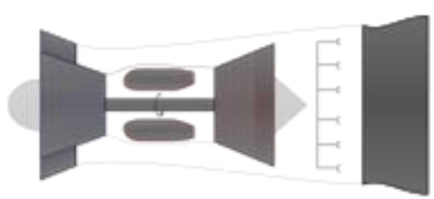
Turboprop



Turboshaft as electric generator



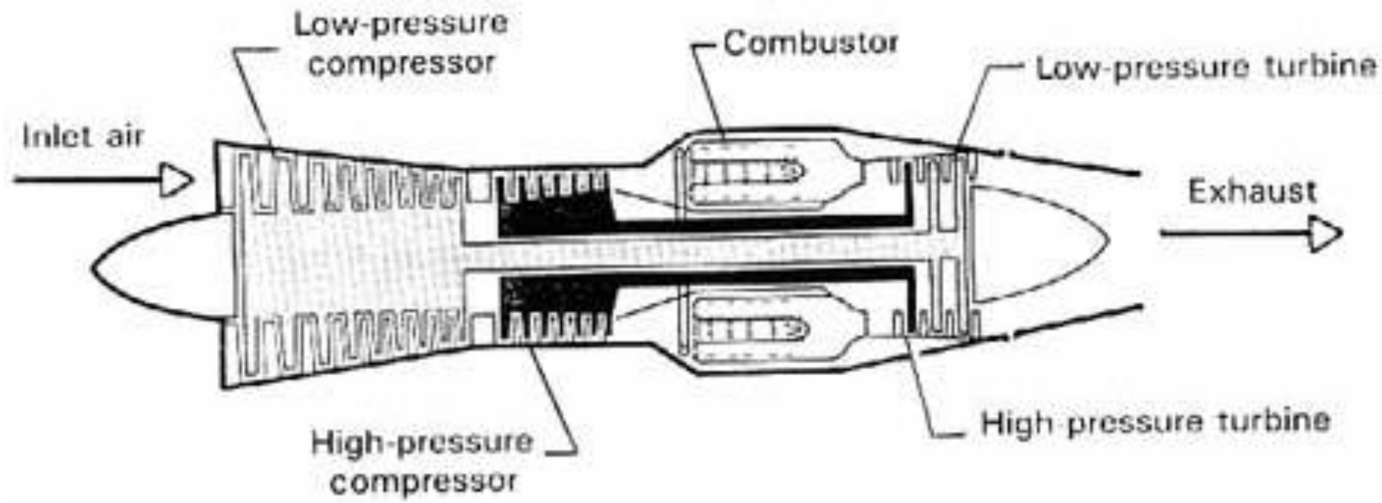
High-bypass turbofan



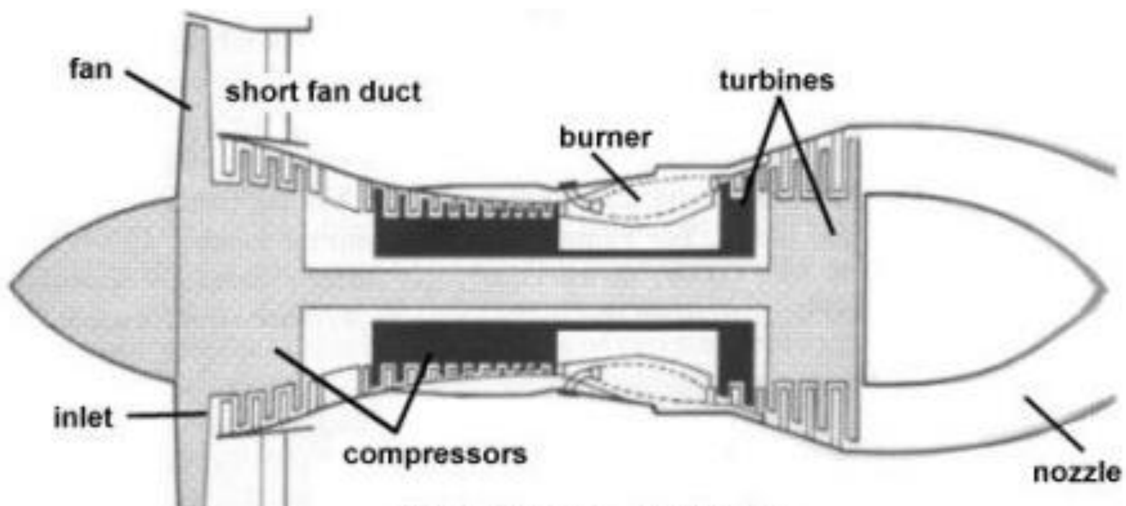
Low-bypass turbofan with afterburner

3. Classification and Nomenclature of Aircraft Engine

Turbojet



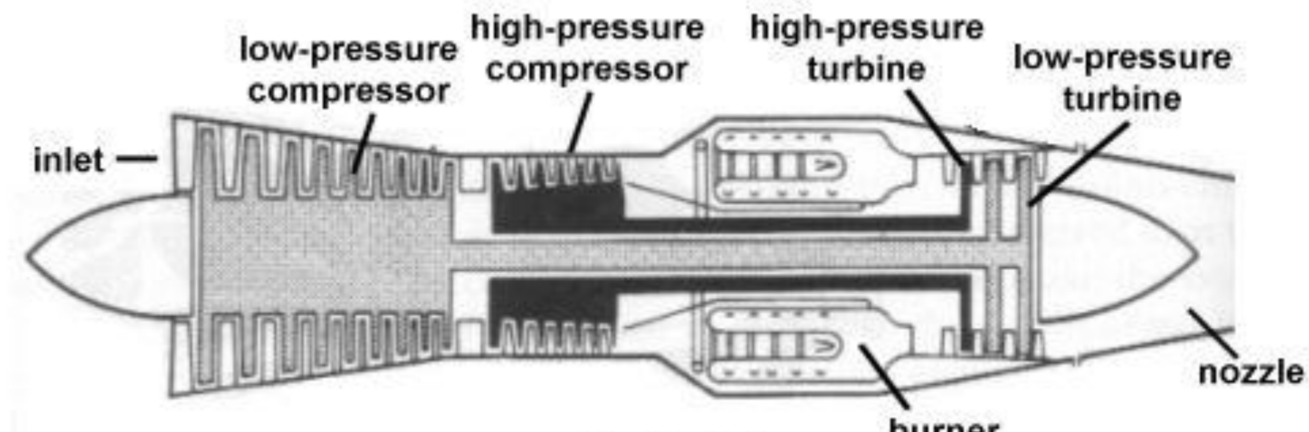
Turbofan



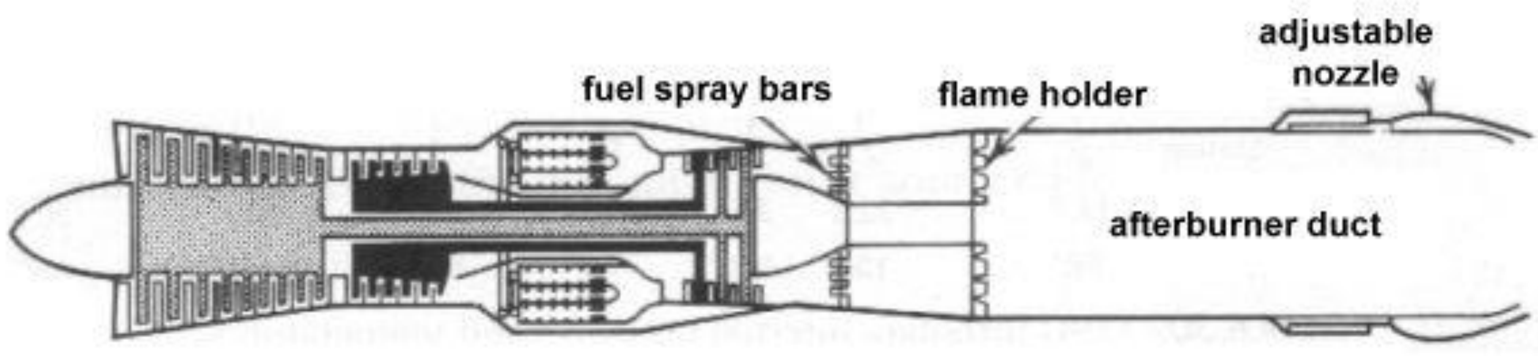
High-Bypass Turbofan

3. Classification and Nomenclature of Aircraft Engine

The Turbojet Engine



Turbojet



Turbojet with Afterburner

3. Classification and Nomenclature of Aircraft Engine

The Turbojet Engine

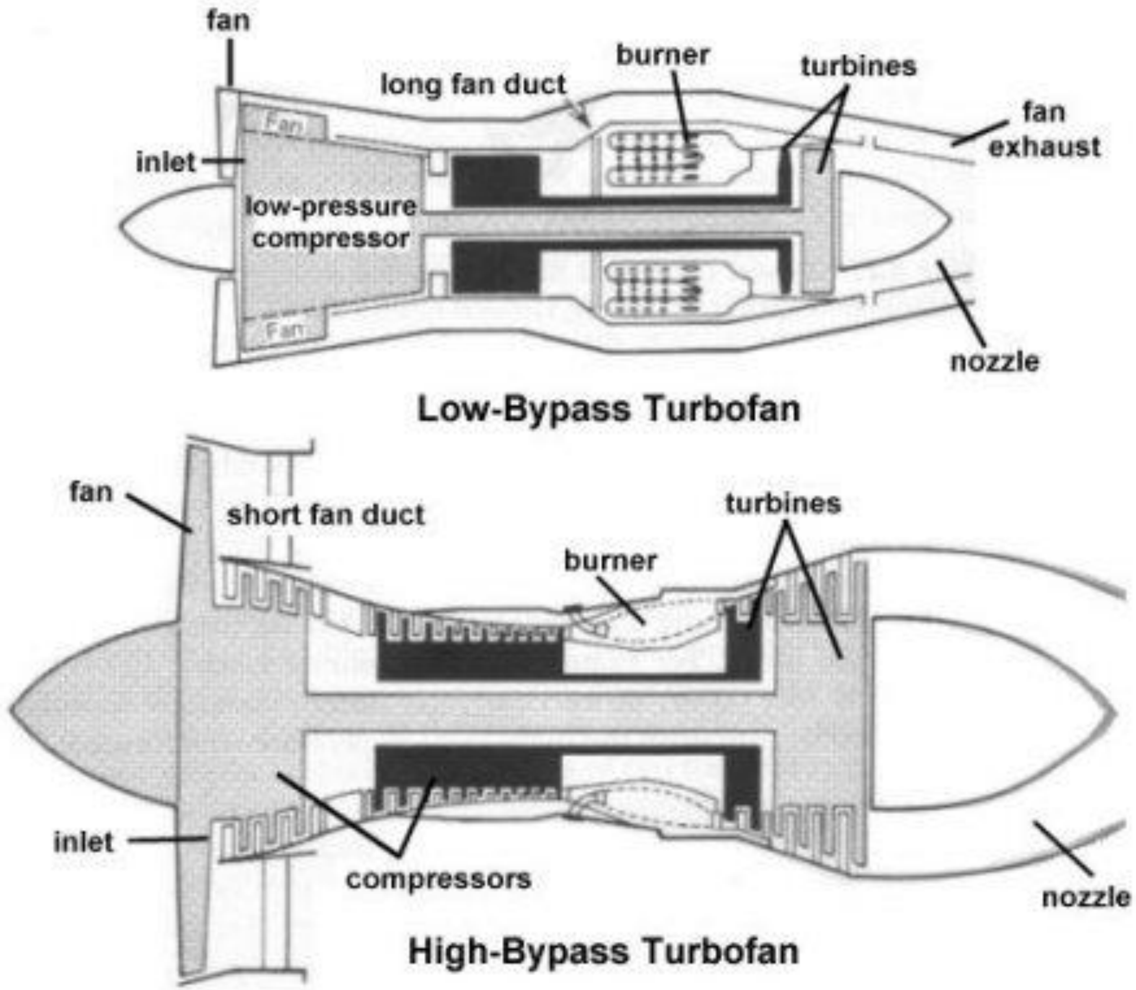
MiG-21 beside its power plant- Tumansky R25 turbojet engine

3. Classification and Nomenclature of Aircraft Engine

MiG-21

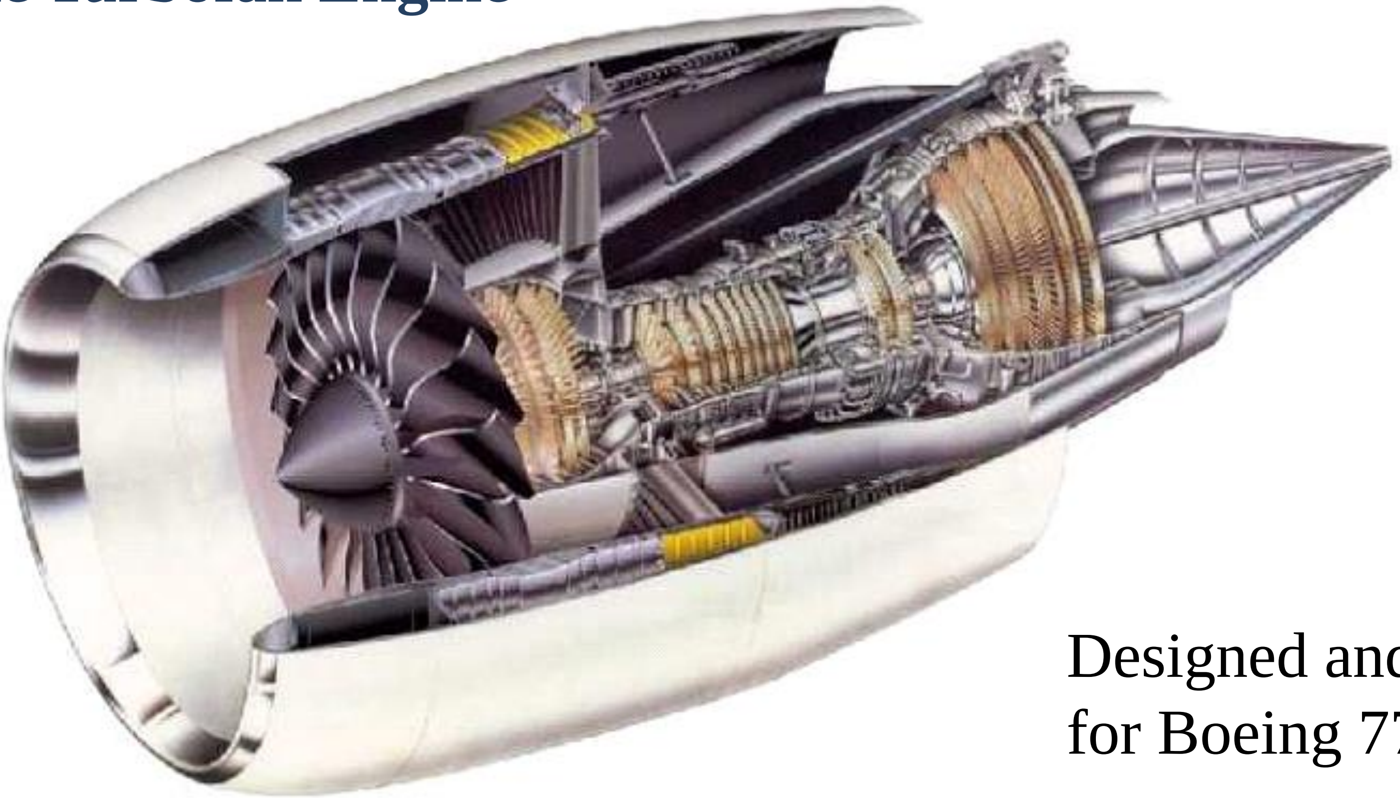
3. Classification and Nomenclature of Aircraft Engine

The Turbofan Engine



3. Classification and Nomenclature of Aircraft Engine

The Turbofan Engine



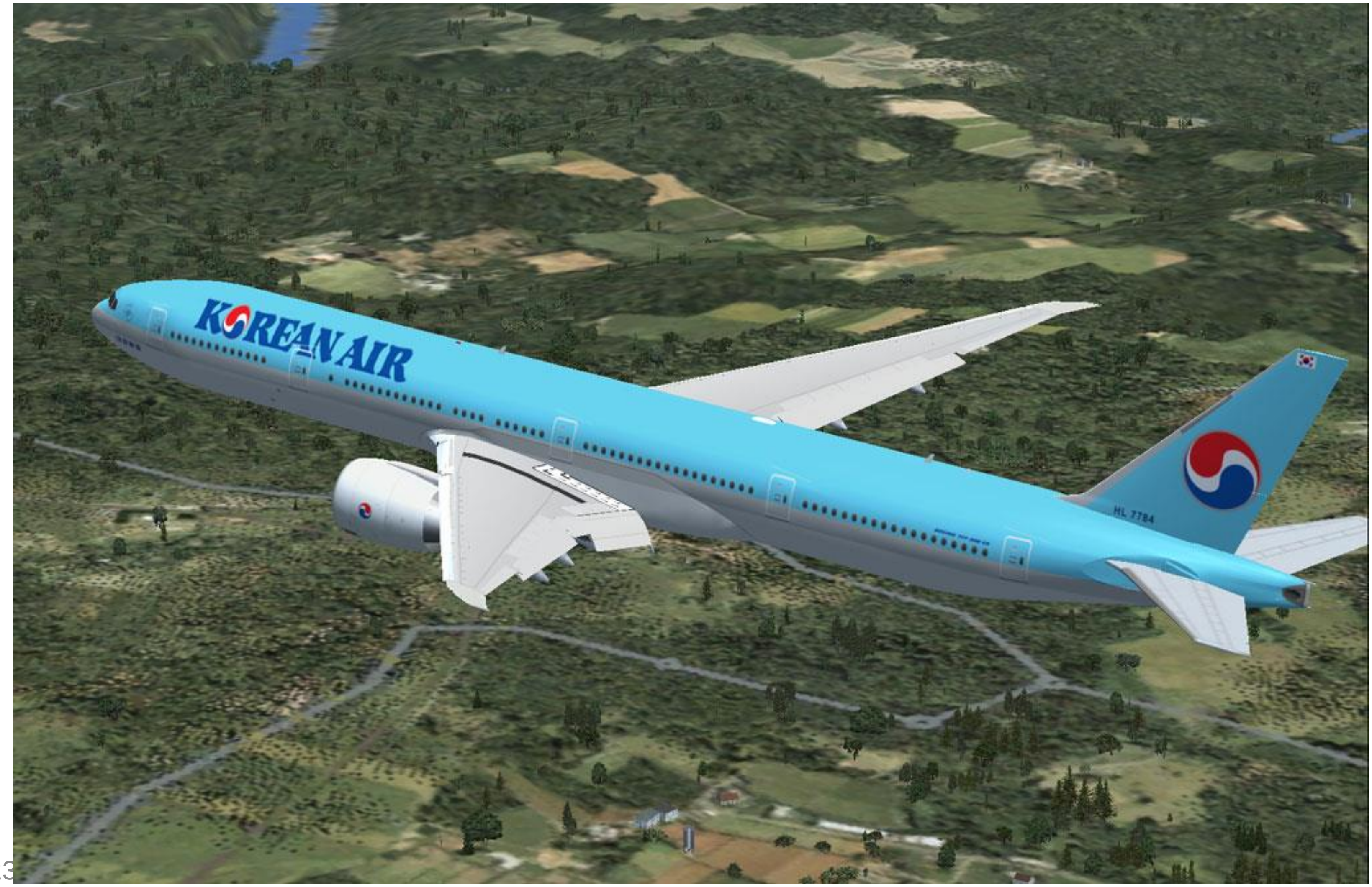
Designed and Built for Boeing 777

G90 Turbo engine

3. Classification and Nomenclature of Aircraft Engine

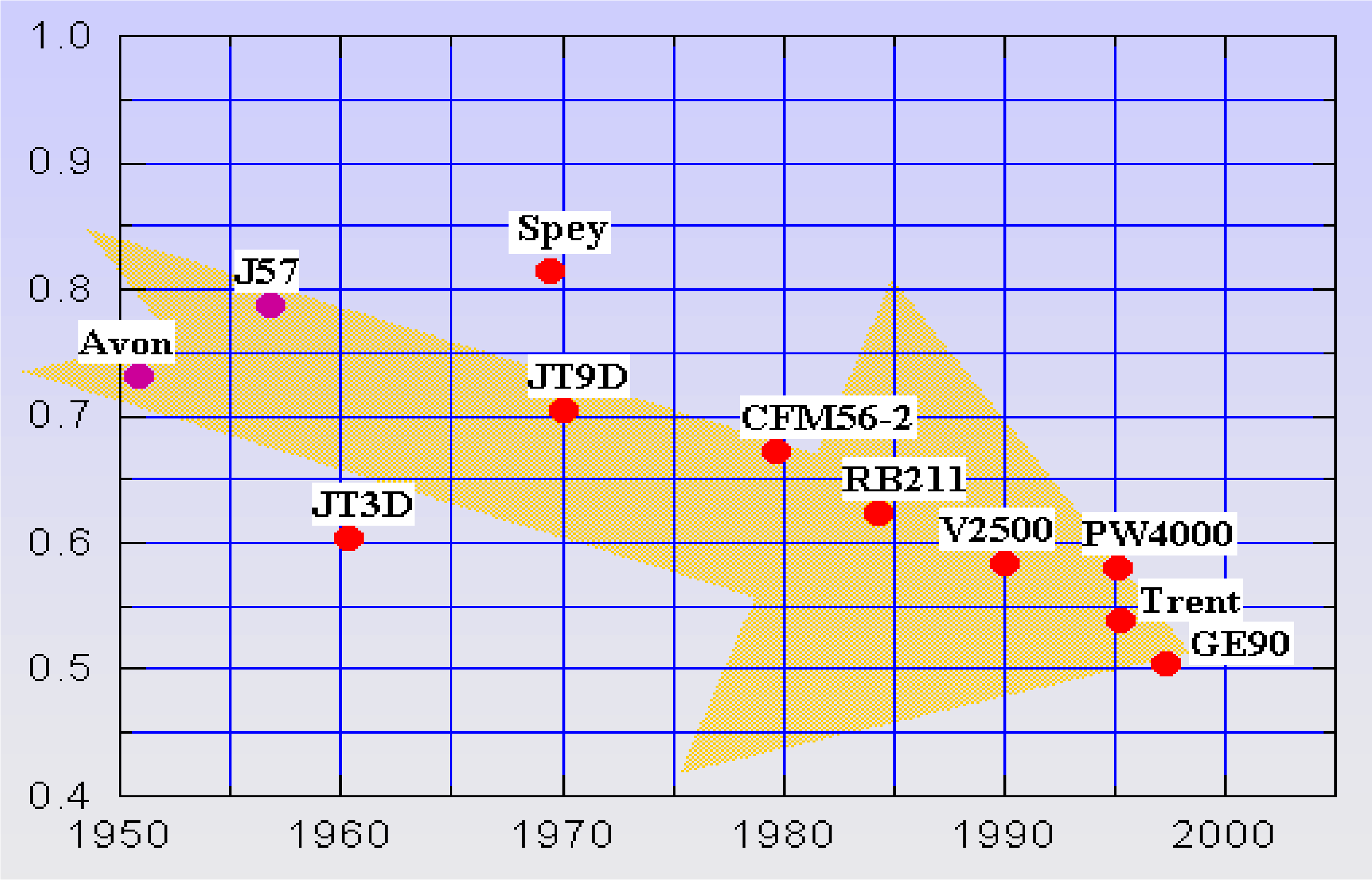
3. Classification and Nomenclature of Aircraft Engine

Boeing 777



3. Classification and Nomenclature of Aircraft Engine

Thrust Specific Fuel Consumption (TSFC) Historical Trend



TSFC

$=f/F_{sp}$

3. Classification and Nomenclature of Aircraft Engine

The Turbofan Engine

Breathing Diagram (F-22 Raptor Turbofans)

3. Classification and Nomenclature of Aircraft Engine

3. Classification and Nomenclature of Aircraft Engine

The Turbofan Engine

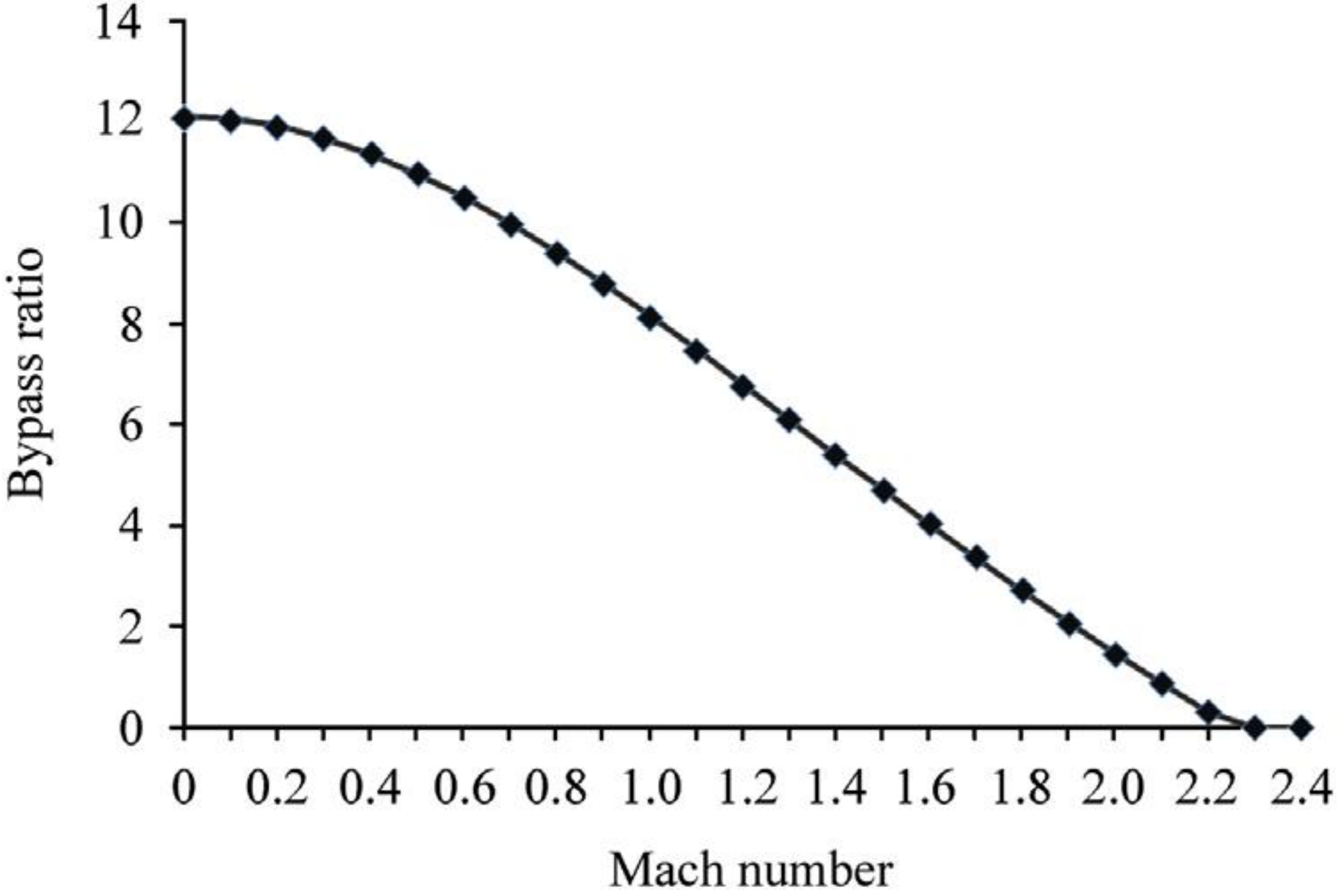
Baseline Turbofan Engine Parameters (TF39-GE-1C)

Input parameters	Values	Input parameters	Values
Mach number (initial)	0	LPC polytropic efficiency	0.89
Reference altitude	15.24 km (50000 ft)	HPC polytropic efficiency	0.90
Reference temperature	216.667 K (390 R)	HPT polytropic efficiency	0.89
Reference pressure	11665.928 Pa (1.692 psi)	LPT polytropic efficiency	0.89
Turbine inlet temperature	1611.112 K (2900 R)	Burner efficiency	0.995
Compressor pressure ratio	26	Mech. shaft LP spool efficiency	0.99
LPC pressure ratio	1.56	Mech. shaft HP spool efficiency	0.99
Fan pressure ratio	1.56	Max turbine inlet temperature	1777.778 K (3200 R)
Back pressure ratio (p_0/p_9)	1	Turbine exit Mach number	0.5
Fuel heating value (kerosene)	42.2 MJ/kg (18400 BTU/lbm)	Max compressor pressure ratio	32
Bypass ratio	Floating values	Max pressure at burner inlet	4481.592 Pa (650 psi)
Compressor sp. heat ratio	1.3986	Max temperature at burner inlet	1033.334 K (1860 R)
Turbine sp. heat ratio	1.2957	Mach number at turbine exit	0.5
Bleed air	1%	Max % ref RPM-LP spool	110
Coolant air	5%	Max % ref RPM-HP spool	110
Burner pressure recovery	0.96	Afterburner pressure recovery	0.96
Nozzle pressure recovery	0.985	Afterburner efficiency	0.995
Diffuser max pressure recovery	0.995	Mixer pressure recovery (max)	0.97
Fan pressure ratio	0.98	Max temperature at afterburner outlet	2000 K (3600 R)
Fan polytropic efficiency	0.89	Afterburner sp. heat ratio	1.3

3. Classification and Nomenclature of Aircraft Engine

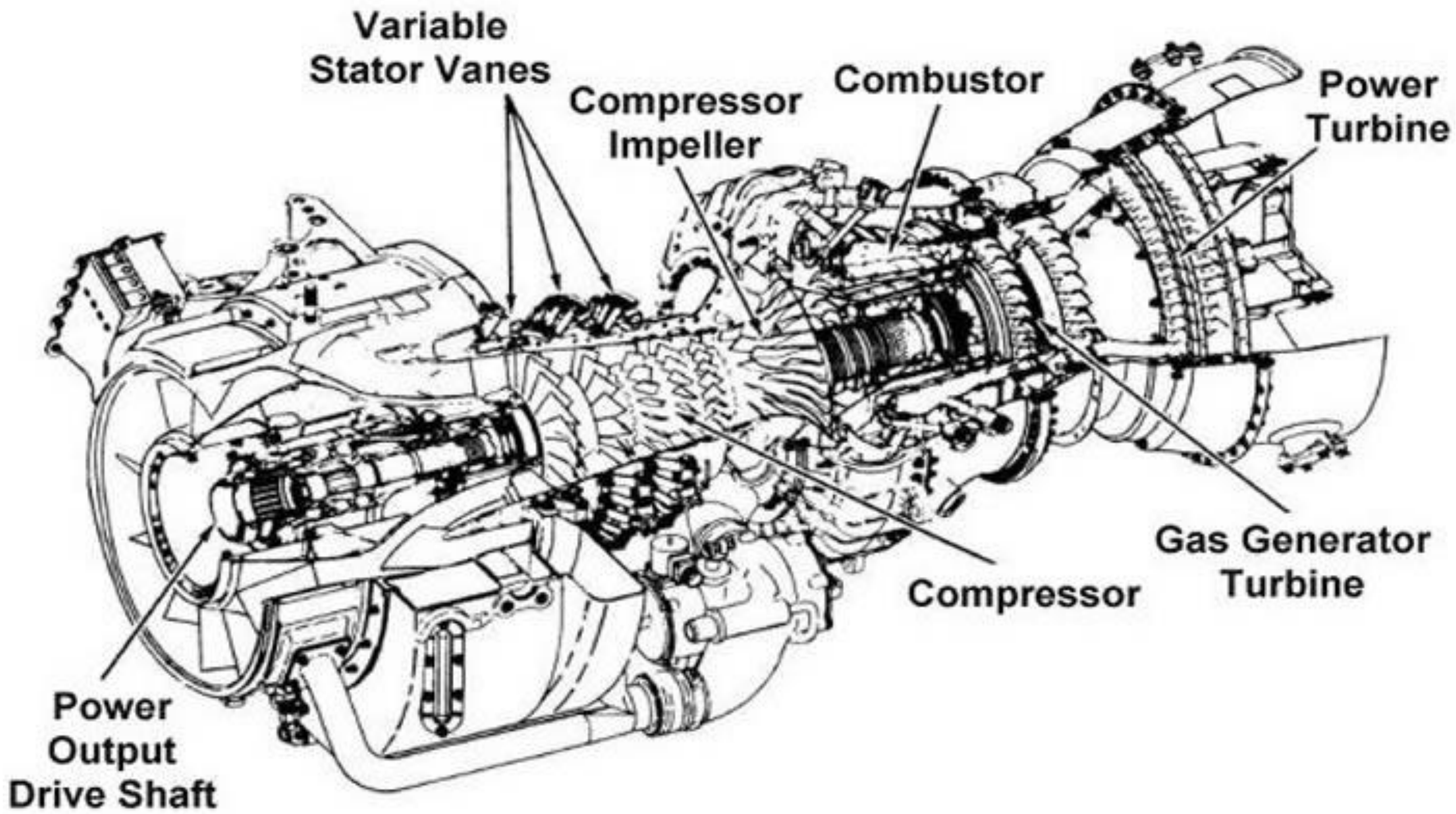
The Turbofan Engine

Turbofan Bypass Ratio Variation with Mach Number



3. Classification and Nomenclature of Aircraft Engine

The Turboshaft Engine



Used in helicopters, auxiliary power units, ships, tanks, hovercraft, and as generators in stationary equipments.

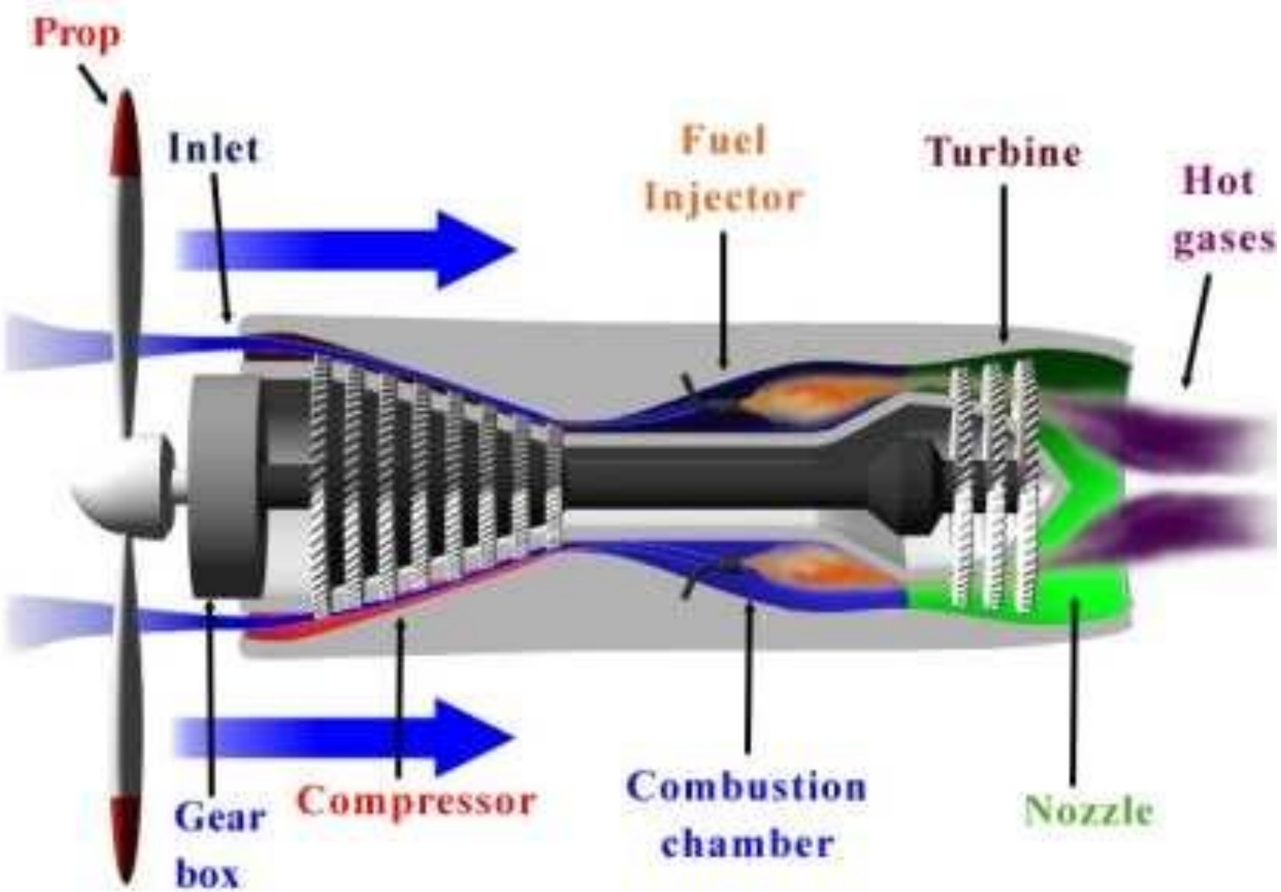
3. Classification and Nomenclature of Aircraft Engine

The Turboshaft Engine

VTOL V-22
(Osprey)

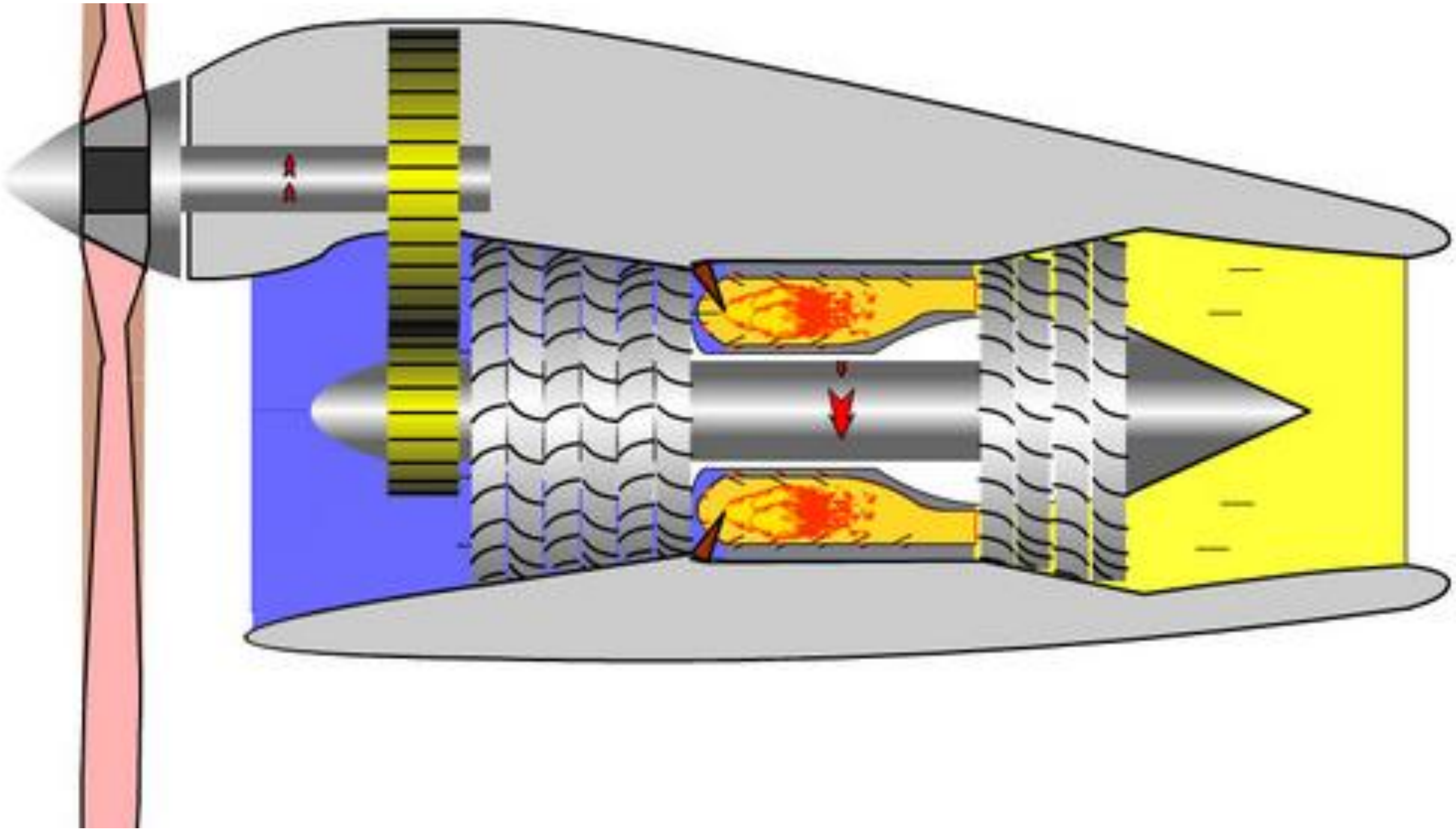
3. Classification and Nomenclature of Aircraft Engine

The Turboprop Engine



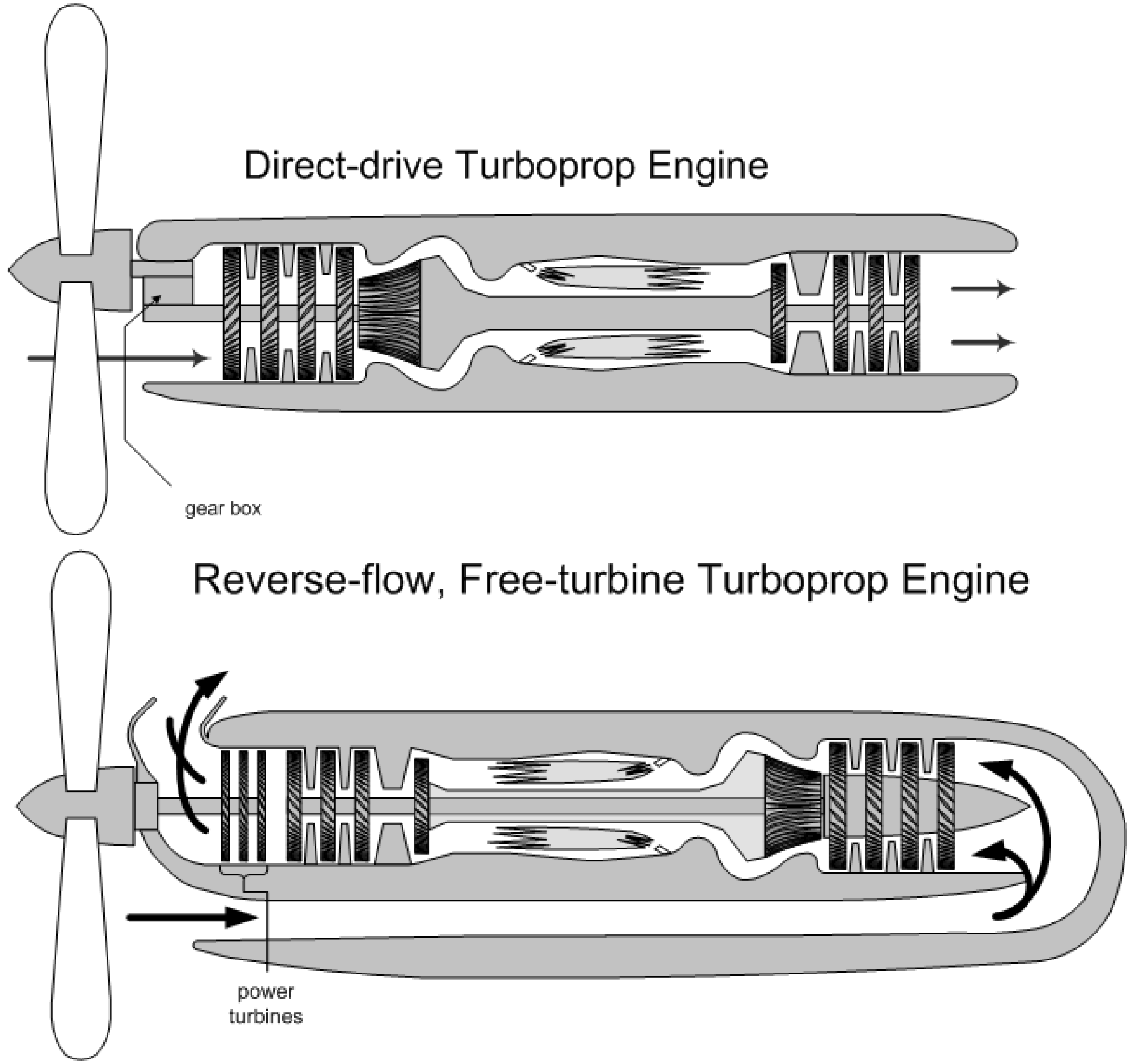
3. Classification and Nomenclature of Aircraft Engine

The Turboprop Engine



3. Classification and Nomenclature of Aircraft Engine

The Turboprop Engine



3. Classification and Nomenclature of Aircraft Engine

The Turboprop Engine

There are two types of turboprop engine

- Direct-drive turboprop, and
- Free-turbine turboprop
- With the direct-drive system, the propeller is connected to a shaft and turbine and the speed of the propeller is modified through a reduction gear mechanism.
- In the free-turbine system, the propeller is connected to a power turbine which “floats” in the high pressure exhaust gases in the turbine section.
- The free-turbine provides easier maintenance as the power section is not physically connected to the core turbine, but are less powerful by weight and less fuel efficient when compared to direct-drive turboprops.

3. Classification and Nomenclature of Aircraft Engine

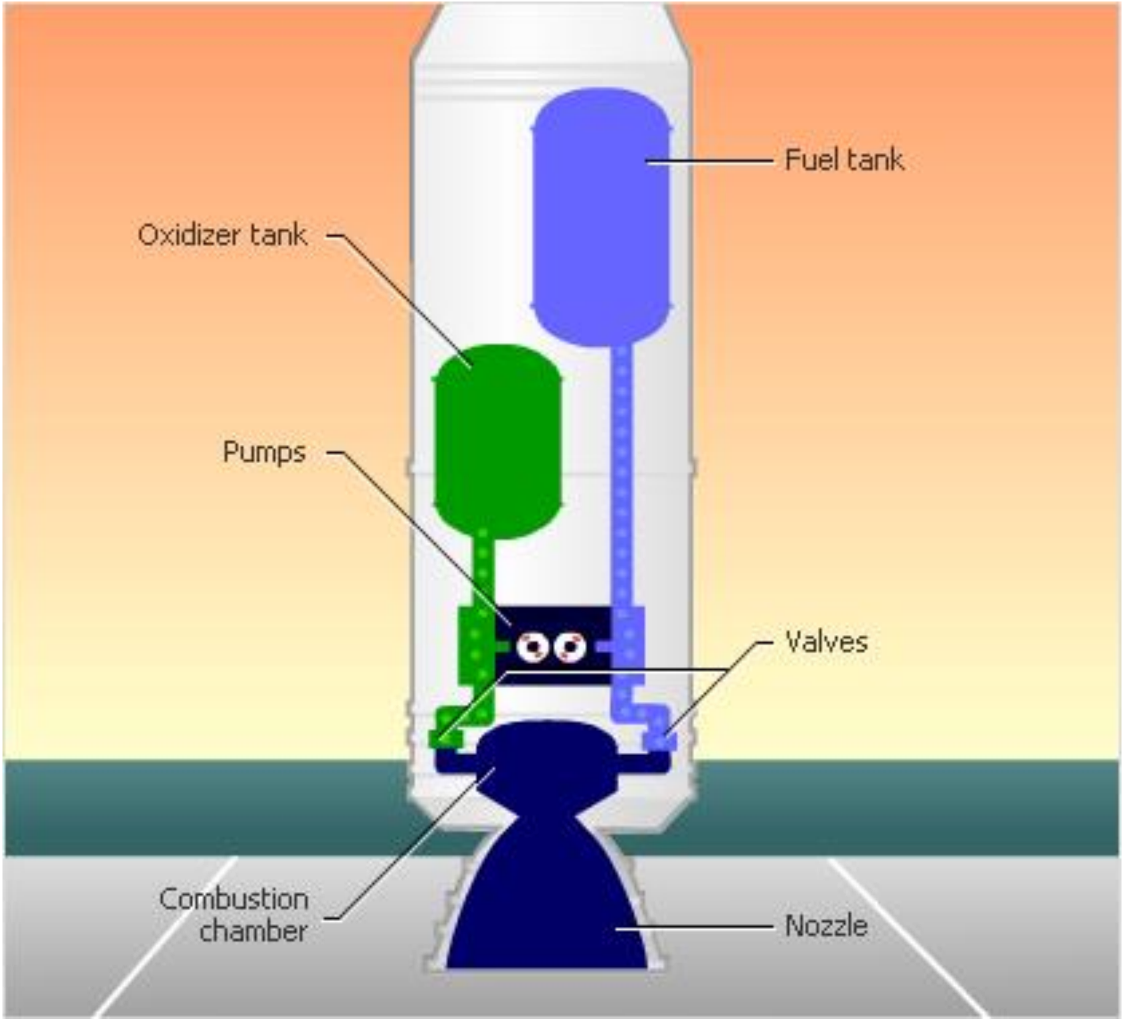
The Turboprop Engine

Advantages over turbojet engines:

- The amount of power available for propulsion is largely independent of the forward speed of the aircraft, so that more power is available during the initial stages of the takeoff run.
- A slipstream is produced behind the propeller that improves elevator and rudder control at low speeds.
- The engine can be run under more efficient and economical conditions at low and medium altitudes, and retains these two qualities at low aircraft speeds.
- With the use of interconnected engine and propeller controls, the power response to throttle movement is more rapid than that of a turbojet engine.
- Operations can be conducted from shorter runways.

3. Classification and Nomenclature of Aircraft Engine

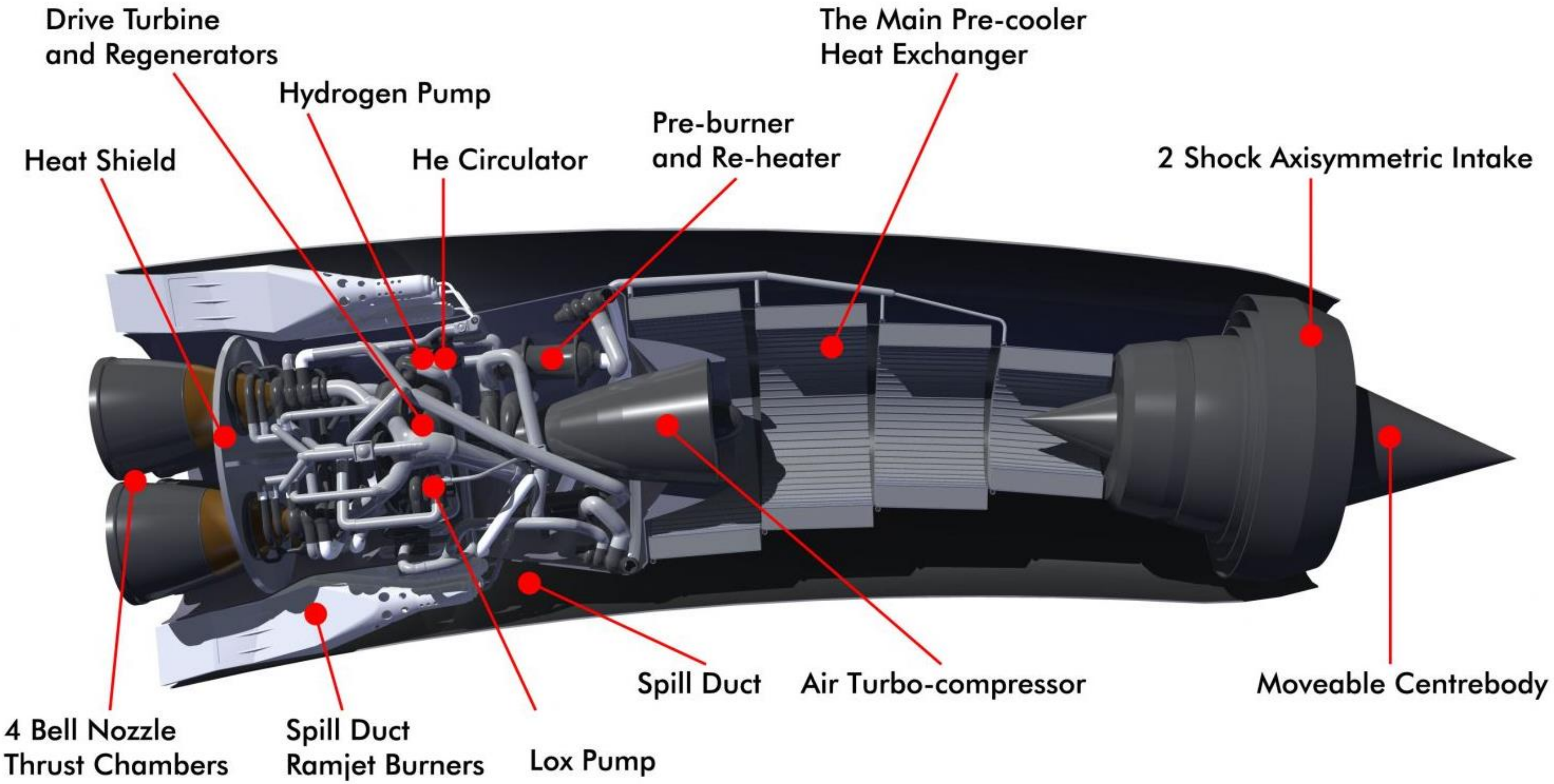
Rocket Engine



3. Classification and Nomenclature of Aircraft Engine

Advanced Propulsion Systems

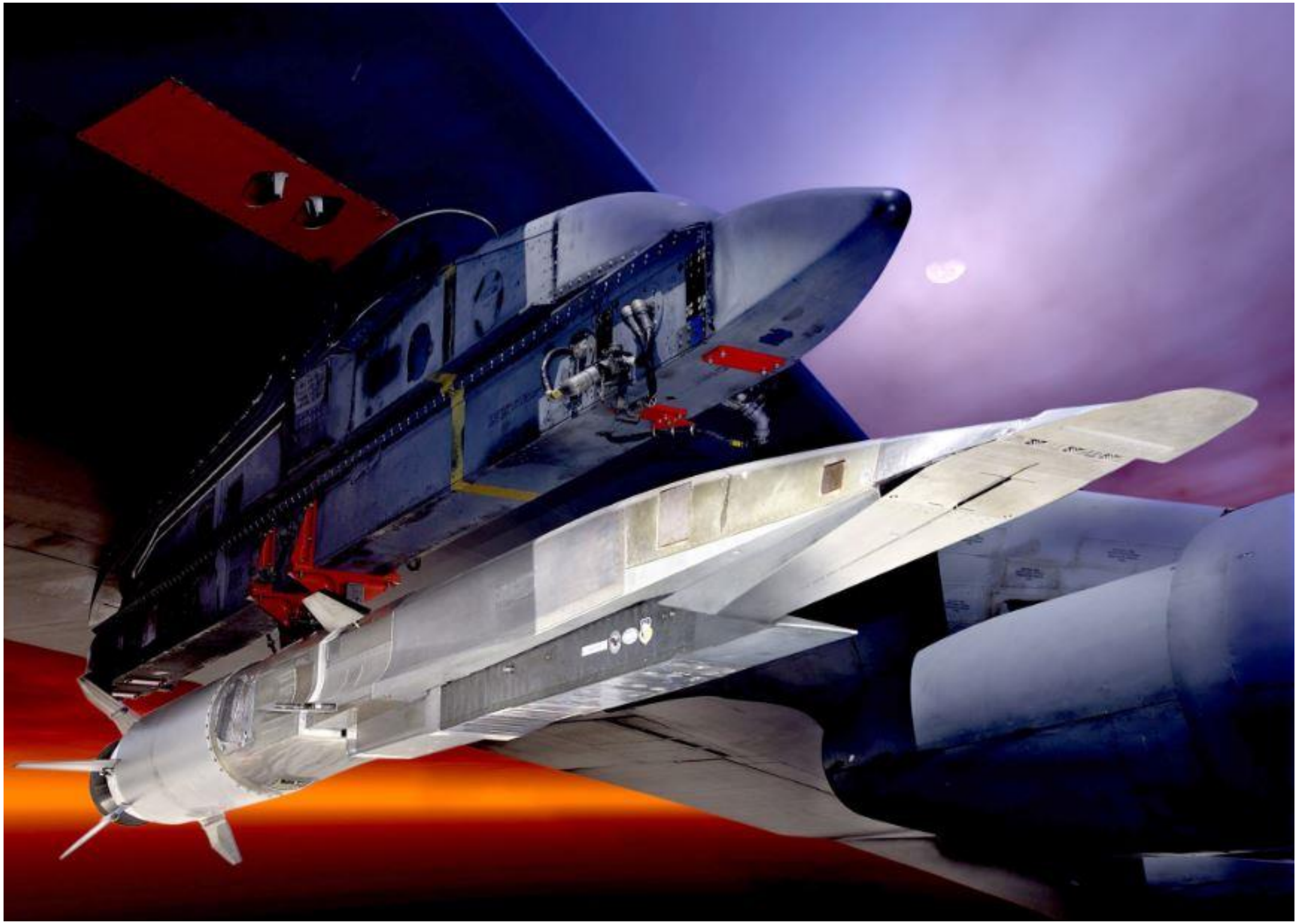
SABRE (Synergetic Air-Breathing Rocket Engine)



3. Classification and Nomenclature of Aircraft Engine

Advanced Propulsion Systems

Boeing X-51
Scramjet



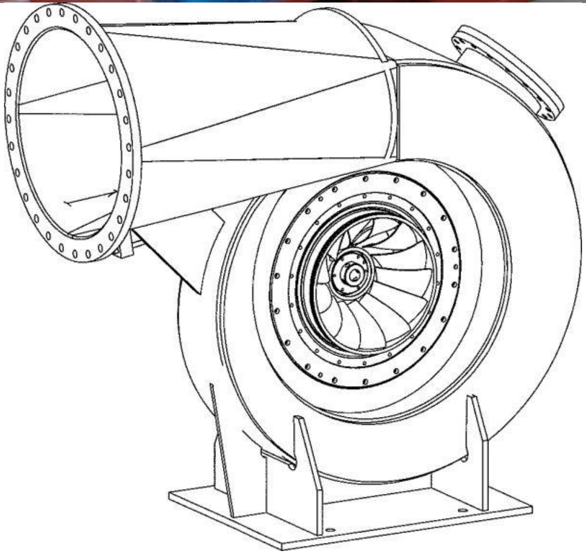
3. Classification and Nomenclature of Aircraft Engine

Advanced Propulsion Systems

- Ducted Fan Engine
- Propfan (Unducted Fan)
- Scramjet/Shcramjet
- Turbo-Rocket Engines (Eg. SABRE)
- Combined-Cycle and Hybrid Engines

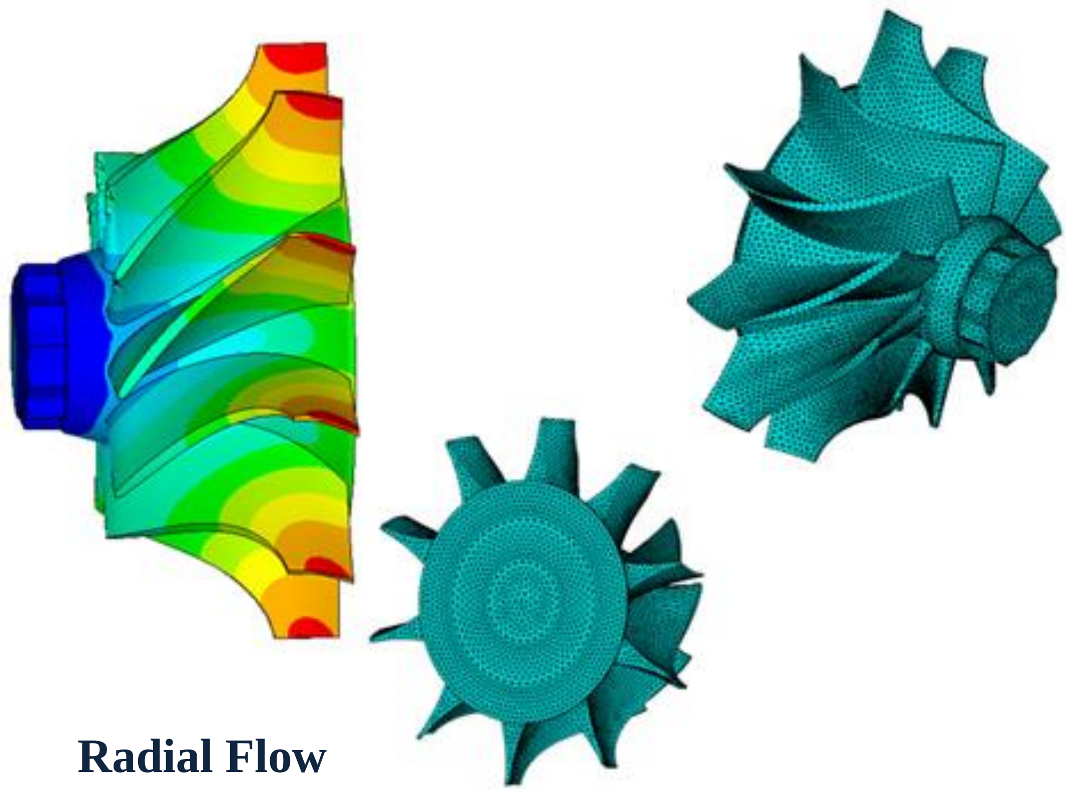
4. Axial Flow Steam and Gas Turbines

Turbines



4. Axial Flow Steam and Gas Turbines

Turbines



Radial Flow

Axial Flow

4. Axial Flow Steam and Gas Turbines

Blade Types

- Steam turbines are usually impulse or a mixture of impulse and reaction stages whereas gas turbines tend to be always of the reaction type.
- Pressure ratio of steam turbines can be of the order 1000:1, whereas it's within the order of 10:1 for gas turbines.
- To reduce the number of stages, pressure drop per stage should be large, but in doing so blade losses and efficiency costs rise.
- Therefore, reaction stages are used where pressure drop per stage is low and also where the overall pressure ratio of the turbine is relatively low.
- Shape and size of the blades can vary with different types of stages

4. Axial Flow Steam and Gas Turbines

Turbine Staging

- Staging of axial-flow compressor-turbine assembly is done in combination of rotor and stators.
- For centrifugal compressors, the staging are the same as spools, for e.g. one compressor-turbine coupled stage is linked through a single 'spool' hence also called a 'single spool compressor/turbine'.
- For axial compressors, the staging is defined in terms of rows of stator-rotor assembly, with a single such assembly referred to as a compressor stage. Each stage can have a compression ratio in the range of 1.05~2 with an efficiency of around 0.94.
- Hence, for axial compressors a single spool can contain several stages. And spools (up to three) in combination can provide compression in the range of 5-40. (5.0 for J35; 42.0 for GE90,)